

1 Potential for resource competition between juvenile groundfishes and  
2 salmon in the eastern Gulf of Alaska

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16

17 ABSTRACT

18

19 Ecologically important juvenile groundfishes and salmon co-occur in the upper water column of  
20 the eastern Gulf of Alaska during the summer, a period when growth is critical to their survival.

21 We quantified fine-scale spatial and trophic overlap of juvenile groundfishes (arrowtooth  
22 flounder, Pacific cod, walleye pollock, and rockfish) and salmon (piscivorous coho and Chinook  
23 as well as planktivorous pink, chum, and sockeye) to examine trophic structuring and potential  
24 survival bottlenecks for these fishes in the Gulf of Alaska between 2010–14. In general, juvenile  
25 groundfish catches had low coherence with station environmental variables with the exception  
26 that across the years, rockfish were correlated with deeper station bottom depths. Juvenile  
27 salmon catches were correlated with station environmental variables such as shallower station  
28 depth and when the pycnocline was closer to the surface, higher chlorophyll levels, and lower  
29 salinities. The overall fish community in 2011 was disorganized compared to 2010 and 2012-  
30 2014 based on higher ordination stress and had poorer environmental correlations. Fine-scale  
31 spatial overlap among juvenile groundfishes and salmon populations was highest in 2011 and  
32 2012 and lowest in 2013 and 2014. Juvenile rockfish had the least spatial overlap with the  
33 juvenile salmon due to their offshore distribution. Fine-scale diet overlap between juvenile  
34 groundfishes and planktivorous juvenile salmon species ranged from 0% to 78%, was highest in  
35 2012, and was lowest in 2011. Fine-scale diet overlap among juvenile groundfishes and  
36 piscivorous juvenile salmon occurred but was typically lower than that with planktivorous  
37 juvenile salmon. Additionally, juvenile groundfishes were directly consumed by juvenile salmon.  
38 Neither the abundance nor stomach fullness of the juvenile planktivorous groundfishes or salmon  
39 correlated with station-level zooplankton biomass in 2012–13, suggesting a lack of a resource

40 bottleneck for these planktivores in these 2 years. Juvenile groundfishes were less frequently  
41 caught at stations where the highest catches of juvenile piscivorous salmon occurred, which  
42 could be due to predation. Overall, during years when juvenile groundfishes survival was high,  
43 juvenile salmon survival was also high, suggesting sufficient food resources in the GOA.  
44 Alternatively, when food resources are low in the GOA, as seen in 2011, competition for  
45 resources by groundfish and salmon was likely, and both appeared to be negatively impacted.

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47 Keywords: Juvenile Pacific salmon; Juvenile groundfishes, Gulf of Alaska, Competition,  
48 Stomach fullness, Plankton biomass, Prey

## 49 1. Introduction

50 The Gulf of Alaska (GOA) is a rich and productive marine ecosystem that supports abundant  
51 populations of groundfishes and salmon that produce some of the world's largest fisheries  
52 (Mundy, 2005; Fissel et al., 2016). In the spring and summer, a number of key groundfishes  
53 occupy the upper water column and coastal-shelf waters as larvae and juvenile fish before they  
54 settle to the demersal environment of the GOA as adults (Doyle and Mier, 2016). Juvenile  
55 salmon migrate into the GOA during spring and summer where they occupy the upper water  
56 column in coastal waters and out to the continental shelf (Groot and Margolis, 1998).  
57 Understanding the potential interactions among juvenile groundfishes and salmon co-occurring  
58 in the upper-water column during their critical growth phases could lead to a more  
59 comprehensive approach to management of key fisheries in Alaska, such as modifying the  
60 production and release of hatchery salmon in the North Pacific, where density-dependent effects  
61 have been documented (Batten and Ruggerone, 2018; Ruggerone and Irvine, 2018). Indirect  
62 interactions, such as competition for limited prey resources, are difficult to quantify. However,  
63 the first steps in understanding potential competition is to determine the extent to which fish  
64 overlap spatially and trophically (Rand et al., 2012; Link and Auster, 2013).

65 Environmental conditions can influence productivity in the GOA during a critical feeding  
66 period for larval and juvenile groundfishes, which in turn can affect their recruitment to the adult  
67 population (Brodeur and Wilson, 1996; Mueter et al., 2007; Doyle et al., 2009; Atwood et al.,  
68 2010; Doyle and Mier, 2012). The primary goal of the GOA Integrated Ecosystem Research  
69 Program (GOAIRP) has been to study the determinants of year-class strength for several  
70 ecologically and commercially important groundfishes within the GOA in their early life stages.  
71 Specifically, the groundfish we examined were: *Atheresthes stomias* (arrowtooth flounder,

72 hereafter referred to as AT\_Flounder), *Sebastes* spp. (rockfish), *Gadus macrocephalus* (Pacific  
73 cod, hereafter referred to as Pcod,) and *Gadus chalcogrammus* (walleye pollock, hereafter  
74 referred to as pollock). In the Gulf of Alaska, adult groundfish release their eggs in offshore  
75 spawning locations and the larvae are then transported to nearshore nursery areas, where they  
76 continue to feed and grow. The fish remain in nearshore nursery areas before they settle into  
77 deeper demersal habitats in offshore waters (Bailey, 1989; Brodeur et al., 2002; Logerwell et al.,  
78 2005). As the larval fish grow into the juvenile stage, the larger fish will start to perform  
79 ontogenetic based vertical diel migrations that are thought to be in responses to predator  
80 avoidance (Brodeur and Wilson, 1996; Hurst et al., 2009) and feed throughout the diel period  
81 (Schabetsberger et al., 2000). Successful survival of the early life history stages is known to be  
82 affected by transport into suitable nursery habitats, feeding and growth conditions, and predator  
83 avoidance, which are all thought to contribute to the establishment of the year-class strength of  
84 these important fish in the GOA (Ciannelli et al., 2004; Siddon et al., 2013; Doyle et al., 2016;  
85 Moss et al., 2016). As such, it is important to understand the interannual variability and to  
86 quantify the degree to which early life stages of groundfish interact and overlap with potential  
87 competitors and/or predators such as juvenile salmon.

88 Juvenile pink (*Oncorhynchus gorbuscha*), chum (*O. gorbuscha*), and sockeye (*O. nerka*)  
89 salmon are primarily planktivorous salmon and the most numerous salmon in the GOA (Cooney  
90 and Brodeur, 1998; Landingham et al., 1998; Fisher et al., 2007), and interannual changes in  
91 their abundance as juveniles have been shown to be correlated (Stachura et al., 2013; Ruggerone  
92 and Connors, 2015; Ruggerone et al., 2016; Kohan et al., this issue). In years when juvenile  
93 planktivorous salmon abundance in the GOA was high, prey resources may become limited for  
94 all planktivores in the surface waters (Shiomoto et al., 1997), although some studies indicate that

95 food is not limited in the GOA (Auburn and Ignell, 1996; Boldt and Haldorson, 2002). Still other  
96 studies have shown that food competition is more prevalent among adult predators (Springer and  
97 van Vliet, 2014; Ruggerone et al., 2016). Juvenile groundfishes also have substantial interannual  
98 variability in their abundance. While the impact that high numbers of juvenile groundfishes can  
99 have on localized prey resources has been documented in the southeast Bering Sea (Ciannelli et  
100 al., 2004), juvenile groundfishes are a small fraction of the body sizes of the juvenile  
101 planktivorous salmon and therefore consume relatively less prey. While changes in  
102 environmental conditions have been shown to affect the success of young groundfishes (Doyle et  
103 al., 2009; Moss et al., 2016; Coffin and Mueter, 2016), it is thought to be more from  
104 environmental limitations of prey production versus the potential for top-down over-grazing  
105 (Kendall et al., 1987). Top-down overgrazing may occur with the larger juvenile and adult  
106 planktivorous salmon, albeit the salmon are also affected by bottom-up processes of zooplankton  
107 production (Ruggerone and Nielsen, 2004; Springer and van Vliet, 2014; Kohan et al., this  
108 issue).

109       There is variability in how these juvenile groundfishes distribute across the GOA. In general,  
110 pollock tend to be distributed consistently inshore to offshore (Doyle et al., 2016) but exhibit  
111 interannual variability longitudinally across the GOA (Brodeur and Wilson, 1996; Moss et al.,  
112 2016; McGowan et al., this issue). Juvenile Pcod are principally found in the central GOA, and  
113 lower numbers are found in the eastern GOA (EGOA). AT\_Flounder are principally found in the  
114 EGOA (Spies and Palsson, 2018). Juvenile rockfishes are distributed across the GOA, especially  
115 in the offshore waters (Doyle et al., 2016; Siddon et al., this issue). As pelagic juveniles, these  
116 groundfishes are primarily planktivorous and feed on copepods, early stages of euphausiids, and

117 fish larvae (prey listed in decreasing order of importance; Rose, 1980; Wilson et al., 2011;  
118 Strasburger et al., 2014; Moss et al., 2016; Debenham et al., this issue).

119       Similar to juvenile groundfishes, the early marine feeding period is also critical to the growth  
120 and survival of juvenile salmon (Fisher and Pearcy, 1988; Pearcy, 1992; Orsi et al., 2014; Daly  
121 and Brodeur, 2015). Juvenile salmon generally occupy the upper water column within coastal  
122 waters (Fisher et al., 2007). Juvenile *Oncorhynchus tshawytscha* (Chinook salmon) are typically  
123 most abundant closest to shore, juvenile *O. kisutch* (coho salmon) are found in the nearshore  
124 waters out to deeper depths. Juvenile chum, pink, and sockeye salmon are abundant in GOA  
125 waters that are deeper with lower salinity (Fisher et al., 2007). Juvenile Chinook and coho  
126 salmon prey upon larval and juvenile fishes (including juvenile groundfishes), squids, decapods,  
127 and adult euphausiids (Landingham et al., 1998; Brodeur et al., 2007; Weitkamp and Sturdevant,  
128 2008; Johnson and Schindler, 2009; Hertz et al., 2015; Daly et al., this issue). In contrast,  
129 juvenile chum, pink, and sockeye salmon are highly planktivorous, eating copepods, pteropods,  
130 early-stage euphausiids, amphipods, and fish eggs and larvae (Landingham et al., 1998;  
131 Kaeriyama et al., 2004; Armstrong et al., 2005, 2008; Brodeur et al., 2007; Daly et al., this  
132 issue).

133       In wild fish populations, the abundance, size, health, and age of the adult population can  
134 determine fluctuations in annual spawning biomass of eggs and larvae (Berkeley et al., 2004;  
135 Marshall et al., 2008; Hixon et al., 2014). For wild salmon populations, annual fluctuations in  
136 eggs and fry occur, but each year this number is augmented by hatcheries that release older  
137 stages of fish. On average, 67 million hatchery salmon smolts are released into Alaska waters  
138 each year (Stopha, 2017) in addition to those from the wild populations. With the consistent  
139 annual release of high numbers of planktivorous and piscivorous salmon into the GOA

140 regardless of environmental conditions, competition and predation may potentially occur  
141 between juvenile salmon and groundfishes. Predation and competition for resources would occur  
142 only when competitors, either interspecific or intraspecific, rely on the same limited resource and  
143 overlap in time and space. Our goal was to determine if there were trophic structuring and  
144 survival bottlenecks of juvenile groundfishes with juvenile salmon as both competitors and  
145 predators. To accomplish this, fine-scale spatial and dietary overlap among juvenile groundfishes  
146 and salmon in the EGOA was quantified. Additionally, we examined the frequency of juvenile  
147 salmon predation on juvenile groundfishes and whether food resources were limited where high  
148 numbers of juvenile groundfishes or salmon were caught.

149



## 150 2. Methods

151

### 152 2.1. *Field and laboratory sampling*

153

154 Annual fisheries oceanographic surveys were conducted by the Auke Bay Laboratory,  
155 Alaska Fisheries Science Center, National Oceanic and Atmospheric Administration, in the  
156 coastal regions of the EGOA during the summers of 2010–2014. Juvenile salmon and  
157 groundfishes were captured in 2010 using a Nordic trawl and in 2011–2014 with a Cantrawl, both  
158 with a 1.2 mm mesh codend liner and fished at the surface (see Straburger et al. (2018) for  
159 sampling details). Daytime tows were made at stations along transects (Fig. 1) for 30 minutes at  
160 approximately 3.3–7.0 km h<sup>-1</sup> with the net towed at or near the surface to an average of 19-m  
161 depth. Sampling station locations and number of stations sampled varied slightly from year to  
162 year, and the sampling map (Fig. 1) is a generalized map of the station locations that were  
163 sampled from 2010–2014. Juvenile salmon and groundfishes collected in the trawl were  
164 identified, counted, weighed, and measured (up to 50 per station per species). A maximum of 10  
165 juvenile groundfishes and salmon per species from each sampling station were frozen at sea  
166 (except for juvenile Chinook salmon, which were all retained) and brought back to the laboratory  
167 for diet analysis

168 On each survey, a Seabird Electronics CTD was deployed throughout the water column  
169 to determine temperature (°C) and salinity at various depths (m). Water samples were taken  
170 using 5-L Niskin bottles to measure chlorophyll-*a* every 10 m from the surface to 50 m.  
171 Zooplankton samples were taken with a 60-cm bongo net (505 μm mesh) towed obliquely from  
172 the surface to 200 m depth or within 20 m of the bottom, at ~ 2 knots. A calibrated General

173 Oceanics flowmeter was used in the bongo nets to determine the volume of water filtered, and  
174 samples were preserved in 10% formalin-seawater solution for later analysis in the laboratory.

175         The mean temperature, salinity, and chlorophyll-*a* were calculated from the top 20 m at  
176 each station. In the lab, chlorophyll-*a* samples were processed using standard fluorometric  
177 analysis (Parsons et al. 1984). Station pycnocline depths were estimated using the station CTD  
178 cast data based on the depth where the density gradient was at a maximum (Thomson and Fine  
179 2003). The depth of the layer of water above where the density gradient was at a maximum,  
180 known as the pycnocline depth, was included as an environmental variable as a shallow  
181 pycnocline in the North Pacific has been shown to be associated with increased primarily  
182 production that would support food resources important to larval and juvenile fishes (Eisner et  
183 al., 2016).

184         In the laboratory, individual fish were thawed, measured (nearest mm), and weighed  
185 (nearest mg). Fish stomachs were removed, weighed full, emptied of contents, and weighed  
186 empty. Stomach contents were identified to the lowest possible taxonomic category using a  
187 dissecting scope and taxa were weighed (nearest mg). Taxonomic categories of the diets were  
188 grouped as follows and were the top prey for both juvenile salmon and groundfishes: capelin  
189 (*Mallotus villosus*), *Sebastes* spp., flatfishes, fishes (all other rarely consumed taxa),  
190 cephalopods, copepods, decapods, euphausiids, hyperiid amphipods, amphipods (non-hyperiid),  
191 pteropods, shrimp, and “other” which were the rarely consumed taxa (barnacle larvae,  
192 chaetognaths, eggs, insects, isopods, gelatinous zooplankton, mysids, tunicates, polychaetes).  
193 Percent stomach fullness was calculated as the (total prey weight) / (predator’s weight – total  
194 prey weight). The biomass of zooplankton biomass available at each station in 2012-2013 only,  
195 and was calculated from the zooplankton samples that were split using a Folsom splitter to obtain

196 a subsample of  $\geq 200$  individuals. Detailed species composition was determined microscopically,  
197 and zooplankton were identified and counted to the lowest possible taxonomic level including  
198 sex and stage, when applicable (Kimmel et al., 2018). The zooplankton were summed into the  
199 same taxonomic groupings as the juvenile groundfishes and salmon diets. Prey counts were  
200 converted to prey wet weight using both literature and unpublished values (E. Fergusson,  
201 personal communication) and the total station biomass of prey was calculated as the sum total of  
202 the estimated wet weights per volume of water filtered. Fish larvae were excluded from the  
203 biomass, and zooplankton samples were only available from 2012-13.

204

## 205 2.2. *Juvenile groundfishes and salmon annual spatial patterns with environmental overlay*

206

207 To determine catch per unit effort (CPUE) for each species, counts of juvenile  
208 groundfishes and salmon at each station were divided by the area trawled ( $\text{km}^2$ ), which was  
209 estimated as the product of the width of the net spread (km) and the distance the net was towed  
210 (km). General patterns in CPUE by year and species were plotted for each station, with the  
211 stations ranked by the bottom depth (m) from shallow to deep to display spatial patterns. We also  
212 analyzed the spatial organization of the fish CPUE at each sampled station using non-metric  
213 multidimensional scaling (NMDS) ordination plots constructed from Bray-Curtis dissimilarity  
214 matrices by year. NMDS ordination plots with generated stress values  $< 0.15$  were considered  
215 ecologically significant and interpretable (Clark 1993). Environmental conditions variables  
216 measured at each station were overlain as vectors in correlation (with corresponding  $R^2$  value) to  
217 the fish CPUE. Station environmental variables of bottom depth, pycnocline depth, mean salinity  
218 (20 m), mean temperature (20 m), and mean chlorophyll-*a* (20 m) were utilized. The average

219 environmental variable from the top 20 meters was used because this was the depth range of the  
220 trawl net utilized to collect the juvenile groundfishes and salmon. Environmental variables were  
221 standardized and the CPUE values were transformed ( $\ln(\text{CPUE} + 1)$ ). The NMDS analysis was  
222 completed using the *vegan*, *mass*, *permute*, *labdsv* packages in R (R Core Team 2019).

223

### 224 2.3. *Statistical analysis of spatial overlap*

225

226 To test if juvenile groundfishes and salmon had different fine-scale spatial distribution  
227 patterns, we used the Cramér-von Mises non-parametric test (Syrjala, 1996). The test accounts  
228 for spatial differences in population abundance, but is insensitive to the differences in abundance  
229 of each population and was chosen because of the observed population size differences between  
230 the fish. For the analysis, a single test statistic  $\Psi$  was calculated for each year between the CPUE  
231 of each species of juvenile salmon and each species of groundfish. The test is calculated as the  
232 square of the differences between the cumulative distributions of the two groups, summed over  
233 all the sampled stations, and it is sensitive to differences in the way groups are distributed across  
234 the study area regardless of differences in abundance. A p-value was computed based on 9999  
235 random permutations of the data using the *Syrjala* routine in the *ecespera* package in R (R Core  
236 Team 2019).

237

### 238 2.4. *Juvenile groundfishes and salmon diet overlap and community analysis*

239

240 To identify whether juvenile groundfishes and salmon had diet composition differences  
241 by weight of prey eaten, we summarized the diet composition for each individual species at each

242 sampling station by taxonomic groupings listed in the diet methods (see above), then averaged  
243 the diets for each species at each station. Trophic relationships were analyzed by calculating the  
244 degree of diet similarity, or diet overlap, between each pairwise species of juvenile groundfishes  
245 and salmon at all sampling stations when data were available, using the Percent Similarity Index  
246 (PSI):

$$PSI = \left( 1 - 0.5 \sum_{i=1}^n |p_{ik} - p_{jk}| \right) \times 100$$

247  
248  
249 where  $p_{ik}$  is the proportion by weight of prey item  $k$  found in the diet of predator  $i$ ,  $p_{jk}$  is the  
250 proportion by weight of prey item  $k$  found in the diet of predator  $j$ , and  $n$  is the total number of  
251 prey categories (Wallace and Ramsay, 1983).

252 To display the diet community of the planktivorous groundfishes relative to the juvenile  
253 salmon, we utilized NMDS ordinations constructed from Bray-Curtis dissimilarity matrices to  
254 plot the station diet composition for each planktivorous salmon and groundfishes by year.  
255 Differences in diet composition were tested using a Multi-Response Permutation Procedure  
256 (MRPP; McCune and Mefford, 1999) which is a multivariate equivalent to analysis of variance  
257 (ANOVA) based on a matrix of pairwise Bray-Curtis similarity coefficients, and the significance  
258 is determined by permutation where  $P < 0.05$ .

259 The prevalence of juvenile salmon consuming juvenile groundfishes was calculated as  
260 the percent frequency of occurrence (%FO) that the prey occurred in station-averaged diets for  
261 each juvenile salmon species by year. Fish prey were grouped by taxonomic family and  
262 included: cod (pollock and Pcod), rockfish, and flatfish (including AT\_Flounder). Fish prey were  
263 primarily identified as “unidentified fish” due to the digestion of identifiable characteristics;

264 therefore, %FO of juvenile groundfishes in juvenile salmon diets was a minimal estimate of  
265 juvenile salmon predation on juvenile groundfishes.

266 To look for fine-scale prey resource bottlenecks, we examined the relationship between  
267 prey biomass and the abundance of predators by testing if the station prey biomass changed  
268 relative to stations grouped into predator CPUE quartiles. Juvenile groundfish were tested  
269 separately from the juvenile salmon. We expected prey resources not to differ relative to fish  
270 abundances. Prey resources for both juvenile groundfishes and planktivorous juvenile salmon  
271 were measured as the station biomass of zooplankton taxa, and the prey resources for the  
272 piscivorous salmon were measured as the total combined CPUE of juvenile groundfishes at a  
273 station. We utilized three predator groups as follows: the sum total station CPUE of juvenile  
274 groundfishes categorized into four quartiles (Q1–4), the sum total station CPUE of juvenile  
275 planktivorous salmon categorized into four quartiles (Q1–4), and the sum total station CPUE of  
276 the juvenile piscivorous salmon, which were grouped into three quartiles (Q1–2, 3, 4). Three  
277 quartiles were used in the case of the juvenile piscivorous salmon because ~50% of the stations  
278 did not have any juvenile salmon; therefore, the first two quartiles were merged. We then tested  
279 if there were statistically different amounts of prey biomass at stations for each quartile of  
280 juvenile groundfishes (Q1–4) or salmon (Q1–2, 3, 4) with the nonparametric Kruskal-Wallis test  
281 for each year with significance of  $P < 0.05$ . The nonparametric test was utilized due to the lack of  
282 normally distributed data.

283 To identify whether there were any prey resource bottlenecks, we tested if there was a  
284 relationship between prey biomass and the percent stomach fullness of juvenile groundfishes or  
285 salmon as it related to their station prey resources (zooplankton biomass for the planktivores, and  
286 CPUE of groundfishes for the piscivores) using linear regression analysis. We also tested if the

287 station average percent stomach fullness was affected by the abundance of potential competitors.  
288 Potential competitors for juvenile groundfishes were the CPUE of the planktivorous salmon, and  
289 we did not have available potential competitor data for the piscivorous salmon. We expected  
290 stomach fullness not to change, dependent upon the amount of prey or abundances of potential  
291 competitors. Tests were done at the station level for each year using linear regression analysis  
292 with significance of  $P < 0.05$ .

293

294

### 295 3. Results

296

#### 297 *3.1. Juvenile groundfishes and salmon annual spatial patterns with environmental overlay*

298

299 Total catches of juvenile groundfishes and salmon were among the highest in 2010 and  
300 lowest in 2011 (Fig. 2). Of the groundfish taxa, juvenile rockfish and pollock were caught in the  
301 highest numbers, especially at deeper bottom depths (Fig. 2-3). There were high catches of  
302 rockfishes at many of the sampling stations in 2010 and especially 2014 (Fig. 2). Juvenile  
303 pollock were caught at ~75% of the sampled stations in 2013, dominating the catch relative to  
304 the other juvenile fishes (groundfishes and salmon). Pollock were also caught in high abundance  
305 in 2014, but were absent in 2011 (Fig. 2). Pcod were typically caught in low numbers at a few  
306 stations (or none in 2011), and were caught in their highest frequency in 2014. AT\_Flounder  
307 were caught in EGOA in relatively low numbers, except in 2010 and 2012 (Fig. 2). For the  
308 juvenile salmon, pink salmon were the dominate species caught, especially in 2010, and were  
309 caught notably reduced in numbers in 2013. Juvenile Chinook salmon were caught in the lowest

310 numbers of the juvenile salmon, and at typically < 30% of the stations in any given year (Fig. 2).  
311 Juvenile coho salmon were caught at 86% of the sampled stations in 2011, and were caught in  
312 relatively high numbers in 2013.

313 For the ordination plots, there were 393 sampling stations where fish were caught and the  
314 full suite of environmental data was available for analysis. Overall, the stations with the highest  
315 catches of juvenile groundfishes or salmon did not overlap, as can be seen by the separation  
316 between the two groups of fishes in the annual NMDS ordination plots (Fig 3). Juvenile  
317 groundfishes were associated along the positive side of NMDS axis 1, and the juvenile salmon  
318 on the negative side (Fig. 3). The environmental variable that consistently showed the highest  
319 correlation with the fish community was the bottom depth of the station (Table 1), which was  
320 aligned along the positive axis 1. In all years except 2011, the correlation of depth was greater  
321 than  $R^2 = 0.50$  (Table 1). In 2014, there was a negative correlation with station temperature for  
322 Pcod and pollock ( $R^2 = -0.30$ ). AT\_Flounder were commonly associated with higher salinity  
323 values (Fig. 3). Juvenile salmon abundance was correlated with lower salinity and higher  
324 chlorophyll-*a* levels, and rockfishes were typically associated with greater bottom and  
325 pycnocline depths. The NMDS plots for each year had organized structure with low to moderate  
326 stress (< 15.0) for the first two axes, except for 2011. In 2011, the stress was higher than the  
327 other years at 18.6, indicating a poorly organized random fish community with low  
328 environmental correlation (Table 1).

329 In 2011, AT\_Flounder and rockfishes, the only juvenile groundfishes present in sufficient  
330 numbers to test, overlapped spatially with all the juvenile salmon. In 2012, when there were  
331 sufficient numbers of all juvenile groundfishes and salmon present for analysis, there was high  
332 spatial overlap (Cramér-von Mises;  $P < 0.05$ ; Table 2; dark gray cells). However, in 2013 and



333 2014 spatial overlap was substantially lower (Cramér-von Mises;  $P < 0.05$ ; Table 2; dark gray  
334 cells). Overall, juvenile rockfishes had the lowest spatial overlap with the juvenile salmon except  
335 in 2011 and 2012. For the juvenile salmon, only the chum and pink salmon were consistently in  
336 significant spatial overlap with each juvenile groundfish, except for rockfishes (Cramér-von  
337 Mises;  $P < 0.05$ ; Table 2; dark gray cells).

338

### 339 *3.2. Juvenile groundfishes and salmon diet overlap and diet composition community*

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341 Diets of juvenile groundfishes and juvenile planktivorous salmon were similar when fish  
342 were caught concurrently. The diet overlap based on the average Percent Similarity Index (PSI)  
343 ranged from 0% to a maximum of 66.6% (Fig. 4; Table 2). Diet overlaps between the juvenile  
344 groundfishes and piscivorous juvenile salmon were lower than those for juvenile planktivorous  
345 salmon (Fig. 4). Average diet overlap in 2011 was relatively low between juvenile groundfishes  
346 and salmon, except at one station between pink salmon and AT\_Flounder (Table 2). In 2010,  
347 average diet overlap was relatively high between the juvenile rockfishes and planktivorous  
348 salmon, yet these populations were not in significant spatial overlap. AT\_Flounder consistently  
349 had some diet overlap with the juvenile planktivorous salmon, and pink salmon had some of the  
350 highest average diet overlap with all four juvenile groundfishes (Fig. 4). Overall, the highest  
351 spatial and average trophic overlap occurred in 2012 between the juvenile groundfishes and  
352 salmon (Table 2).

353 The diet composition community of the juvenile groundfishes were different from those  
354 of the juvenile planktivorous salmon primarily due to higher amounts of copepods being eaten by  
355 the groundfishes relative to the salmon. The diet ordination plots showed that the juvenile

356 groundfish diets were grouped on the negative side of NMDS axis 1, and the juvenile  
357 planktivorous juvenile salmon were on the positive side, illustrating diet separation between  
358 these fish groups. The exception was 2010 when rockfish diets overlapped in ordination space  
359 with the salmon (Fig. 5). However, only the ordination in 2010 had a stress of  $< 0.1$ ; the stress  
360 for the other years was  $> 0.2$  suggesting low community structure as the diets were highly  
361 variable between stations. In 2013 and 2014, almost all juvenile groundfishes ate different prey  
362 types and amounts than juvenile planktivorous salmon, and all comparisons showed highly  
363 significant diet differences (Fig. 5; MRPP;  $P < 0.001$ ). Rockfish diets were not significantly  
364 different from chum or pink salmon diets in 2010, nor were AT\_Flounder from chum salmon in  
365 2011 (Fig. 5; MRPP;  $P > 0.05$ ). The diet community in 2012 had the least separation in diets  
366 between the juvenile groundfishes and salmon, yet it still showed significantly different diets  
367 (MRPP;  $P < 0.05$ ). As there was low diet overlap between the juvenile piscivorous salmon and  
368 groundfishes, we omitted them from the NMDS plots.

369

### 370 *3.3. Juvenile salmon predation on juvenile groundfishes*

371

372 Coho and Chinook salmon had higher frequency of occurrence (%FO) of juvenile  
373 groundfishes in their diets relative to the planktivorous salmon, and the frequency varied from  
374 year to year (Table 3). The juvenile groundfishes eaten by salmon in highest FO were rockfish in  
375 2010 when 20% to 68.4% of the juvenile salmon diets had juvenile rockfishes in them, which  
376 was a year in which rockfishes were not in spatial overlap with the salmon (Table 2), but were  
377 caught in high numbers (Fig. 2). Juvenile Chinook, coho, and sockeye salmon regularly had  
378 rockfish in their diets in all other years (Table 3), again, with low spatial overlap between the

379 populations (Table 2). Flatfish were eaten frequently by juvenile Chinook salmon in 2012. Both  
380 cod were infrequently eaten in any given year, but were consumed slightly more frequently by  
381 juvenile coho salmon than the other salmon (Table 3).

382

### 383 *3.4. Relation between prey amount and predator CPUE*

384

385           Generally, the number of zooplankton available to planktivores was lower in 2013  
386 relative to 2012 (Fig. 6a-d). In looking for potential prey-limitation bottlenecks, we examined the  
387 relation between the available zooplankton biomass relative to the station CPUE of juvenile  
388 groundfishes or planktivorous salmon grouped into quartiles for the years 2012 and 2013. In  
389 2013, zooplankton biomass was lowest for the 25% of stations with the highest CPUE of juvenile  
390 groundfishes, and in 2012, zooplankton was highest for the 25% of stations with the highest  
391 CPUE of juvenile planktivorous salmon; however, neither of these relationships were  
392 significantly lower (Fig. 6a-d; Kruskal-Wallis test,  $P > 0.05$ ). In 2013, there were higher amounts  
393 of zooplankton biomass at the higher CPUE quantile of juvenile planktivorous salmon, although  
394 not significantly more (Fig. 6d; Kruskal-Wallis test,  $P > 0.05$ ).

395           Lastly, in all five years of the study, there were higher abundances of juvenile  
396 groundfishes at stations with the fewest amount of juvenile piscivorous salmon (Fig. 7 a-f;  
397 Kruskal-Wallis test,  $P < 0.05$ ). There were significantly more juvenile groundfishes at the  
398 stations with the least amount of piscivores in 2010 and 2011 and there was the least amount of  
399 juvenile groundfishes at the stations with the highest amount of piscivores in 2012 (Kruskal-  
400 Wallis test,  $P < 0.05$ ). In 2014, there were no differences between the quartiles. In summary,  
401 based on the available biomass of zooplankton, there did not appear to be any indication that

402 planktivorous juvenile fish grazed down the available prey where they were most abundant.  
403 However, there were significantly more juvenile groundfishes in 2010-2012 when there were  
404 fewer numbers of juvenile piscivorous salmon, possibly due to predation.

405

### 406 *3.5. Predator stomach fullness relative to prey or potential competitors*

407

408         We did not find significant relationships between any of the juvenile groundfishes'  
409 average station stomach fullness and their food based on the station zooplankton biomass in  
410 either 2012 or 2013 ( $P > 0.05$ ). In 2012, juvenile rockfish stomachs were significantly less full  
411 when there was a higher CPUE of planktivores ( $P = 0.02$ ,  $R^2 = 0.299$ ), suggesting a decrease in  
412 prey resources for rockfish when there were many juvenile planktivorous salmon co-occurring.  
413 In 2014, juvenile Pcod and pollock stomach fullness was significantly higher when there were  
414 more planktivores at a station ( $P = 0.03$ ;  $R^2 = 0.358$ ,  $P = 0.03$ ,  $R^2 = 0.078$ , respectively),  
415 suggesting that there was sufficient prey for these groundfishes even at high abundances of  
416 juvenile salmon. Lastly, there were no significant relationships between the station average  
417 stomach fullness of the juvenile piscivorous salmon and the sum total CPUE of all juvenile  
418 groundfishes in any of the study years ( $P > 0.05$ ).

419

## 420 4. Discussion

421

### 422 4.1. *Interannual CPUE and spatial overlap*

423

424 Our study documents that juvenile, groundfishes and salmon have fine-scale spatial,  
425 temporal, and trophic overlap in the GOA and therefore these abundant juvenile fish have the  
426 potential to impact one another during periods of low prey abundance and/or from top-down  
427 predation. We also identify that these interactions varied in intensity from year to year. Juvenile  
428 groundfishes and salmon exhibit different spatial differences and the correlations of  
429 environmental variables with the CPUE of juvenile groundfishes and salmon during our study  
430 were similar to those found in other studies (Morris et al., 2007; Orsi et al., 2007; Weitkamp et  
431 al., 2011; Doyle and Mier, 2016). The highest abundances of juvenile groundfishes were caught  
432 farther offshore, which had deeper pycnocline depths and warmer temperatures. Generally, the  
433 juvenile salmon were caught in nearshore waters of the GOA relative to the juvenile  
434 groundfishes, and the planktivorous salmon were caught together in less saline waters (this  
435 study; Fisher et al., 2007; Echave et al., 2012). Juvenile coho and Chinook salmon were usually  
436 caught together but coho salmon were also caught farther offshore (but not as far as the juvenile  
437 groundfishes), and both were positively correlated with chlorophyll-*a* levels in some years.  
438 Juvenile Chinook and coho salmon along the Washington and Oregon coast and Bering Sea have  
439 also been shown to have spatial distributions influenced by increased levels of chlorophyll-*a*,  
440 most likely due to the increased levels of prey associated with higher primary production (Pearcy  
441 and Fisher, 1990; Ciciel et al., 2009). Lastly, the 2011 overall fish community structure based  
442 on the ordination had the highest stress value, indicating a poorly organized community and very  
443 poor correlations to environmental variables. Ecologically, 2011 was quite different from other  
444 years in the GOA, with low productivity (Waite and Meuter, 2013; Moss et al., 2016; Strom et

445 al., 2016), and the high stress in the community ordination indicated an unusual lack of a spatial  
446 structure of the fish community.

447 Juvenile groundfishes and salmon were often caught together in fine-scale spatial  
448 overlap. Other studies have noted general spatial overlap between these fishes during summer  
449 within the GOA (Mecklenburg et al., 2002; Echave et al., 2012; Martinson et al., 2012; Moss et  
450 al., 2016; McGowan et al., this issue). Our study indicated interannual variability in intensity of  
451 fine-scale spatial overlap between juvenile groundfishes and salmon, with years of higher or  
452 lower spatial overlap and therefore opportunity for resource competition. Few studies have  
453 documented the interannual changes in spatial overlap between potential competitors (Brodeur et  
454 al., 2014). In the Mediterranean Sea, the spatial overlap between two fish populations increased  
455 in years with increased numbers of one fish, sardines, but decreased in years with increased  
456 numbers of the other fish, anchovies (Barra et al., 2015). In 2013, there were consistent high  
457 catches of pollock across the EGOA, yet low spatial overlap occurred with the salmon, and in  
458 2012, there were good catches of both groundfishes and salmon, and the highest spatial overlap  
459 between fish. Further investigation of the interannual variability in the strength of fine-scale  
460 spatial (and diet) overlap would be of interest due to the potential for competition, especially in  
461 years of low productivity when resources are restricted. There also could be a seasonal  
462 component to the amount of spatial and diet overlap between fish populations, as identified in  
463 Kemp et al. (2013), which warrants further study. Annual variability in the degree of fine-scale  
464 spatial overlap of populations is important to our understanding the potential for increased or  
465 decreased competition and population structures within the GOA.

466

467 *4.2. Fine-scale diet overlap and predation between juvenile groundfishes and salmon*

468

469           When juvenile groundfishes and salmon were caught together, there was, in general,  
470 moderate diet overlap. While our study focused on fine-scale diet overlap between juvenile  
471 groundfishes and salmon, diet overlap between juvenile non-salmonid fishes in Alaska waters  
472 has been studied but on a limited basis. The diet overlap between pollock and herring  
473 (Sturdevant et al., 2001), pollock and Pcod (Strasburger et al., 2014), and pollock and capelin  
474 (Wilson et al., 2006) has been shown to occur. Diet overlap between juvenile pink salmon and  
475 pollock (as well as jellyfish) has been shown to be low due to the high amounts of larvaceans  
476 eaten by pink salmon relative to pollock, although the comparisons were made using diets from  
477 two different years (Purcell and Sturdevant, 2001). Monthly diet overlap analysis of juvenile  
478 Pcod, pollock, pink, sockeye, and chum salmon revealed that these fishes had moderate to  
479 significant levels of diet overlap (Sturdevant and Willette, 1999). The diet overlap among salmon  
480 has been well studied in the North Pacific, with the highest overlap being between the  
481 planktivorous salmon and the piscivorous salmon (Sturdevant et al., 1997; Davis et al., 2004;  
482 Ruggerone and Nielsen, 2004; Blikshiteyn, 2005; Brodeur et al., 2007; Weitkamp and Sturdevant,  
483 2008; Daly et al., this issue). Overall, our study confirms, along with other studies, that juvenile  
484 salmon and groundfishes do have some similarities in their diets.

485           The highest rates of diet overlap in our analysis occurred primarily due to the high  
486 planktivory rates of juvenile groundfishes and juvenile pink, chum, and sockeye salmon. Fine-  
487 scale diet overlap between the planktivores during the study period was typically between 20–  
488 50% of their diets being comprised of similar taxa, and there was modest interannual variability.  
489 Diets can vary even over small distances due to changes in the prey community, and diets of  
490 fishes caught at the same location and time usually have the most diet similarity (Weitkamp and  
491 Sturdevant, 2008). Even though we analyzed the spatial and diet overlap between the fish at the

492 station level, the finest spatial scale possible, each trawl still sampled several kilometers of  
493 water. While juvenile groundfish and salmon were consistently caught together during the  
494 sampling effort, they may not actually be overlapping in the water column or even near each  
495 other along the transect, reducing competition of common prey resources.

496 Not only did groundfishes and salmon show some spatial and trophic overlap, but also  
497 the juvenile groundfishes were directly consumed by juvenile salmon. Of the groundfishes,  
498 juvenile rockfishes were most frequently found in salmon stomachs, particularly in 2010, when  
499 our analysis showed low spatial overlap between juvenile salmon and rockfishes. Juvenile  
500 Chinook and coho salmon also frequently consumed rockfishes in 2011, when these groups  
501 exhibited significant spatial overlap. Both cods were eaten with low frequency by the juvenile  
502 salmon (< 17%) in all years, while flatfishes were eaten just in 2012–13. Overall, rockfishes  
503 were the most frequently-eaten groundfish taxa by the juvenile salmon, yet had the least spatial  
504 overlap. Juvenile rockfish are darkly pigmented, and the salmon may be highly selective in their  
505 consumption of rockfishes (Schabetsberger et al., 2005) even with low spatial overlap.

506

#### 507 *4.3. Prey bottlenecks*

508

509 With the spatial and trophic overlap between juvenile planktivorous groundfishes and  
510 salmon, there may have been competition for prey resources if limitations existed (Link and  
511 Auster, 2013). Competition could ultimately impact growth and survival of these fishes during  
512 their early marine period. In 2012, there was high CPUE of the fish in our study, as well as  
513 significant diet and spatial overlap, but there was no evidence in either year when we had  
514 zooplankton data, that prey consumption and growth were limited. Adult pink salmon that were  
515 juveniles in 2012 returned in record numbers the following year, and were noted to be heavier



516 than usual (Orsi et al., 2016). Both pollock and Pcod that were juveniles in 2012, had a higher  
517 than average recruitment to the adult population from that year class (Barbeaux et al., 2017;  
518 Dorn et al., 2016). Additionally, our data suggest that plankton biomass in 2012 was not  
519 diminished at the stations with the highest catches of juvenile planktivorous salmon or  
520 groundfishes.

521 Prey resources did not appear to be limiting in 2013. The salmon and groundfish were not  
522 in high spatial or diet overlap, except for AT\_Flounder, and recruitment levels of juvenile fishes  
523 from 2013 were average (McGowan et al., this issue; Orsi et al., 2016). Even with a lower  
524 biomass of zooplankton in 2013 relative to 2012, we did not observe a significant reduction of  
525 food resources even at stations with high fish catches. Similar to 2012, there were high CPUE of  
526 juvenile groundfishes and salmon in 2014, when pollock were the only juvenile groundfish in  
527 spatial and trophic overlap with salmon. However, stock assessment data reflect that recruitment  
528 during 2014 was low (Dorn et al., 2018) possibly due to competition. In 2011, a year with  
529 documented low primary production (Stabeno et al., 2015) and plankton resources (Hopcroft et  
530 al., 2016), there was spatial and diet overlap between juvenile planktivorous salmon and  
531 rockfishes and AT\_Flounder. Having more than just two years of zooplankton data, especially in  
532 a year of low productivity like 2011, could be useful in understanding prey resource bottlenecks  
533 in the GOA. The year 2011 was an anomalously poor year for juvenile Pcod and pollock, which  
534 were largely absent in the GOA (McGowan et al., this issue; and this study), and the North  
535 Pacific groundfish stock assessments confirm poor recruitment success for both these stocks for  
536 the year class of 2011 (Dorn et al., 2014; Barbeaux et al., 2017). Juvenile salmon in 2011 were  
537 thin and small, and there were poor returns of pink salmon the following year (Orsi et al., 2016;  
538 Daly et al., this issue). Finally, in 2010, when above average catches of rockfishes were present

539 with high diet overlap with the juvenile planktivorous salmon, but low spatial overlap,  
540 competition was not likely present. Overall, the conditions in the GOA during our study period  
541 were not consistent, and as such, it is difficult to draw conclusions on competition between  
542 juvenile groundfish and planktivorous salmon, but most likely, in 2011, there was competition  
543 that negatively affected both salmon and groundfishes, and in 2012, there were likely sufficient  
544 food resources that competition was not an issue.

545 Catches of juvenile groundfishes were higher at stations where there were less  
546 piscivorous salmon in all years of our study, possibly due to increased juvenile salmon predation.  
547 In most years, juvenile Chinook and coho salmon had significant spatial overlap with the  
548 juvenile groundfishes, and directly consumed juvenile groundfishes in their diets. However, with  
549 the exception of rockfishes, they ate higher proportions of other juvenile fish such as sandlance  
550 (*Ammodytes personatus*) or capelin (Weitkamp and Sturdevant, 2008; Daly et al., this issue). The  
551 reduction of juvenile groundfishes co-occurring with piscivorous salmon could have been due to  
552 predation. Predation by salmon would negatively affect the recruitment success of these  
553 economically important fishes especially if most of their population were in direct overlap in the  
554 GOA. Overall, juvenile Pcod, pollock, and in some years, rockfishes, had higher CPUE in the  
555 CGOA versus EGOA (Siddon et al., this issue), whereas juvenile Chinook salmon have higher  
556 CPUE in EGOA than CGOA, albeit a low overall CPUE relative to coho salmon and the  
557 groundfish. Coho salmon do utilize, in relatively high abundances, the EGOA and CGOA and  
558 therefore could have an impact on juvenile groundfishes recruitment success, especially  
559 rockfishes, which coho salmon ate in highest frequency of the four juvenile groundfish.

560 The stomach fullness of the juvenile groundfishes and juvenile piscivorous salmon were  
561 not related to the amount of prey available, as indicated by the zooplankton biomass or the

562 CPUE of juvenile groundfishes. In the summer of 2012 or 2013, plankton prey did not appear to  
563 be limited in the EGOA. Stomach fullness of the juvenile planktivores was minimally related to  
564 the abundance of other planktivores; in only one case negatively, and two cases positively, and  
565 for the juvenile piscivorous salmon, not in any case. These results were different from what was  
566 observed in several other studies in the region. In a study by Sturdevant and Willette (1999),  
567 planktivorous fish caught in the same location as other planktivorous fish had less full stomachs  
568 then when caught in allopatric aggregations (regardless of aggregation size), which suggested  
569 competition when mixed planktivores were sympatric. Steelhead (*O. mykiss*) had less full  
570 stomachs when there were higher catches of pink salmon in the oceanic Gulf of Alaska  
571 (Atcheson et al., 2012). The effect that high abundances of pink salmon have on grazing down  
572 the plankton community may occur in their second year, as adult fish returning across the GOA,  
573 versus during their juvenile stage, as noted in Springer and van Vliet (2014) and Ruggerone et al.  
574 (2016). For example, in 2013, there were high numbers of juvenile pollock that did not appear to  
575 survive (Dorn et al., 2014), and there were record numbers of adult pink salmon returning across  
576 the GOA at the same time.

577 Identifying whether juvenile groundfishes and salmon had a negative impact on each  
578 other due to prey competition or direct predation is complex. Overall, juvenile groundfishes and  
579 salmon frequently occupied the same place at the same time and showed some diet overlap, and  
580 salmon also preyed directly upon juvenile groundfishes. When juvenile groundfishes  
581 experienced high recruitment rates during their first marine summer, as they did during 2012,  
582 there is evidence that juvenile salmon did so as well. We did not identify that food resources  
583 were depleted in 2012 causing survival bottlenecks, and even in 2013 when there was less food,  
584 recruitment was not poor. Increased growth of juvenile salmon has been shown to be a positive

585 predictor of favorable conditions for young pollock (Martinson et al., 2012). This suggests that  
586 when conditions are good for groundfishes, they are good for salmon. In conditions, such as were  
587 found in 2011, when there was evidence that prey resources were limited and the fishes  
588 overlapped spatially and trophically, juvenile salmon and groundfish were both negatively  
589 affected indicating trophic bottlenecks (Orsi, 2016; Moss et al., 2016). Predation of juvenile  
590 groundfish by piscivorous salmon occurred, with significantly fewer groundfishes where larger  
591 abundances of coho and Chinook salmon were located. Overall, quantifying interannual changes  
592 in fine-scale spatial and trophic overlap between juvenile groundfishes and salmon can allow  
593 fisheries managers to better identify survival bottlenecks in the GOA and understanding  
594 recruitment variability for these important fish stocks.

595

596

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598

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899

900 Table 1. Sampling station environmental correlation  $R^2$  values relative to the non-metric  
901 multidimensional scaling (NMDS) community analysis of juvenile groundfishes and salmon  
902 CPUE by year.

Year	Station Depth (m)	Top 20 m Temperature (°C)	Top 20 m Salinity	Top 20 m total Chlorophyll- <i>a</i>	Pycnocline depth (m)
2010	0.52	0.16	0.28	0.20	ns
2011	0.15	ns	ns	ns	0.12
2012	0.72	ns	ns	ns	ns
2013	0.67	0.11	0.30	0.31	0.18
2014	0.57	0.30	0.15	0.10	0.09

903

904 Table 2. Spatial and diet overlap between juvenile groundfish and salmon by year. Cell color  
 905 represents the results of Cramér-von Mises test on spatial overlap; dark gray cells:   
 906 represents significant spatial overlap between the populations,  represents non-significant  
 907 spatial overlap between the populations, and  represents insufficient sample size of the  
 908 populations to test for differences. Text in cells is the average percent diet overlap ( $\pm$  SD)  
 909 between juvenile groundfishes and salmon by year. Text without ( $\pm$  SD) represent just one  
 910 station and therefore not an average.

	Chinook	Coho	Chum	Pink	Sockeye
<b>2010</b>					
Arrowtooth					
Pcod					
Pollock					
Rockfish			49.7 ( $\pm$ 41.1%)	66.5 ( $\pm$ 31.5%)	66.58( $\pm$ 31.9%)
<b>2011</b>					
Arrowtooth	0%	0%	16.5% ( $\pm$ 4.7%)	78.10%	44.90%
Pcod					
Pollock					
Rockfish		0%	30.8% ( $\pm$ 24.9%)	3.30%	14.7 ( $\pm$ 16.1%)
<b>2012</b>					
Arrowtooth	0.8 ( $\pm$ 2.4%)	0.0 ( $\pm$ 0.1%)	53.8% ( $\pm$ 40.0%)	44.0 ( $\pm$ 43.5%)	47.4 ( $\pm$ 38.5%)
Pcod		4.3 ( $\pm$ 7.5%)	9.8%	10.4 ( $\pm$ 14.8%)	49.4 ( $\pm$ 46.9%)
Pollock	10.6 ( $\pm$ 12.2%)	1.1 ( $\pm$ 2.5%)	32.5% ( $\pm$ 22.4%)	39.3 ( $\pm$ 37.2%)	30.1 ( $\pm$ 45.5%)
Rockfish	0%	0%	18.3% ( $\pm$ 3.6%)	53.0 ( $\pm$ 62.0%)	26.0 ( $\pm$ 33.3%)
<b>2013</b>					
Arrowtooth	19.2 ( $\pm$ 27.2%)	10.2 ( $\pm$ 30.6%)	44.3 ( $\pm$ 51.0%)		
Pcod	0.7%	1.70%	0%		
Pollock	0%	2.1 ( $\pm$ 7.1%)	20.5 ( $\pm$ 44.0%)	94.90%	
Rockfish					
<b>2014</b>					
Arrowtooth					
Pcod	1.9 ( $\pm$ 2.7%)		15.5 ( $\pm$ 26.6%)	27.5 ( $\pm$ 31.1%)	47.4 ( $\pm$ 43.3%)
Pollock	11.7 ( $\pm$ 13.3%)		20.0 ( $\pm$ 34.3%)	24.1 ( $\pm$ 30.2%)	32.9 ( $\pm$ 38.3%)
Rockfish					

911

912

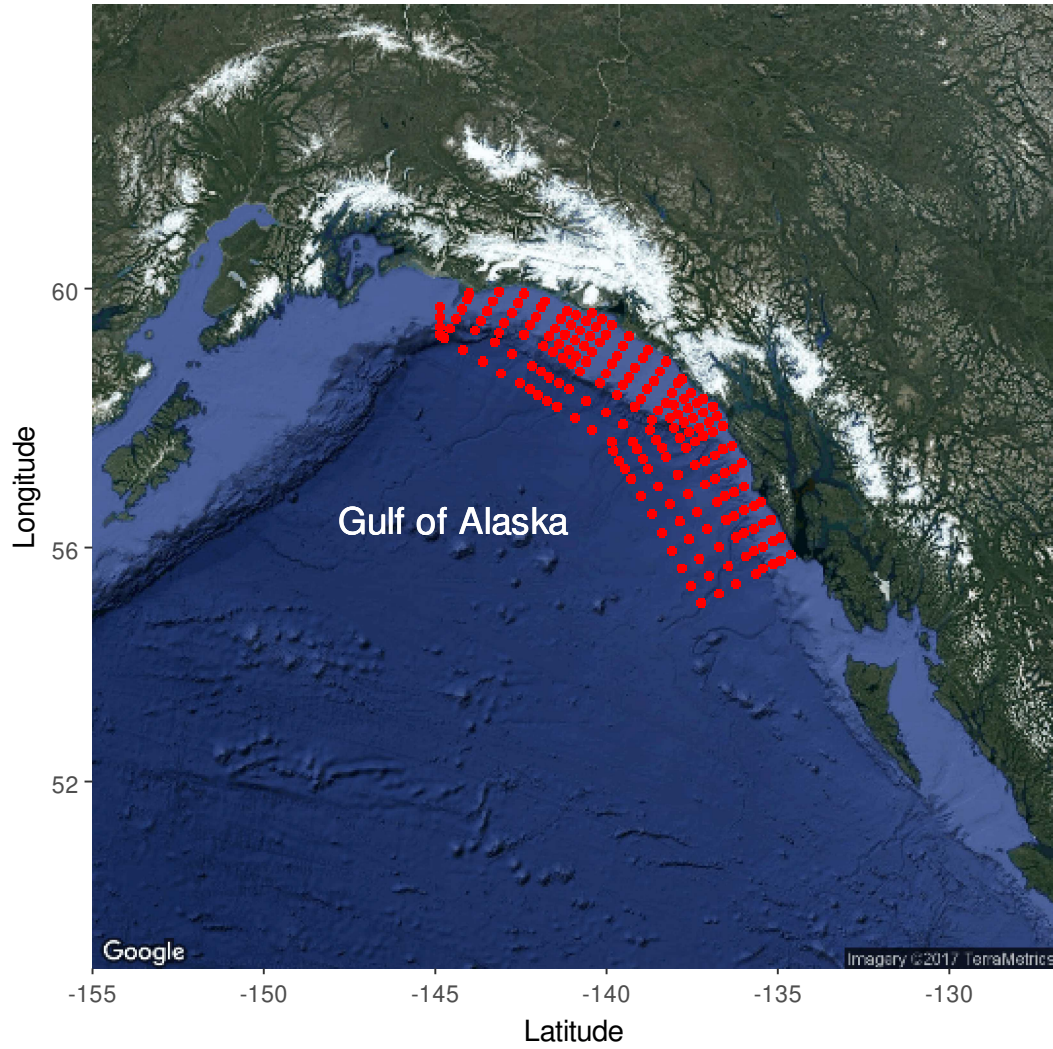
913 Table 3. Juvenile salmon predation upon juvenile groundfishes by percent frequency of  
 914 occurrence for each year. Cod included both Pcod and pollock, and flatfish included  
 915 AT\_Flounder. Shaded cell reflect values above zero.

916

	Chinook	Coho	Chum	Pink	Sockeye
<b>2010</b>					
Flatfish	0.0%	0.0%	0.0%	0.0%	0.0%
Cod	0.0%	10.5%	0.0%	0.0%	0.0%
Rockfish	20.0%	68.4%	24.1%	28.2%	20.7%
<b>2011</b>					
Flatfish	0.0%	0.0%	0.0%	0.0%	0.0%
Cod	13.0%	0.0%	0.0%	0.0%	0.0%
Rockfish	47.8%	67.6%	0.0%	7.1%	23.1%
<b>2012</b>					
Flatfish	50.0%	0.0%	0.0%	0.0%	0.0%
Cod	0.0%	9.1%	0.0%	0.0%	0.0%
Rockfish	38.9%	22.7%	0.0%	15.8%	42.1%
<b>2013</b>					
Flatfish	28.6%	8.0%	0.0%	0.0%	0.0%
Cod	0.0%	16.0%	0.0%	0.0%	0.0%
Rockfish	14.3%	16.0%	0.0%	0.0%	0.0%
<b>2014</b>					
Flatfish	0.0%		0.0%	0.0%	0.0%
Cod	9.1%		10.5%	0.0%	0.0%
Rockfish	18.2%		10.5%	8.3%	11.8%

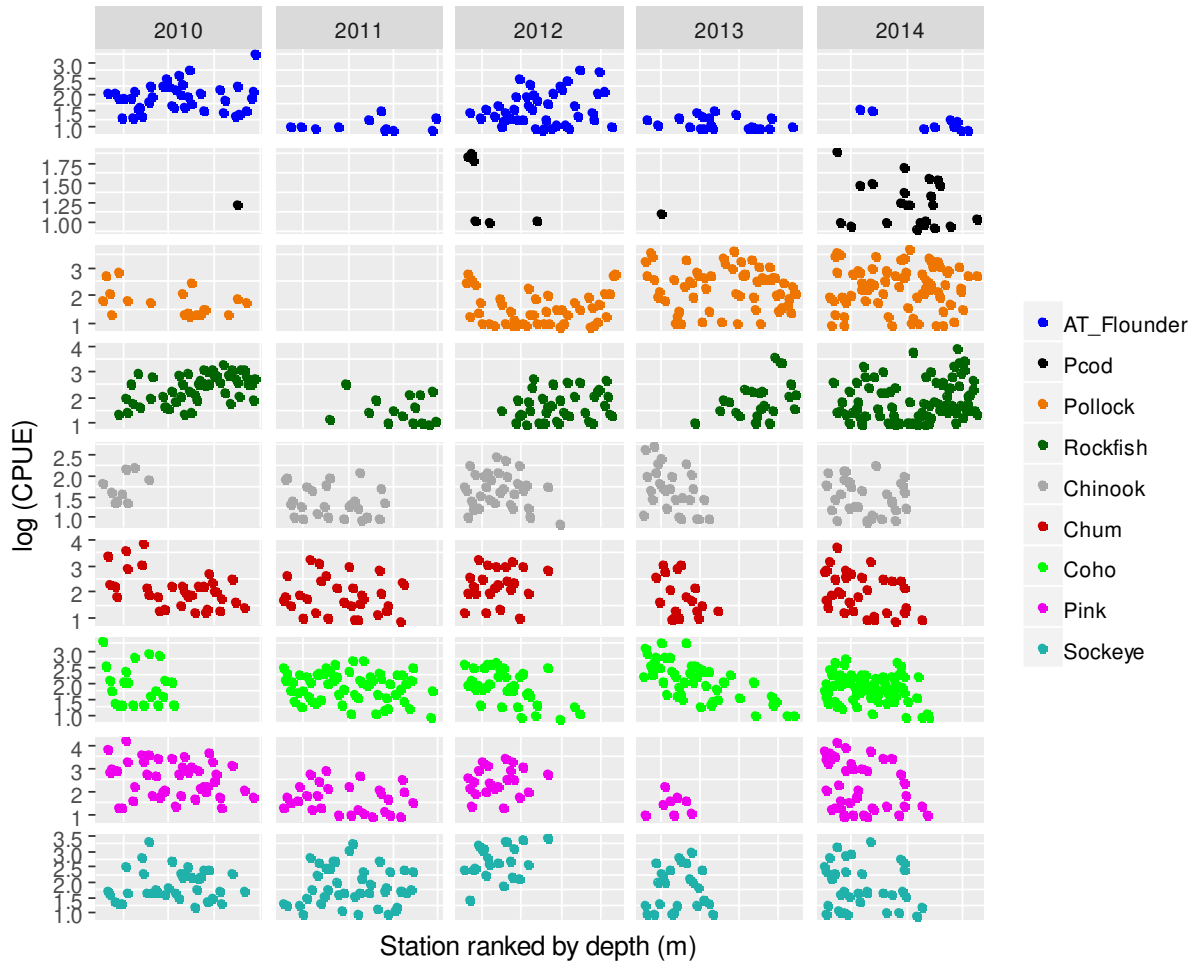
917

918 Figure 1. Map of the eastern Gulf of Alaska (EGOA) and the general station locations (red  
919 circles) during 2010-2014. Not all stations were sampled each year.



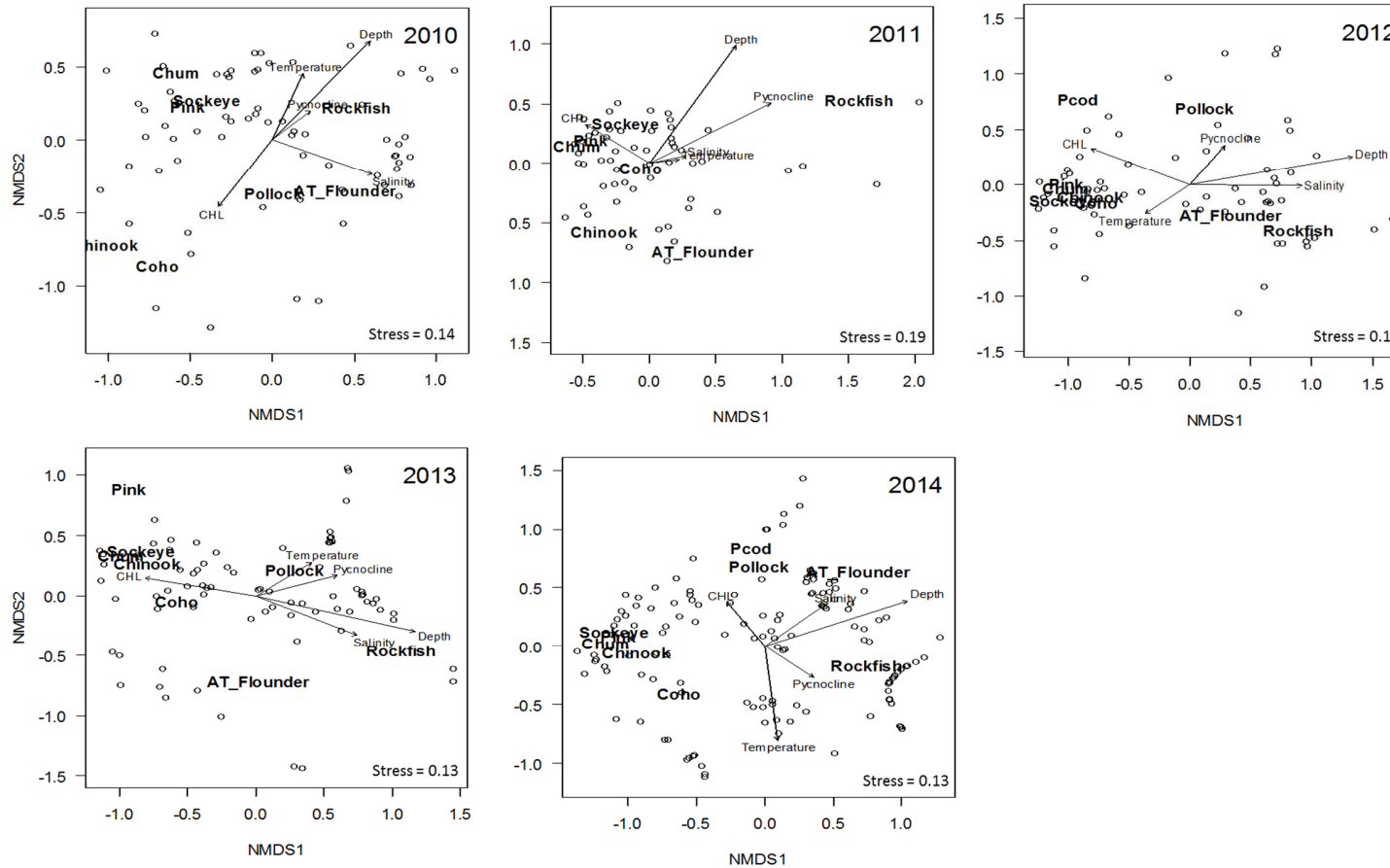
920

921 Figure 2. Log scale catch per unit effort ( $\log(\text{CPUE})$ ) at each sampling station ranked by bottom  
922 depth (m) of juvenile groundfishes and salmon for each year, note the y-scale is different.

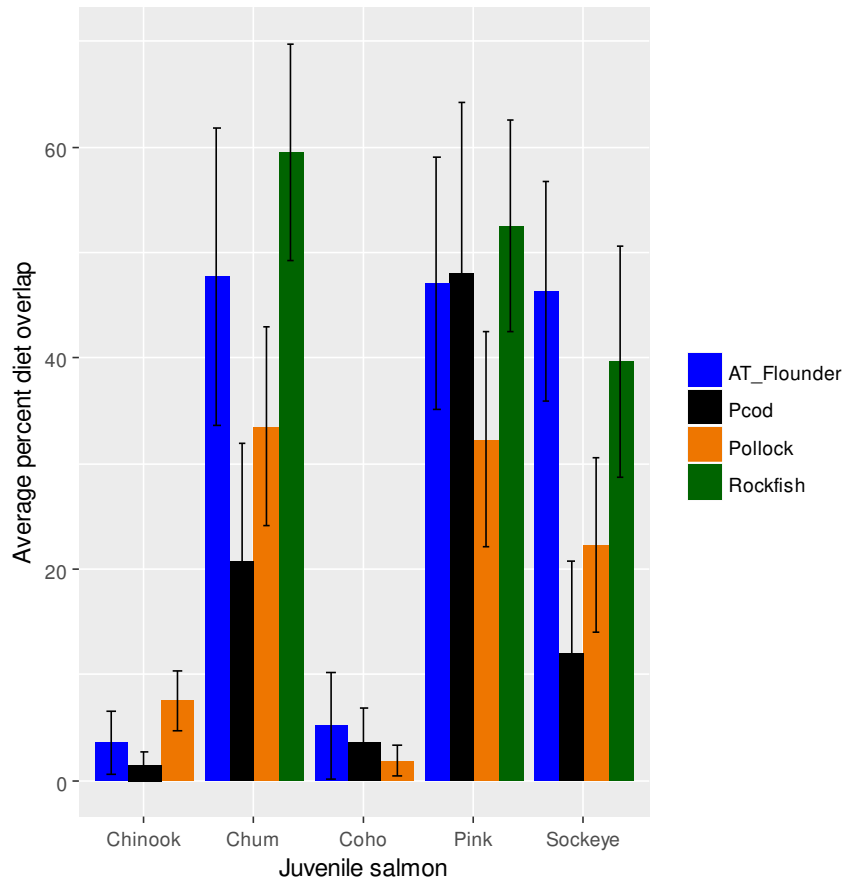


923

924 Figure 3. Non-metric multidimensional scaling (NMDS) plots of catch per unit effort (CPUE) of juvenile groundfishes and salmon  
 925 species for each year with vectors of physical variables overlaid on each plot. Each point represents station CPUE of the juvenile  
 926 groundfishes and salmon. The temperature ( $^{\circ}\text{C}$ ), salinity units and total chlorophyll a (CHL) levels were average station values from  
 927 the top 20 m, depth represents station depth (m), and pycnocline was an estimated depth (m) where the change in density was at  
 928 maximum.



930 Figure 4. Average percent diet overlap of the four groundfish species with each juvenile  
931 salmonid for all years combined.

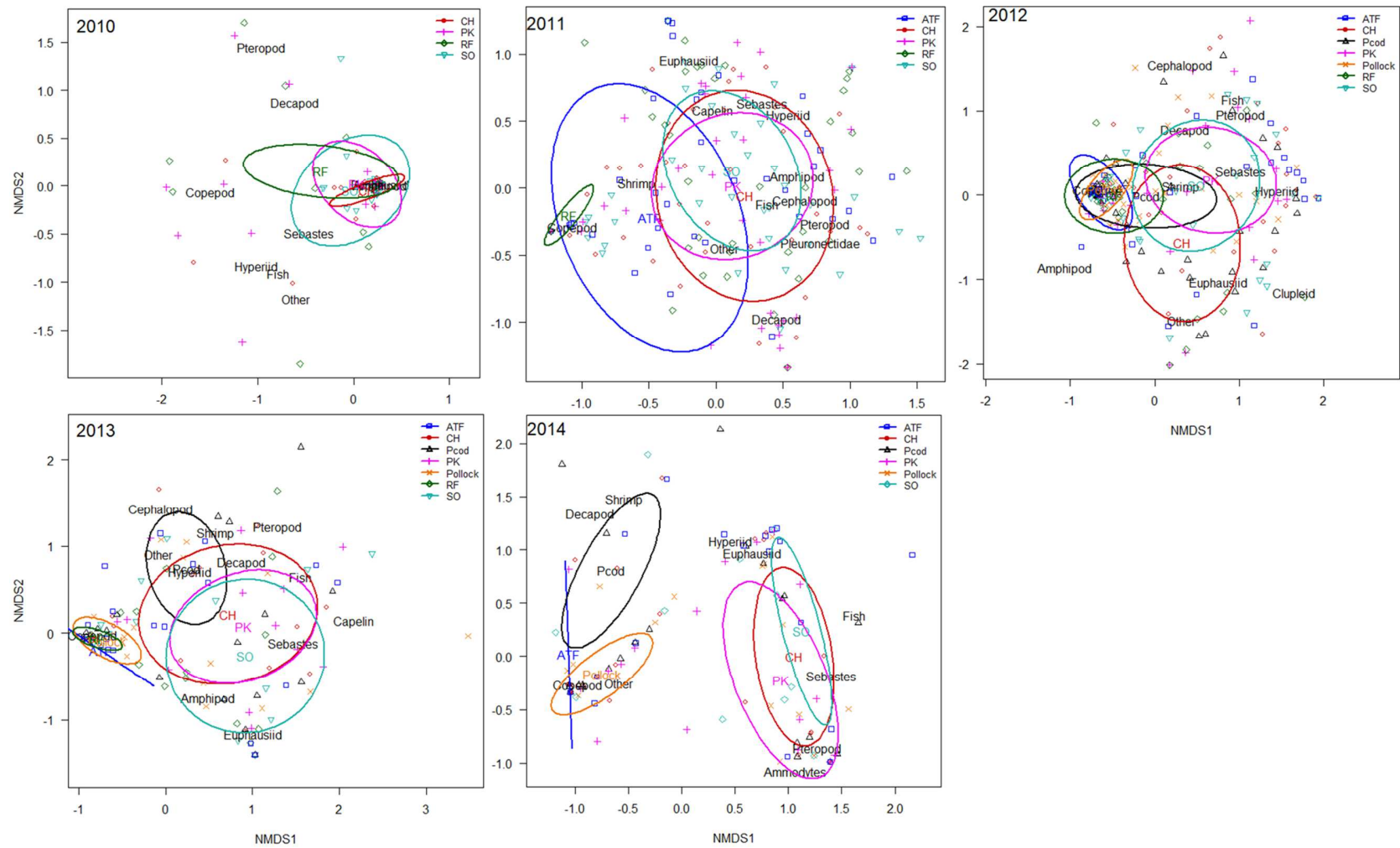


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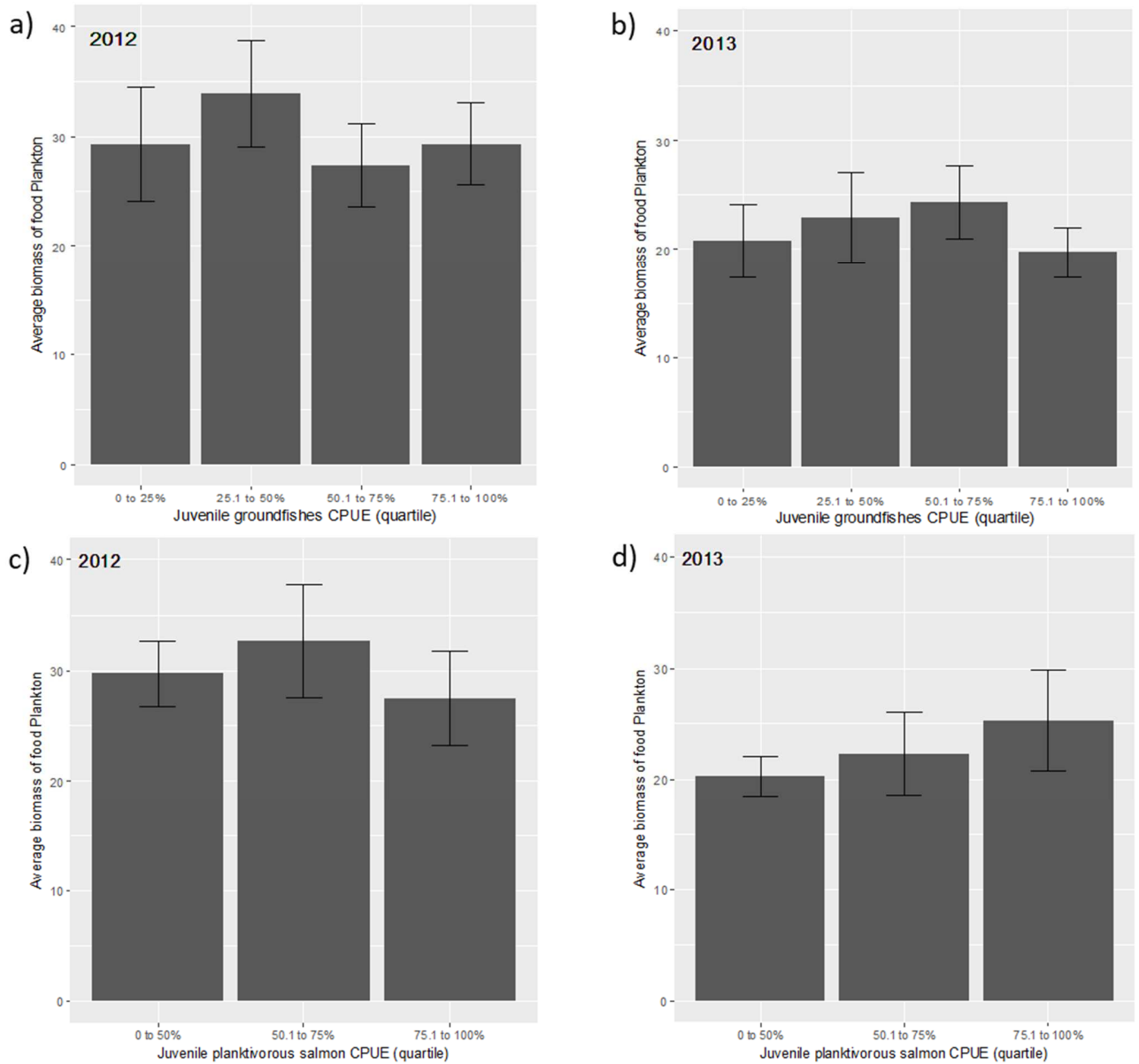
933



934 Figure 5. Non-metric multidimensional scaling (NMDS) plots of juvenile groundfishes and salmon diets by year. Each colored symbol  
 935 represents diets of juvenile fishes averaged at each sampling station. Abbreviations of the predator taxa are as follows: Arrowtooth  
 936 flounder (ATF), chum (CH), Pacific cod (Pcod), pink salmon (PK), walleye pollock (pollock), rockfish (RF), and sockeye salmon  
 937 (SO). Ellipses encompass the major and minor axes of each species diet deviation.

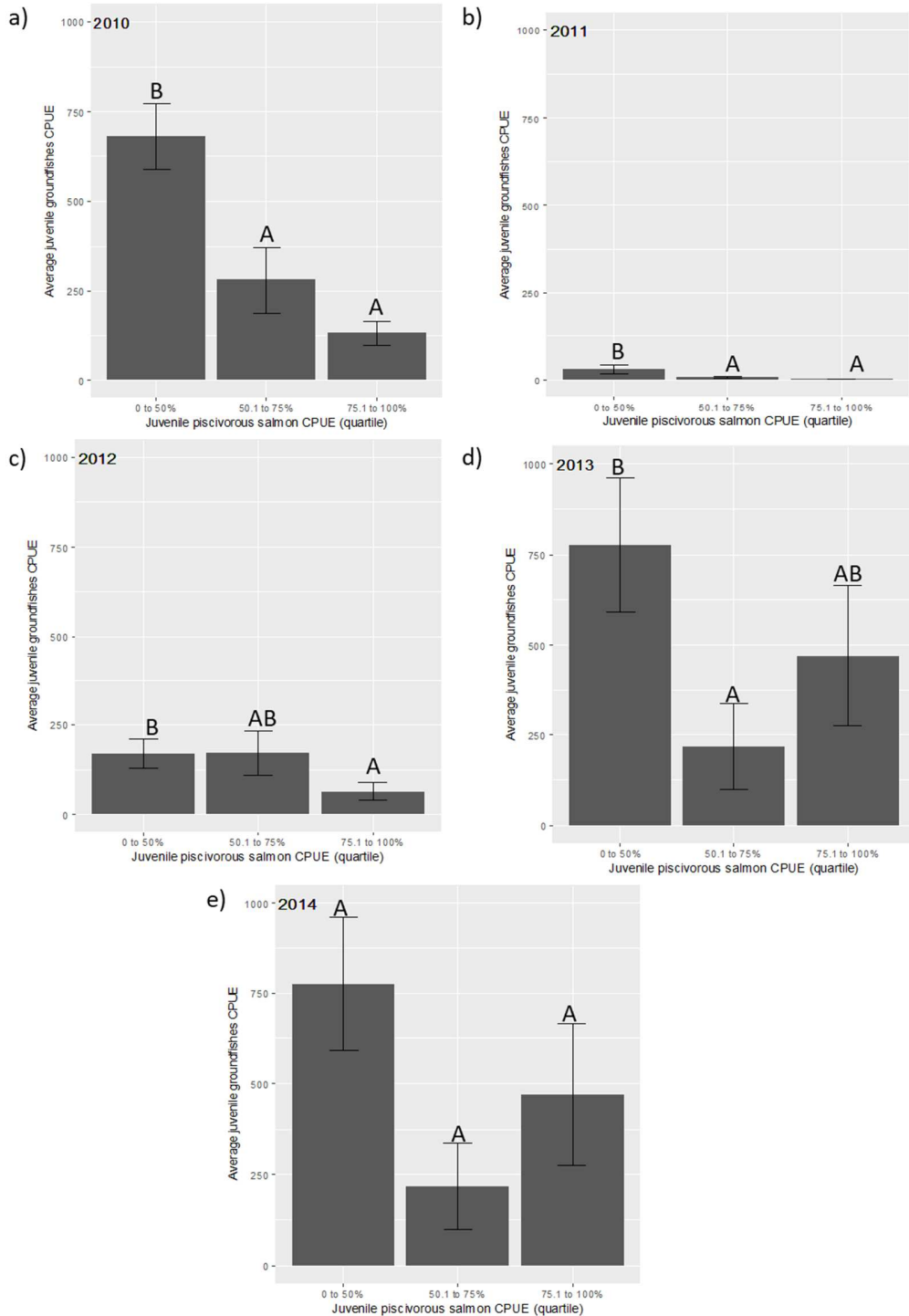


939 Figure 6. Average zooplankton food biomass ( $\pm$  SE) at each sampling station grouped by  
940 juvenile groundfishes CPUE quartiles and year (a-b) and by juvenile piscivorous salmon CPUE  
941 quartiles and year (c-d). There were no significant pairs based on the Kruskal-Wallis test;  $P <$   
942 0.05.



943  
944

945 Figure 7. Average groundfishes CPUE ( $\pm$  SE) at each sampling station grouped by juvenile  
 946 piscivorous salmon CPUE quartile and year. Letters above error bar represent significantly  
 947 different groups based on the Kruskal-Wallis test;  $P < 0.05$ .



948

949