

Passive reclamation of soft-sediment ecosystems on the North Coast of British Columbia, Canada

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1 Passive Reclamation of Soft-Sediment Ecosystems on the North Coast of British Columbia, Canada

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10

11 **Abstract**

12 Estuarine ecosystems are degraded through anthropogenic development, leading to reduced
13 habitat suitability for biological communities. The Skeena River estuary (British Columbia, Canada) is
14 undergoing passive reclamation from historical salmon canneries and pulp mills, while localized
15 disturbances continue at present. To reveal both current impacts and the trajectory of passive
16 reclamation from historical activities, the intertidal mudflat surrounding the longest operating salmon
17 cannery, Cassiar Cannery, within the Skeena estuary was surveyed. Nutrient availability (chlorophyll *a*
18 concentration/organic matter content), sediment variables (particle size, water content, penetrability,
19 woody debris/macroalgae cover, apparent redox potential discontinuity depth), and infaunal community
20 composition varied spatiotemporally, and suggest that an old dock may be influencing the infaunal
21 community given the abundance of disturbance indicating taxa below the dock. However, with
22 populations of amphipods, mobile polychaetes, and a complex community structure, the mudflat as a
23 whole appears to be relatively healthy. Therefore, cessation of historic activities has allowed for
24 passive reclamation to a reasonably unstressed state, though a threshold of recovery may exist for
25 intertidal mudflats beyond which passive reclamation will not be effective.

26 **Key Words:** Infauna, Intertidal, Habitat Disturbance, Passive Restoration, Salmon Cannery, Soft-
27 Sediment

29 **1. Introduction**

30 Soft-sediment ecosystems represent over 70% of coastal ecosystems, and are important
31 components of estuarine habitats (Constable and Fairweather 1999; Schlacher and Thompson 2013).
32 Estuaries are productive regions with importance for commercial fisheries, providing habitat for
33 sensitive species (especially migratory shorebirds), as well as recreational uses for human populations
34 (Carr-Harris et al. 2015; Constable and Fairweather 1999; Dissanayake et al. 2018; Kennish 2002).
35 However, urbanization and industrial development have resulted in the degradation of soft-sediment
36 ecosystems and estuaries (Constable and Fairweather 1999; Crain et al. 2008; Kennish 2002; Schlacher
37 et al. 2016). Coastal developments will increase as human populations grow, with the associated habitat
38 degradation leading to substantial ecological consequences (Dissanayake et al. 2018; Kritzer et al.
39 2016). As such, understanding human impacts and subsequent management is now a fundamental
40 component of research into coastal and estuarine ecology (Gonzalez et al. 2016; Vackar et al. 2012).

41 Within estuarine soft-sediments, detrimental effects can occur through physical damage to the
42 substrate surface, organic enrichment, oxygen depletion, and accumulation of contaminants (Dernie et
43 al. 2003; Pearson and Rosenberg 1978). Physical disturbance results in the creation of surface features
44 such as pits and troughs, thus allowing water accumulation, disturbing biological communities and
45 structures, and possibly disrupting the redox potential discontinuity (RPD; transition from oxidizing to
46 reducing sediment conditions) layer (Dernie et al. 2003; Fonseca et al. 1982; Hansen and Skilleter
47 1994). Organic enrichment, such as from human sewage or effluent from pulp mills, can substantially
48 alter infaunal biodiversity and community composition (Ahn et al. 1995; Buttermore 1977; Caswell et
49 al. 2018; Heilskov and Holmer 2001; Pearson and Rosenberg 1978) and potentially lead to oxygen
50 depletion and anoxia (Buttermore 1977; Kristensen 2000; Levin et al. 2009; Waldichuk 1979). Such
51 enrichment can also lead to sulphide accumulation, altering infaunal communities through toxicological
52 effects and exacerbation of hypoxia (Heilskov and Holmer 2001; Wu 1995). Furthermore, sediment

53 contamination is not restricted to organic enrichment and occurs through pollution and industrial
54 effluents containing polycyclic aromatic hydrocarbons, sulfides, coppers and other chemicals (Hoos
55 1975; Turner 2019; Yunker et al. 2002), with negative impacts on infaunal communities (Pires et al.
56 2017; Pocklington and Wells 1992; Waldichuk 1966).

57 Due to their well-understood responses to disturbance, invertebrates are invaluable for
58 evaluating ecosystem health and identifying disturbed habitats (Gesteira and Dauvin 2000; Guerra-
59 Garcia and Garcia-Gomez 2004; Pearson and Rosenberg 1978). Invertebrates have been used to
60 develop ecological theories on organismal responses to disturbance (Cowie et al. 2000; Gerwing et al.
61 2017a; Pearson and Rosenberg 1978), and are employed in both monitoring and assessing human
62 impacts on natural ecosystems (Borja and Muxika 2005; Gerwing et al. 2018a; Hereward et al. 2017;
63 Muxika et al. 2005; Pearson and Rosenberg 1978). In addition to monitoring applications, marine
64 benthic invertebrates support commercial fisheries, both by serving as dietary sources for fish and as
65 industrial bait (Davis et al. 2014; Kritzer et al. 2016; Pires et al. 2017). Therefore, studying
66 invertebrates is a pro-active strategy to detect disturbances before productivity of commercial fisheries
67 is impaired (Ozdemir et al. 2011; Pinto et al. 2009). In soft-sediment ecosystems, infaunal invertebrates
68 have been employed as successful indicators for multiple disturbance mechanisms including organic
69 enrichment, hypoxia, and pollution (Bett 1988; Pearson and Rosenberg 1978; Thrush et al. 2003).

70 Although disturbance can have detrimental effects, soft-sediment ecosystems and infaunal
71 communities are resilient to disturbance as the fauna are exposed to extreme variability on a daily basis
72 (Altieri 2006; Cowie et al. 2000; Gerwing et al. 2018a; Valdivia et al. 2011), and are responsive to
73 passive reclamation through both physical and biological processes such as wave action, sediment
74 deposition, and bioturbation (Dernie et al. 2003; Gerwing et al. 2018a; Skilleter 1996). Passive
75 reclamation is the cessation of activities causing ecosystem degradation, thus allowing for unassisted
76 recovery (Benayas et al. 2009; Holl and Aide 2011). Considered to be the first and most crucial step in
77 ecological reclamation, passive reclamation can be highly effective in coastal and estuarine ecosystems

78 without the associated cost of active reclamation; however, not all reclamation efforts track progress
79 against recovery targets, or consider infaunal communities (Bayraktarov et al. 2016; Holl and Aide
80 2011; Kauffman et al. 1997; Marquiegui and Aguirrezabalaga 2009; McCrackin et al. 2017).

81 Along the North Coast of British Columbia (BC) Canada, the Skeena River estuary has
82 experienced a variety of disturbances, including physical disruption of soft-sediment, organic
83 enrichment, and accumulation of toxins (Carr-Harris et al. 2015; Gerwing et al. 2018c). Near the mouth
84 of the Skeena River, the mudflat surrounding Cassiar Cannery in Inverness Passage (Figure 1)
85 experiences physical disturbance to the sediment from logs that are transported down the Skeena River,
86 flow through Inverness Passage, and accumulate on the mudflat, while an old dock structure may
87 deposit woody debris into the sediment, potentially resulting in organic enrichment. However, in
88 addition to these current impacts, this mudflat has also been undergoing passive reclamation from
89 historical activities. Established in 1889, Cassiar Cannery was the longest consecutively operating
90 salmon cannery on BC's coast before closing in 1983, with associated disturbances including toxic
91 inputs like copper and creosote, and organic enrichment from discarded salmon carcasses (Beyer et al.
92 1975; Faggetter 2008; Stone et al. 1981). Furthermore, through the 1900s, 12 salmon canneries
93 operated near the mouth of the Skeena River, with the last cannery ceasing operation in 1989, while
94 pulp mill operations commenced in the 1970s and continued through 2001 (Akenhead 1992; Faggetter
95 2008; Yunker et al. 2002). Unfortunately, estuarine and coastal ecosystems may require at least 15-25
96 years to recover from degradation spanning a century, or alternatively may never recover and instead
97 exist in a perpetual alternate state (Borja et al. 2010; McCrackin et al. 2017; Simenstad et al. 2006).
98 Therefore, considering historical impacts is crucial when assessing estuary health and ecosystem
99 functioning (Szabo 2010).

100 At the Cassiar Cannery mudflat, the sediment is predominantly fine silt (< 63 μm) and fine-
101 grained sand (125-250 μm) with coarser grain sand and pebbles present within small patches. A 1-3mm
102 layer of oxic mud occurs at the sediment surface (Gerwing et al. 2017a; McLaren 2016). The mudflat

103 was sampled at four distinct locations (Figure 1), with two locations considered impacted (hereafter
104 referred to as Resort and Dock locations) and two chosen as reference stations. As both the Resort
105 Location and Dock Location are within the historical footprint of the salmon cannery, they were thus
106 historically impacted via chemicals such as creosote, copper and copper soldering products, pyrogenic
107 polycyclic aromatic hydrocarbons, grease and other chemicals (Faggetter 2008; Page et al. 1999).
108 Substantial nutrient inputs also occurred due to salmon carcass discards (Beyer et al. 1975; Stone et al.
109 1981). The Dock Location (DL) is situated below the historical wooden dock and is hypothesized to be
110 currently impacted by the dock depositing woody debris on the mudflat surface. Additionally, the
111 benthos below the dock has not seen direct sunlight for ~130 years, and sedimentation and hydrology
112 are likely affected by the physical structure of the dock. The Resort Location (RL) is in front of former
113 homes of cannery managers that have been restored to heritage houses, allowing Cassiar Cannery to
114 continue operating as an ecotourism resort. This study does not examine impacts of the resort itself, but
115 instead looks at the current physical disturbance to the sediment surface that occurs at the Resort
116 Location from accumulated logs that flow from the Skeena River through Inverness Passage and scour
117 the sediment surface (Gerwing et al. 2015a; Herbert et al. 2009).

118 The majority of mudflats in the region had salmon canneries operating on them, greatly
119 decreasing the availability of reference locations within the immediate region that reflect unimpacted
120 soft-sediment ecosystems. The reference locations employed (North Reference (NR) and South
121 Reference (SR)) are both outside the area of current impacts of physical disturbance from logs and the
122 dock structure, and are also outside the historical footprint of the salmon cannery. Due to high tidal
123 flushing, as well as water and sediment input from the Skeena and Nass Rivers (McLaren 2016) any
124 organic matter or chemicals present would likely have been diluted and had minor impacts upon the
125 reference locations (Beyer et al. 1975). Therefore, these locations are adequate reference locations
126 (Underwood 1994; 1997; 2009).

127 By employing these four study locations, this study attempts to reveal current impacts regarding
128 organic enrichment and physical disturbance from potential woody debris deposition and log scour at
129 the intertidal mudflat surrounding Cassiar Cannery, while also considering historical impacts and the
130 trajectory of passive reclamation. To accomplish these goals, the infaunal community, sediment
131 parameters and nutrient availability were examined at reference and potentially impacted locations.
132 Within the infaunal community, high abundances of indicator taxa including oligochaetes, nematodes,
133 and polychaetes from the families Spionidae and Capitellidae may indicate impacted habitat, as these
134 taxa are often found in higher abundances in disturbed habitats (Chollett and Bone 2007; Pearson and
135 Rosenberg 1978), and these were thus hypothesized to be present at higher abundances at the Dock and
136 Resort Locations. Conversely, taxa indicating healthy habitats such as amphipods and mobile, errant
137 polychaetes were expected to be absent from disturbed locations (Cardoso et al. 2007; Gesteira and
138 Dauvin 2000). The dock was also expected to decrease the depth to the apparent redox potential
139 discontinuity depth (aRPD), due to increased oxygen consumption during decomposition of woody
140 debris, with a subsequent increase in organic matter content at the Dock Location (Kristensen 2000;
141 Pearson and Rosenberg 1978). Impacted locations were also expected to have reduced primary
142 productivity due to disruption to biotic structures and the dock reducing light availability. A greater
143 understanding of passive reclamation and its efficacy would help to inform cost-benefit decisions of
144 coastal management and reclamation activities, given the high costs associated with active reclamation.

145

146 **2. Methods**

147 2.1 Sampling Scheme and Field Methods

148 At each location three transects were established, stretching from the start of the mudflat to the
149 low tide waterline (Cox et al. 2017; Gerwing et al. 2015b). Transects were 60m long, placed 10m apart,
150 and stratified into three equal zones based upon distance from shore (near, middle, far). Within each
151 zone, a 1m² quadrat was randomly selected and established (n = 3 per transect, 9 per location). All 4

152 locations were sampled in a day, 3 times throughout the summer of 2017 (May 30, June 21, and July
153 20) at the lowest low tides (Cox et al. 2017; Gerwing et al. 2017a) for a total of 27 sampling events per
154 location.

155 At each 1m² quadrat, infauna was collected with a core of 10cm in length and a diameter of
156 7cm. Following collection, the sediment was passed through a 250µm sieve and stored in vials of 95%
157 ethanol (Bringloe et al. 2013; Gerwing et al. 2017a; Hamilton et al. 2003; Sizmur et al. 2013). Forty
158 infaunal taxa have previously been identified at the Cassiar Cannery (Gerwing et al. 2017a; Gerwing et
159 al. 2018c), and specimens were identified to the lowest possible taxonomic unit (Gerwing et al. 2017a;
160 Thrush et al. 2003) as follows: cumaceans, amphipods, polychaetes, nemertean and bivalves were
161 identified to species; chironomids (larvae) to family; copepods to order; ostracods to class; and
162 nematodes to phylum.

163 For sediment parameters, surface wood cover (%) and macrophyte cover (%) of the quadrat
164 were visually estimated, and sediment penetrability was assessed by dropping a metal weight (15cm
165 long, 1.9cm diameter, 330g) from a height of 0.75m above the sediment (Gerwing et al. 2015b). The
166 depth the weight penetrated the sediment was measured as an indication of how easily water and
167 animals can penetrate the sediment, therefore generating an index that can be compared between
168 quadrats and locations. Additionally, water content, and volume weighted mean particle size in the
169 upper 1cm of sediment were quantified as outlined in Gerwing et al. (2015b) by collecting a sediment
170 core (4.5cm diameter, 5cm length) from each quadrat. The top 1cm of each core was weighed, placed
171 in a drying oven at 110°C for 12 hours, and re-weighed. Percent water-content was calculated as:

172

173
$$(\text{mass wet sediment} - \text{mass dry sediment}) / (\text{mass wet sediment}) \times 100$$

174

175 Volume-weighted mean particle-size of the sediment for each sample was determined using a Malvern
176 Mastersizer 2000 (www.malvern.com). Particle size was measured in triplicate and a mean value per
177 sample calculated (Gerwing et al. 2015b).

178

179 Depth of the apparent redox potential discontinuity (aRPD) was measured to the nearest 1mm
180 as an index of sediment dissolved oxygen content (Gerwing et al. 2017b; Gerwing et al. 2015c). aRPD
181 depth gives a relative measure of sediment dissolved oxygen content and redox conditions. The aRPD
182 was measured in the sediment void left by the removal of the 7cm diameter infauna core (Gerwing et
183 al. 2013).

184 Organic matter content was quantified from the sediment core as outlined by Gerwing et al.
185 (2015b). Briefly, dried sediment samples were ashed in a muffle furnace at 550°C for four hours and
186 re-weighed. Percent organic-content was calculated as:

187

188
$$(\text{mass dry sediment} - \text{mass of ashed sediment}) / (\text{mass of dry sediment}) \times 100$$

189

190 Chlorophyll *a* concentration was used as a proxy for the abundance of benthic diatoms
191 (Coulthard and Hamilton 2011; Hargrave et al. 1983; Trites et al. 2005). A 2cm diameter core was
192 taken to determine the concentration of chlorophyll *a* in the top 2-3mm of sediment as outlined by
193 Coulthard and Hamilton (2011). Briefly, chlorophyll pigments were extracted from sediment samples
194 via buffered acetone (90%) and processed through a spectrophotometer to assess reflectance of
195 chlorophyll pigments (664 and 750nm)

196

197 2.2 Statistical Analysis

198 The Permutational Multivariate Analysis of Variance (PERMANOVA) package in the
199 statistical program PRIMER 7 (McArdle and Anderson 2001; Clarke and Gorley 2015) was used to

200 elucidate how biotic and abiotic parameters varied between reference and impacted locations. These
201 parameters were divided into infaunal community (species composition and abundance), sediment
202 parameters (depth to the aRPD, sediment water content, volume weighted mean particle size,
203 penetrability, % macroalgae coverage, and % wood coverage), and nutrient variables (chlorophyll *a*
204 concentration and sediment organic matter). Groups of variables were then analyzed separately, to
205 elucidate any differences between reference and potentially impacted areas.

206 Infaunal abundances were fourth root ($x^{1/4}$) transformed to decrease the importance of very
207 abundant species on the outcome of analyses and improve the assessment of less common species.
208 Subsequently, Bray-Curtis distances were used to create a resemblance matrix (Clarke et al. 2006) for
209 the PERMANOVA. Within this PERMANOVA, Location (4 levels), and Sampling Date (3 levels)
210 were fixed factors, while Transect nested within Location (Transect(Location); 3 levels) was a random
211 factor. Four *a priori* planned contrasts examined how locations varied from each other as follows: 1)
212 Dock Location (DL) vs. reference locations (NR + SR); 2) Resort Location (RL) vs. reference locations
213 (NR + SR); 3) DL vs. RL; and 4) NR vs. SR. An α of 0.05 denotes statistical significance for all
214 analyses. A PERMANOVA was also run to determine if taxonomic richness varied between impacted
215 and reference locations, by summing the number of taxa observed at each quadrat, with Bray-Curtis
216 distances for the resemblance matrix. Taxonomic richness was used as not all specimen could be
217 identified to species, therefore richness is not a true measure of species richness, instead it measures the
218 number of observed taxa (Gerwing et al. 2016; Gerwing et al. 2015b).

219 For the sediment PERMANOVA, depth to the aRPD, volume-weighted mean sediment size, %
220 macroalgae cover and % wood cover were square root (\sqrt{x}) transformed to correct for skewed
221 distributions. For the nutrient matrix, all variables were square root (\sqrt{x}) transformed. All variables
222 were normalized, and Euclidean distances were used to calculate a resemblance matrix. Factors and
223 planned contrasts for both the sediment and nutrient PERMANOVA were as described above in the

224 infauna PERMANOVA. Sediment variables also had an *a priori* analysis conducted for Date X
225 Location comparisons.

226 Similarity Percentages analyses (SIMPER; Clarke 1993) were used to examine the contribution
227 of each variable (infaunal, sediment or nutrient) to the observed differences between locations or
228 sampling dates. Increased percent dissimilarity indicates increased dissimilarity between locations. The
229 ratio of each variable's average dissimilarity to the standard deviation of dissimilarities (Diss/SD) for
230 infauna, or average squared Euclidean distance to the standard deviation of squared distances
231 (Sq.Dist/SD) for sediment and nutrient variables were calculated. These values represent how
232 consistently each variable contributed to the observed difference; variables with a ratio greater than 1
233 consistently contributed whereas those with a value below 1 did not (Gerwing et al. 2015b). Finally,
234 non-metric multidimensional scaling (nMDS, 100 restarts) plots were used to visualize variation in
235 infauna, sediment conditions, and nutrient availability between locations. All nMDS graphs had a stress
236 of ~ 0.2, and were considered to be good two-dimensional representations (Clarke 1993).

237

238 **3. Results**

239 Analysis of the invertebrate community and sediment variables through PERMANOVAs
240 showed statistically significant spatiotemporal variation, while nutrient availability varied significantly
241 through time (Figures 2-3; Tables 1-2; Supplemental Material Tables 1-3). Both the infauna community
242 and sediment parameters varied significantly between impacted locations (Dock and Resort Locations)
243 and reference locations (North and South Reference; Table 1). Percent dissimilarity of the infaunal
244 community between locations varied between 44 and 52% (Table 3). A large proportion of the
245 variation in dissimilarity of location comparisons was driven by four taxa: Oligochaeta, *Pygospio*
246 *elegans*, *Capitella* Species Complex and Nematoda (40-45%; Table 3). However, taxa contributing to
247 observed differences between locations varied. Nematoda, Oligochaeta, and *P. elegans* were
248 consistently more abundant at DL (7.00, 5.55 and 6.08 individuals/m² respectively) compared to

249 reference locations (6.10, 3.23 and 4.71 individuals/m²), but these taxa were consistently higher at
250 reference locations compared to RL (4.74, 1.07 and 4.57 individuals/m²). Furthermore, *Capitella*
251 Species Complex was consistently higher at reference locations (5.49 individuals/m²) than either
252 disturbed location (3.71 and 3.70 individuals/m²) (Table 3). The amphipod *Americorophium salmonis*
253 was present at higher abundances in reference locations compared to the Dock Location (4.76 Vs 2.66),
254 but at lower abundances compared to the Resort Location (4.82) (Table 3). The errant polychaete
255 *Eteone californica* was also present in high abundances at each location with average abundances at
256 DL, RL, and the reference locations being 2.49, 2.90 and 4.07 respectively. Taxonomic richness did not
257 vary significantly with either location or date ($p = 0.5298$ and 0.0950 respectively; Table 1).

258 A significant interaction was found for Date and Location factors of sediment parameters,
259 therefore *a priori* contrasts were conducted for each location and sampling date comparison. Sediment
260 properties varied significantly for all location comparisons, except between reference locations (NR vs
261 SR; Table 2). Wood cover contributed the most to location comparisons including DL; however it only
262 consistently contributed for the June 21 sampling date as shown by the Sq.Dist/SD ratio greater than 1
263 (Table 4). No other trend was observed, and average squared distance for location comparisons ranged
264 from 12.29-14.42.

265 Nutrient availability had significant differences between sampling dates ($p = 0.0002$), but with
266 no observed effect of location on availability (Table 1). Neither chlorophyll *a* concentration nor organic
267 matter content consistently contributed to the differences between sampling dates (Table 5). Average
268 squared distance between sampling dates was between 2.28 and 5.18.

269

270 **4. Discussion**

271 Along the North Coast of British Columbia, Canada, the intertidal mudflat surrounding Cassiar
272 Cannery may be impacted from current disturbances including physical disruption of the sediment from
273 logs and a dock structure depositing woody debris on the substrate. Simultaneously, this mudflat is also

274 undergoing passive reclamation from historical impacts associated with salmon canneries and a pulp
275 mill. Therefore, the objective of this study was to examine current impacts while considering historical
276 impacts in the region with regards to the infaunal community, sediment conditions, and nutrient
277 availability.

278

279 4.1 Infaunal Community

280 With regards to community composition, there was conflicting evidence of disturbance and of
281 overall health at different spatial scales. The infaunal community exhibited significant spatiotemporal
282 variation, with the presence of oligochaetes, nematodes, and polychaetes from the families Spionidae
283 and Capitellidae, as well as low abundances of amphipods indicative of current or historic disturbances
284 (Chollett and Bone 2007; Keats et al. 2004; Kesaniemi et al. 2012; Pearson and Rosenberg 1978). The
285 infaunal community under the dock (DL) was characterized by higher abundances of oligochaetes,
286 nematodes, and Spionidae polychaetes when compared to the reference locations, as well as by smaller
287 populations of amphipods. Furthermore, DL had an increased abundance of *Nippoleucon hinumensis*
288 than reference areas which could be indicative of disturbance, as *N. hinumensis* is an invasive
289 cumacean from Asia (Light and Smith 2007) and disturbance can facilitate biological invasions (Burke
290 and Grime 1996; Smith and Knapp 1999). These community characteristics are all representative of a
291 disturbed habitat, and it is unsurprising that the dock is altering the infaunal community composition
292 beneath it. Conversely, the mudflat in front of the ecotourism resort (RL) had smaller populations of
293 oligochaetes, nematodes, and Spionidae and Capitellidae polychaetes, as well as higher populations of
294 amphipods when compared to reference locations. As such, there is no evidence that the mudflat in
295 front of the ecotourism lodge (RL) is negatively impacted by log scour or by the activities of the lodge
296 itself. Moreover, no differences in taxonomic richness were revealed between impacted or reference
297 locations, further suggesting that the potentially disturbing agents occurring at the Cassiar Cannery are
298 not impacting the mudflat.

299 Interestingly, reference locations had higher average abundances of Capitellidae polychaetes
300 when compared to the dock (DL) and resort (RL) locations. This was unexpected, as Capitellidae
301 polychaetes can be indicative of disturbance, particularly of organic enrichment that was expected to
302 occur under the dock structure (Pearson and Rosenberg 1978). However, and as discussed in detail
303 below, no organic enrichment under the dock was observed. Further, Capitellidae polychaete
304 abundance in all locations on the Cassiar Cannery mudflat were similar to those observed on non-
305 organically enriched mudflats in the region (Campbell, Unpublished Data) as well as on mudflats on
306 the Atlantic coast (Gerwing et al. 2015b). Therefore, Capitellidae polychaetes were within normal
307 abundances when considering the scale of the entire mudflat.

308 Beyond contrasting different locations within the Cassiar Cannery mudflat, some inferences can
309 be made regarding the overall health of this mudflat. First, all locations had high populations of mobile
310 errant polychaetes and amphipods. Amphipods and mobile errant polychaetes are powerful indicator
311 species (Cardoso et al. 2007; Conlan 1994; Gerwing et al. 2018a; Gerwing et al. 2018b; Gesteira and
312 Dauvin 2000; Thomas 1993), whose high densities throughout this mudflat suggest that the Cassiar
313 Cannery mudflat is relatively healthy. Additionally, complex community structure with multiple
314 species present at all levels of the food web, coupled with high biodiversity is also often representative
315 of relatively undisturbed and/or functional habitats (Pearson and Rosenberg 1976; Pearson and
316 Rosenberg 1978). With high biodiversity, and a complex community across trophic levels, the Cassiar
317 Cannery mudflat has a diverse and functioning food web and as such the community structure is similar
318 to undisturbed mudflats (Cardoso et al. 2007; Gerwing et al. 2015b; Gesteira and Dauvin 2000; Hooper
319 et al. 2005).

320 While at the scale of the mudflat, Cassiar Cannery may be relatively healthy and functional,
321 community composition at the spatial scale of the 1m² quadrat offers a slightly contradictory
322 perspective. Invasive Cumacea, Capitellidae and Spionidae polychaetes, oligochaetes, and nematodes
323 were observed in some quadrats in all locations at densities indicative of disturbance (Chollett and

324 Bone 2007; Keats et al. 2004; Kesaniemi et al. 2012; Pearson and Rosenberg 1978). While this could
325 be the result of natural variability, previous investigations of infaunal community composition along
326 BC's north coast have detected remnant signals of historical disturbances within relatively healthy
327 mudflats decades after disturbance (e.g. logging practices (Gerwing et al. 2018b)). It is hypothesized
328 that a similar phenomenon may have been observed here. Within Inverness Passage, 3 salmon
329 canneries besides Cassiar were operating, and another 8 operated around the mouth of the Skeena River
330 (Hoos 1975). Furthermore, a pulp mill in the region discharged highly toxic effluents and spent sulfite
331 liquid (500 tons/day) into the nearshore environment commencing in the 1970s (Hoos 1975; Waldichuk
332 1966; Wilkes and Dwernychuk 1991). The decomposition of the spent sulfite liquid led to greatly
333 reduced biological oxygen demand, and the effluent accumulated in a three-meter thick layer of toxic
334 sludge on the littoral zone near the discharge pipe. Although the discharge pipe was moved in the early
335 1990s before the mill ceased operations in 2001, much of the invertebrate community was defaunated
336 by effluents (Akenhead 1992; Hoos 1975; Waldichuk 1966). Therefore, while the Cassiar Cannery
337 mudflat is now overall relatively healthy, biological signals of disturbance at the scale of the 1m²
338 quadrat may be remnants of the historical disturbances this mudflat has experienced. Cessation of
339 disturbances associated with the pulp mill and canneries would have allowed for the process of passive
340 reclamation, which appears to have been relatively successful for this infaunal community.

341

342 4.2 Sediment Parameters

343 Sediment parameters varied significantly through time and space, including in comparisons
344 between impacted and reference locations, but no variable consistently contributed to location
345 differences. Wood cover had the largest percent contribution for all comparisons including the Dock
346 Location (18.9 - 27.0%), but only consistently contributed for one sampling date (June 21). It was
347 hypothesized that the accumulation of woody debris at DL would decrease the depth to the aRPD as
348 oxygen is consumed during the degradation of woody debris. However, this was not observed and may

349 be due to tidal flushing either replenishing oxygen consumed in decomposition or removing woody
350 debris before it has sufficient time to decompose (Kristensen 2000). Evidence suggests the latter, as
351 organic matter content was not significantly higher at DL compared to the other locations.
352 Interestingly, DL was the only location that had no macroalgae cover for any quadrat on any sampling
353 date (Supplemental Material Table 2), which may indicate that the dock structure is affecting the
354 hydrology and light availability at the Dock Location.

355 As physical disturbance can disrupt the redox potential discontinuity and result in water
356 accumulation in associated pits and furrows (Dernie et al. 2003), changes to the aRPD depth and water
357 content were potential indicators of physical disturbance at the Resort Location due to scour by logs.
358 However, this was not observed in this location, as neither the aRPD depth nor water content
359 consistently contributed to differences in sediment variables between RL and other location
360 comparisons. Additionally, mudflats show high spatiotemporal variation in their sediment parameters
361 (Gerwing et al. 2015b), suggesting that the variability present on this mudflat may not be a result of
362 current or historical impacts.

363

364 4.3 Nutrient Availability

365 Although the biological community and sediment conditions showed significant spatiotemporal
366 variation, nutrient availability (chlorophyll *a* concentration and percent organic matter) only showed
367 temporal variation. Both chlorophyll *a* and organic matter content are known to vary through time, so
368 temporal differences were not surprising (Gerwing et al. 2015b; Hargrave et al. 1983; Trites et al.
369 2005). However, a lack of spatial variation was unexpected. As the Dock Location receives no direct
370 sunlight, it was hypothesized to have the lowest chlorophyll *a* concentration, yet this was not observed.
371 Some species of microalgae can acclimatize to shade (Katayama et al. 2018), and cyanobacteria can
372 produce more chlorophyll *a* at low light intensities compared to high light intensities (Muller et al.
373 1993; Raps et al. 1983). It is possible that these shade-acclimatized primary producers may be driving

374 chlorophyll *a* productivity at DL, or tidal transport of diatoms to the substrate surface may be occurring
375 under the dock. Regardless, future work should address how disturbance can influence species
376 composition of photosynthetic organisms on intertidal mudflats. Additionally, as physical disruption to
377 sediment can be detrimental to a variety of biotic parameters besides infaunal community composition
378 (Dernie et al. 2003; Fonseca et al. 1982; Hansen and Skilleter 1994) it was expected that the Resort
379 Location would have reduced chlorophyll *a* concentration compared to the reference locations;
380 however, this was not supported by the data.

381 While the physical disturbance at RL was not expected to alter organic matter content (Dernie
382 et al. 2003), the dock and potential accumulation of wood fibres was expected to result in organic
383 matter enrichment at DL, and the historic cannery may have led to organic matter enrichment compared
384 to the reference locations. This was not observed, suggesting that if organic enrichment occurred, it has
385 decreased over the past 25 years. Additionally, the average organic content in any location was not
386 higher than non-organically enriched mudflats on the east coast of Canada (~2.2-4.5%; (Gerwing et al.
387 2015b) it was marginally higher than at other mudflats nearby, as well as within the disturbed Kitimat
388 Estuary (1.81-3.97%; Campbell, Unpublished Data; Gerwing et al. 2018a). Future research should
389 determine natural ranges of organic matter content at Northeast Pacific mudflats not experiencing
390 anthropogenic nutrient inputs.

391

392 4.4 Passive Reclamation

393 Passive reclamation can be highly effective in coastal and estuarine systems
394 (Bayraktarov et al. 2016; Holl and Aide 2011; Marquiegui and Aguirrezabalaga 2009), while the
395 associated costs of active reclamation can be extremely high (Bayraktarov et al. 2016; Holl and Aide
396 2011). Additionally, there is no clear relationship between the cost of reclamation and the success of
397 marine coastal reclamation efforts (Bayraktarov et al. 2016). At the Cassiar Cannery mudflat,
398 quantifiable comparisons were not possible due to a lack of pre-disturbance data, but the cessation of

399 historical activities would have allowed for passive reclamation. These findings suggest that passive
400 reclamation was sufficient to return this intertidal mudflat to a relatively productive, functional and
401 diverse ecosystem, therefore in some scenarios passive reclamation may be an effective reclamation
402 tool without the burden of high operating costs (Holl and Aide 2011). However, in this study passive
403 reclamation did not restore the community to an entirely unstressed state, as evidenced by locally
404 abundant populations of Capitellidae/Spionidae polychaetes and invasive cumaceans. Therefore, more
405 time may be necessary for further progression towards an unstressed state, or a threshold may exist
406 beyond which intertidal mudflats cannot be reclaimed through passive means. For instance, it is
407 unlikely that an invasive species will passively die off once established.

408 The Cassiar Cannery mudflat would also have been impacted by chemical contaminants during
409 its operation, and while this study did not quantify residual contaminants (e.g. copper or polycyclic
410 aromatic hydrocarbons from the historical pulp mill and salmon cannery,) Sizmur et al. (In Press)
411 showed no evidence of sediment contamination by potentially toxic elements (a naturally occurring
412 element that can be toxic in high concentrations, e.g, arsenic, cadmium, cobalt, chromium, nickel, lead,
413 and zinc) in the top 20 cm of the Cassiar Cannery mudflat. All potentially toxic elements studied at the
414 Cassiar Cannery mudflat can be classified as unpolluted due to their low concentration (Muller 1969).
415 This result indicates that if contaminants were present, sediment inputs from the Skeena and Nass River
416 have buried contaminated sediment as part of the passive reclamation process.

417 Passive reclamation therefore is an effective tool for intertidal mudflats; however, more
418 research is required to see if thresholds exist to the efficacy of passive reclamation and whether these
419 thresholds shift based on the level of disturbance to an estuarine system. Regardless, if thresholds do
420 exist for passive reclamation but the goal is full reclamation, allowing for passive reclamation to the
421 existing threshold before commencing active reclamation may be more cost-effective than a complete
422 active reclamation scheme.

423

424 **5. Conclusions**

425 Overall the Cassiar Cannery mudflat appears to be relatively healthy and reasonably unstressed,
426 and it appears that passive reclamation from historical disturbances has occurred at these locations.
427 Therefore, passive restoration may be an appropriate reclamation technique in other soft-sediment or
428 estuarine ecosystems degraded by industrial activities. However, within the mudflat, some patches
429 (1m² quadrat) reveal the legacy of past disturbances in the form of patchy distributions of taxa which
430 are known indicators of disturbance. Therefore, thresholds may exist to the efficacy of passive
431 reclamation, and future research should address potential thresholds of reclamation. Regardless,
432 allowing for passive reclamation of the soft-sediment ecosystem to a relatively unstressed state before
433 commencing active reclamation may be successful without the high cost associated with a full active
434 reclamation scheme.

435

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Tables and Figures

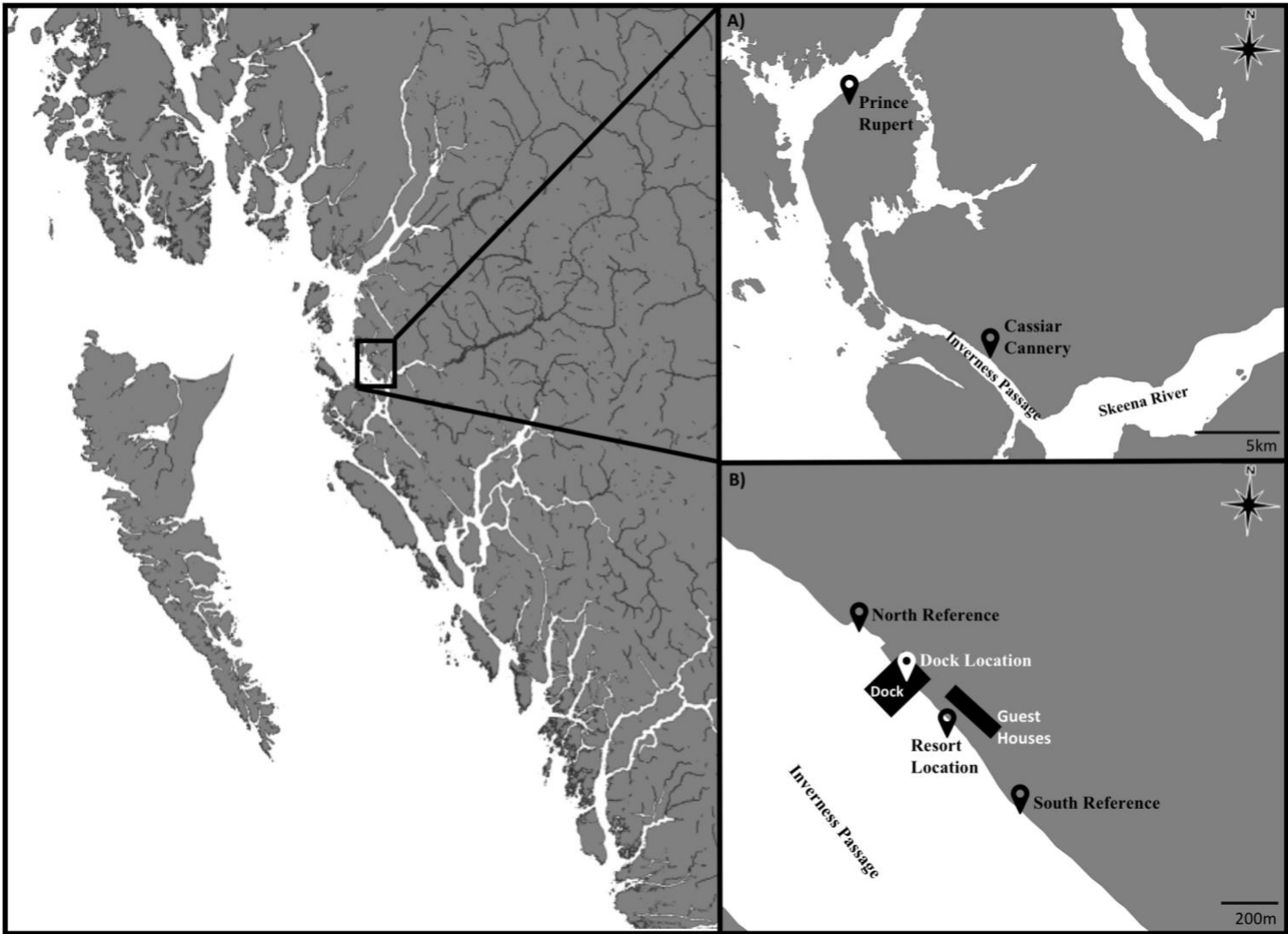


Figure 1. Location of the Cassiar Cannery mudflat (54.178092° , -130.176924°) sampled during summer 2017, in Inverness Passage, British Columbia, Canada. A) shows the location of the Cassiar Cannery mudflat within Inverness Passage relative to the Skeena River and Prince Rupert. B) shows the 4 locations sampled on the Cassiar Cannery mudflat. DL: Dock Location (benthos underneath the dock denoted by DK), RL: Resort Location (in front of guest houses denoted by GH), NR: North Reference, SR: South Reference.

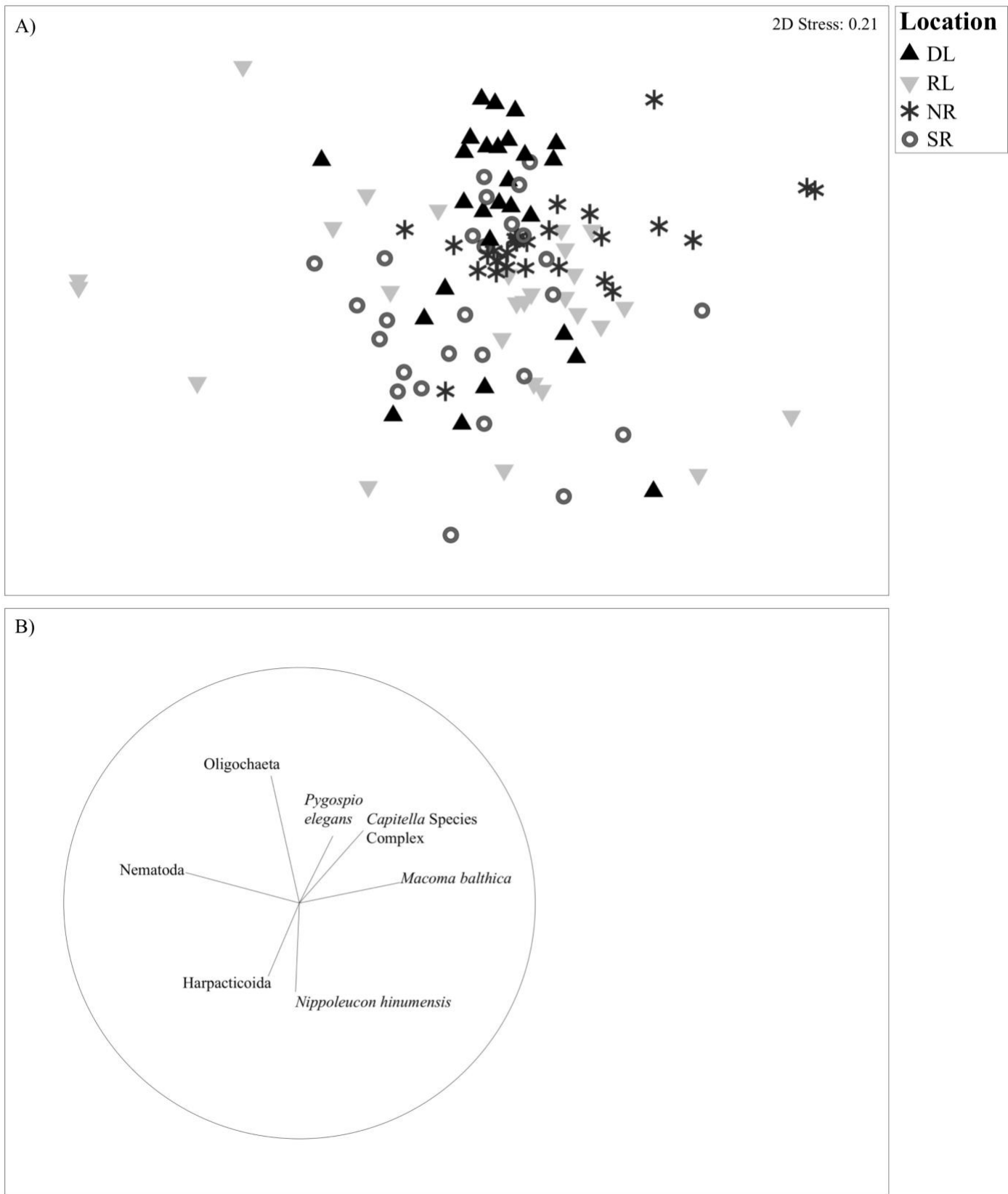


Figure 2. Non-metric multidimensional scaling (nMDS) graphs showing infaunal invertebrate community at four locations on the intertidal mudflat at Cassiar Cannery in Inverness Passage, British Columbia, during the summer of 2017. A) the infaunal community by location and B) the vector overlay indicates the direction of increased density, with correlations > 0.3 shown. DL: Dock Location. RL: Resort Location. NR: North Reference. SR: South Reference.

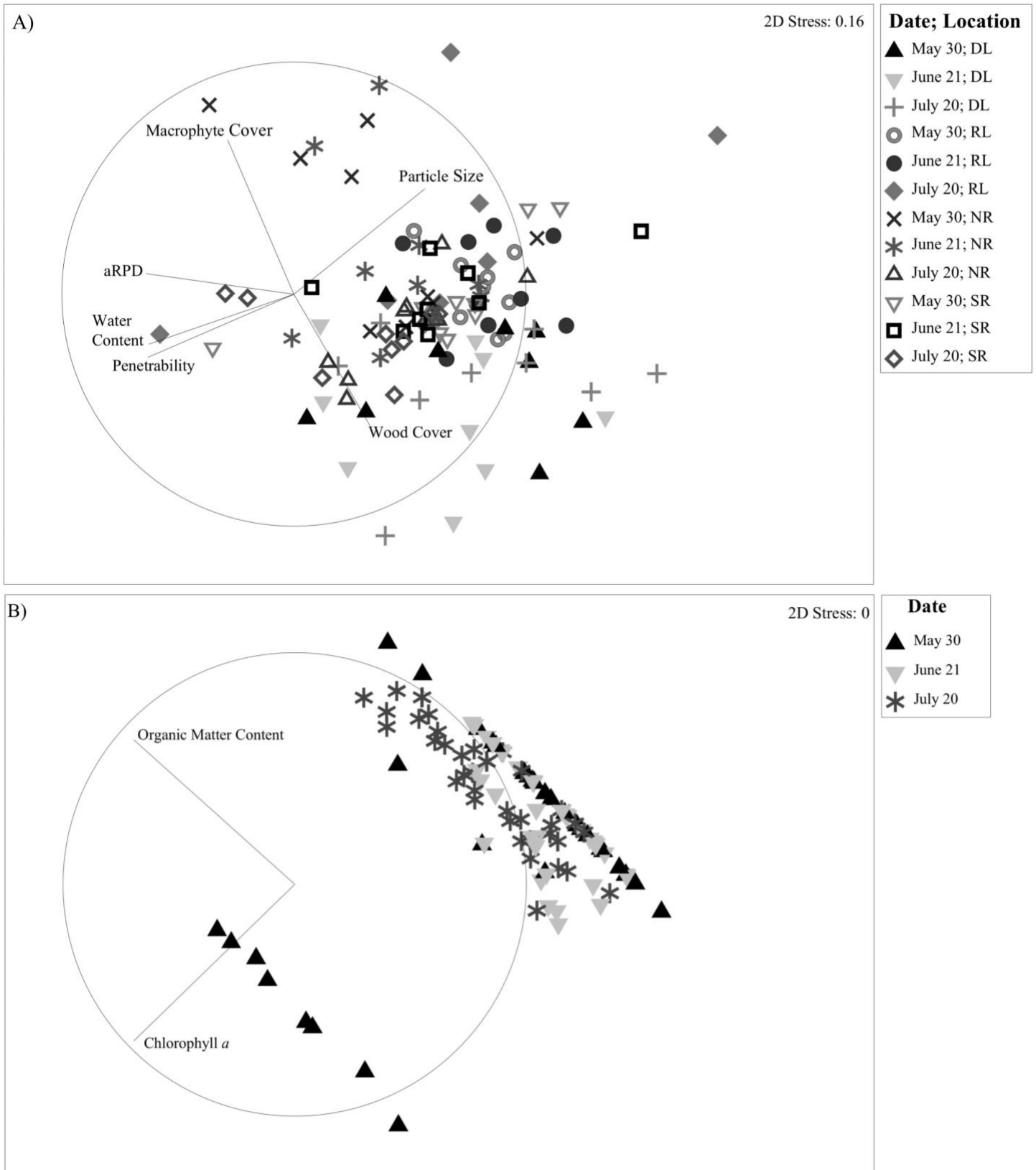


Figure 3. Non-metric multidimensional scaling (nMDS) graphs of A) sediment parameters (depth to the aRPD, water content, particle size, penetrability, % macroalgae coverage, and % wood cover) by time and location and B) the nutrient availability (chlorophyll *a* and organic matter content) at four locations on the intertidal mudflat at Cassiar Cannery in Inverness Passage, British Columbia, during the summer of 2017. Vector overlays for sediment and nutrient variables show the correlation between variables and nMDS axes, with each vector showing the direction of increased value. DL: Dock Location. RL: Resort Location. NR: North Reference. SR: South Reference.

Table 1. Permutational multivariate analysis of variance (PERMANOVA) quantifying the spatiotemporal variation in A) infaunal invertebrate community, and B) taxonomic richness, and C) sediment parameters, and D) the nutrient parameters at four locations at the intertidal mudflat at Cassiar Cannery during the summer of 2017. DL: Dock Location. RL: Resort Location. NR: North Reference. SR: South Reference. Significant p values ($\alpha < 0.05$) are denoted in bold.

A)						
Source	df	MS	Pseudo-F	Unique Permutations	p	
Date	2	6939.90	6.93	4982	0.0002	
Location	3	6316.20	3.38	4237	0.0002	
DL vs (NR + SR)	1	6973.10	6.95	4986	0.0002	
RL vs (NR + SR)	1	5798.70	4.69	4992	0.0008	
DL vs RL	1	7738.00	5.97	4990	0.0002	
NR vs SR	1	5500.80	5.81	4986	0.0002	
Transect(Location)	8	1869.20	2.11	4971	0.0002	
Date X Location	6	1345.20	1.34	4978	0.1550	
Date X Transect(Location)	16	1001.50	1.13	4958	0.2372	
Residual	72	885.96				
Total	107					
B)						
Source	df	MS	Pseudo-F	Unique Permutations	p	
Date	2	435.28	2.13	4990	0.0950	
Location	3	1004.20	0.90	4225	0.5298	
Transect(Location)	8	1121.80	4.57	4975	0.0002	
Date X Location	6	244.31	1.19	4988	0.3290	
Date X Transect(Location)	16	204.67	0.83	4978	0.6982	
Residual	72	245.43				
Total	107					
C)						
Source	df	MS	Pseudo-F	Unique Permutations	p	
Date	2	4.58	1.29	4974	0.2670	
Location	3	35.72	5.48	4248	0.0004	
Transect(Location)	8	6.52	1.25	4977	0.1486	
Date X Location	6	6.96	1.96	4982	0.0278	
Date X Transect(Location)	16	3.55	0.68	4961	0.9826	
Residual	72	5.21				
Total	107					
D)						
Source	df	MS	Pseudo-F	Unique permutations	p	
Date	2	9.76	11.49	4989	0.0002	
May 30 vs June 21	1	7.74	8.79	4987	0.0002	
May 30 vs July 20	1	6.77	3.50	4987	0.0306	
June 21 vs July 20	1	15.85	8.79	4987	0.0002	
Location	3	2.35	1.12	4258	0.4162	
Transect(Location)	8	2.10	0.99	4983	0.4696	
Date X Location	6	0.69	0.81	4980	0.6526	
Date X Transect(Location)	16	0.85	0.40	4967	0.9976	
Residual	72	2.12				
Total	107					

Table 2. Permutational multivariate analysis of variance (PERMANOVA) quantifying the spatiotemporal variation in sediment variables on three sampling dates at the Cassiar Cannery intertidal mudflat during the summer of 2017. Date was run as separate PERMANOVAs due to the significant interaction term between Date X Location in Table 1. DL: Dock Location. RL: Resort Location. NR: North Reference. SR: South Reference. Significant p values ($\alpha < 0.05$) are denoted in bold.

May 30						
Source	df	MS	Pseudo-F	Unique Permutations	p	
Location	3	14.32	3.37	4269	0.0008	
DL Vs (NR + SR)	1	16.48	2.95	4989	0.0128	
RL Vs (NR + SR)	1	15.11	2.68	4985	0.0214	
DL Vs RL	1	12.56	2.25	4516	0.0328	
NR Vs SR	1	13.13	2.36	4483	0.0800	
Transect(Location)	8	4.25	0.77	4969	0.8500	
Residual	24	5.54				
Total	35					
June 21						
Source	df	MS	Pseudo-F	Unique Permutations	p	
Location	3	18.83	4.06	4238	0.0008	
DL Vs (NR + SR)	1	26.10	5.02	4983	0.0002	
RL Vs (NR + SR)	1	17.50	3.16	4986	0.0084	
DL Vs RL	1	27.39	5.87	4468	0.0002	
NR Vs SR	1	5.69	0.94	4503	0.4700	
Transect(Location)	8	4.64	0.96	4967	0.5600	
Residual	24	4.85				
Total	35					
July 20						
Source	df	MS	Pseudo-F	Unique Permutations	p	
Location	3	14.68	2.75	4245	0.0032	
DL Vs (NR + SR)	1	23.23	4.37	4979	0.0020	
RL Vs (NR + SR)	1	12.20	2.12	4978	0.0438	
DL Vs RL	1	15.49	2.87	4533	0.0058	
NR Vs SR	1	8.63	1.48	4517	0.1700	
Transect(Location)	8	5.33	1.04	4958	0.4200	
Residual	24	5.14				
Total	35					

Table 3. SIMPER (Similarity Percentages) determining the contribution of each taxonomic grouping to the observed differences between intertidal locations at Cassiar Cannery in Inverness Passage during summer of 2017. Diss/SD represents the ratio of the dissimilarity to the standard deviation. Values >1, denoted in bold, represent groups that consistently contribute to the observed differences between location types. Taxa with Diss/SD <1 did not consistently contribute to the observed differences between location types. Only groups that contributed ≥ 1% to the observed differences between locations are shown. DL: Dock Location. RL: Resort Location. NR: North Reference. SR: South Reference.

DL vs (NR+SR)							RL vs (NR+SR)						
Average Dissimilarity = 45.90%		DL	(NR + SR)				Average Dissimilarity = 50.09%		RL	(NR + SR)			
Species	Abundance	Abundance	Av.Diss	Diss/SD	Contribution (%)	Cumulative (%)	Species	Abundance	Abundance	Av.Diss	Diss/SD	Contribution (%)	Cumulative (%)
Oligochaeta	5.55	3.23	5.01	1.23	10.91	10.91	Capitella Species Complex	3.71	5.49	5.95	1.18	11.88	11.88
Pygospio elegans	6.08	4.71	4.85	1.19	10.56	21.47	Nematoda	4.74	6.10	5.87	1.18	11.72	23.59
Nematoda	7.00	6.10	4.55	1.13	9.91	31.38	Pygospio elegans	4.57	4.71	5.41	1.20	10.80	34.39
Harpacticoida	1.06	4.03	4.38	1.24	9.54	40.93	Americorophium salmonis	4.82	4.76	5.00	1.14	9.98	44.37
Americorophium salmonis	2.66	4.76	4.23	1.27	9.22	50.15	Macoma balthica	3.60	4.68	4.54	0.98	9.06	53.43
Capitella Species Complex	3.70	5.49	4.15	1.20	9.05	59.19	Eteone californica	2.90	4.07	4.21	1.09	8.40	61.82
Nippoleucon hinumensis	2.79	2.27	3.61	1.05	7.86	67.05	Oligochaeta	1.07	3.23	4.16	1.08	8.30	70.13
Eteone californica	2.49	4.07	3.35	1.12	7.30	74.35	Harpacticoida	3.37	4.03	4.12	0.96	8.22	78.35
<i>Aricidea hartleyi</i>	2.29	0.07	2.55	0.79	5.56	79.91	<i>Nippoleucon hinumensis</i>	1.76	2.27	3.56	0.94	7.11	85.45
<i>Macoma balthica</i>	4.99	4.68	2.45	0.94	5.34	85.26	<i>Cumella vulgaris</i>	1.13	0.45	1.90	0.62	3.79	89.25
<i>Cumella vulgaris</i>	1.67	0.45	2.13	0.78	4.64	89.90	Chironomidae Larvae	0.99	0.00	1.34	0.49	2.68	91.93
<i>Paranemertes peregrina</i>	0.66	0.81	1.38	0.61	3.00	92.90	<i>Paranemertes peregrina</i>	0.18	0.81	1.12	0.49	2.24	94.17
<i>Abarenicola pacifica</i>	0.18	0.85	1.06	0.48	2.31	95.21	<i>Abarenicola pacifica</i>	0.00	0.85	1.07	0.43	2.14	96.31
Ostracoda	0.30	0.32	0.76	0.39	1.66	96.87	Ostracoda	0.15	0.32	0.67	0.32	1.35	97.65
<i>Fabricia stellaris</i>	0.41	0.13	0.51	0.31	1.10	97.97							

DL vs RL							NR vs SR						
Average Dissimilarity = 52.98%		DL	RL				Average Dissimilarity = 44.17%		NR	SR			
Species	Abundance	Abundance	Av.Diss	Diss/SD	Contribution (%)	Cumulative (%)	Species	Abundance	Abundance	Av.Diss	Diss/SD	Contribution (%)	Cumulative (%)
Oligochaeta	5.55	1.07	6.81	1.37	12.86	12.86	Nematoda	5.11	7.09	5.81	1.14	13.15	13.15
Pygospio elegans	6.08	4.57	5.42	1.14	10.22	23.08	Pygospio elegans	6.29	3.13	5.62	1.40	12.72	25.86
Capitella Species Complex	3.70	3.71	4.93	1.21	9.30	32.39	Capitella Species Complex	6.82	4.15	4.65	1.33	10.53	36.39
Americorophium salmonis	2.66	4.82	4.82	1.24	9.10	41.48	Americorophium salmonis	5.92	3.60	4.57	1.26	10.35	46.74
Nematoda	7.00	4.74	4.80	1.26	9.06	50.54	Harpacticoida	3.81	4.24	3.89	1.00	8.81	55.56
Macoma balthica	4.99	3.60	4.40	1.01	8.31	58.85	Oligochaeta	3.56	2.90	3.82	1.19	8.64	64.20
Harpacticoida	1.06	3.37	4.16	1.23	7.84	66.69	Nippoleucon hinumensis	1.81	2.74	3.54	1.02	8.01	72.21
<i>Nippoleucon hinumensis</i>	2.79	1.76	4.02	0.95	7.59	74.28	<i>Eteone californica</i>	3.75	4.40	2.98	0.95	6.75	78.96
Eteone californica	2.49	2.90	3.75	1.08	7.08	81.36	Macoma balthica	5.33	4.03	2.76	1.06	6.24	85.20
<i>Aricidea hartleyi</i>	2.29	0.00	2.85	0.77	5.39	86.75	<i>Abarenicola pacifica</i>	1.15	0.55	1.68	0.63	3.81	89.02
<i>Cumella vulgaris</i>	1.67	1.13	2.69	0.86	5.08	91.83	<i>Paranemertes peregrina</i>	1.27	0.34	1.62	0.68	3.68	92.69
Chironomidae Larvae	0.33	0.99	1.66	0.55	3.14	94.97	<i>Cumella vulgaris</i>	0.15	0.76	1.03	0.43	2.32	95.02
<i>Paranemertes peregrina</i>	0.66	0.18	0.94	0.45	1.77	96.74	Ostracoda	0.00	0.64	0.82	0.39	1.85	96.87
Ostracoda	0.30	0.15	0.66	0.33	1.24	97.98	<i>Eogammarus confervicolus</i>	0.49	0.00	0.58	0.34	1.31	98.18

Table 4. SIMPER (Similarity Percentages) showing percent contribution (%) of each sediment variable collected at each quadrat (normalized) to the dissimilarity in sediment environment at Cassiar Cannery in Inverness Passage, during 2017. Particle size, aRPD, wood cover, and macrophyte cover were SQRT(X) transformed. Av. Sq. Dist: Average squared distance. Sq Dis/SD: Ratio of the average squared distance to the standard deviation. Values >1, denoted in bold, represent variables that consistently contribute to the observed differences between location types. DL: Dock Location. RL: Resort Location. NR: North Reference. SR: South Reference.

May 30; DL vs (NR + SR)					May 30; RL vs (NR + SR)					May 30; DL vs RL				
Average Squared Distance = 12.92					Average Squared Distance = 12.29					Average Squared Distance = 12.73				
Variable	Av.Sq.Dist	Sq.Dist/SD	Contribution (%)	Cumulative (%)	Variable	Av.Sq.Dist	Sq.Dist/SD	Contribution (%)	Cumulative (%)	Variable	Av.Sq.Dist	Sq.Dist/SD	Contribution (%)	Cumulative (%)
Wood Cover (%)	3.48	0.74	26.94	26.94	Wood Cover (%)	2.74	0.57	22.28	22.28	Wood Cover (%)	2.40	0.71	18.87	18.87
Penetrability (mm)	2.34	0.81	18.08	45.02	Penetrability (mm)	2.17	0.79	17.67	39.94	Penetrability (mm)	2.25	0.74	17.69	36.56
aRPD (mm)	1.98	0.53	15.30	60.32	Water Content (%)	2.06	0.60	16.73	56.68	Macrophyte Cover (%)	2.15	0.43	16.93	53.48
Water Content (%)	1.86	0.63	14.42	74.73	aRPD (mm)	1.97	0.46	16.04	72.71	Water Content (%)	2.07	0.72	16.24	69.72
Macrophyte Cover (%)	1.73	0.53	13.43	88.16	Particle Size	1.70	0.70	13.81	86.53	aRPD (mm)	1.95	0.77	15.31	85.03
Particle Size	1.53	0.77	11.84	100	Macrophyte Cover (%)	1.66	0.58	13.47	100	Particle Size	1.91	0.71	14.97	100
June 21; DL vs (NR + SR)					June 21; RL vs (NR + SR)					June 21; DL vs RL				
Average Squared Distance = 13.95					Average Squared Distance = 12.82					Average Squared Distance = 14.38				
Variable	Av.Sq.Dist	Sq.Dist/SD	Contribution (%)	Cumulative (%)	Variable	Av.Sq.Dist	Sq.Dist/SD	Contribution (%)	Cumulative (%)	Variable	Av.Sq.Dist	Sq.Dist/SD	Contribution (%)	Cumulative (%)
Wood Cover (%)	3.78	1.18	27.09	27.09	aRPD (mm)	2.61	0.79	20.35	20.35	Wood Cover (%)	2.92	1.09	20.28	20.28
Penetrability (mm)	2.53	0.80	18.12	45.21	Penetrability (mm)	2.34	0.76	18.28	38.62	Penetrability (mm)	2.72	0.9	18.92	39.2
Water Content (%)	2.08	0.87	14.92	60.13	Wood Cover (%)	2.27	0.76	17.71	56.33	aRPD (mm)	2.32	0.59	16.11	55.31
aRPD (mm)	2.03	0.77	14.56	74.69	Particle Size	2.06	0.63	16.05	72.39	Water Content (%)	2.27	0.87	15.76	71.07
Particle Size	1.81	0.49	12.94	87.63	Water Content (%)	1.87	0.70	14.59	86.97	Macrophyte Cover (%)	2.24	0.63	15.61	86.67
Macrophyte Cover (%)	1.73	0.44	12.37	100	Macrophyte Cover (%)	1.67	0.53	13.03	100	Particle Size	1.92	0.68	13.33	100
July 20; DL vs (NR + SR)					July 20; RL vs (NR + SR)					July 20; DL vs RL				
Average Squared Distance = 14.12					Average Squared Distance = 14.42					Average Squared Distance = 13.05				
Variable	Av.Sq.Dist	Sq.Dist/SD	Contribution (%)	Cumulative (%)	Variable	Av.Sq.Dist	Sq.Dist/SD	Contribution (%)	Cumulative (%)	Variable	Av.Sq.Dist	Sq.Dist/SD	Contribution (%)	Cumulative (%)
Wood Cover (%)	3.62	0.90	25.65	25.65	Particle Size	3.12	0.62	21.65	21.65	Wood Cover (%)	2.71	0.89	20.76	20.76
Penetrability (mm)	2.36	0.97	16.68	42.34	Macrophyte Cover (%)	2.61	0.45	18.11	39.76	aRPD (mm)	2.28	0.53	17.48	38.24
Particle Size	2.28	0.57	16.14	58.48	Water Content (%)	2.30	0.78	15.98	55.74	Particle Size	2.15	0.62	16.49	54.73
Water Content (%)	2.18	0.73	15.42	73.9	Wood Cover (%)	2.17	0.43	15.02	70.76	Macrophyte Cover (%)	2.13	0.41	16.30	71.03
aRPD (mm)	2.04	0.49	14.43	88.33	Penetrability (mm)	2.17	0.59	15.02	85.78	Water Content (%)	1.89	0.79	14.49	85.52
Macrophyte Cover (%)	1.65	0.37	11.67	100	aRPD (mm)	2.05	0.56	14.22	100	Penetrability (mm)	1.89	0.78	14.48	100

Table 5. SIMPER (Similarity Percentages) showing percent contribution (%) of each nutrient variable (normalized) collected at each quadrat to the dissimilarity in nutrient availability between each location at Cassiar Cannery in Inverness Passage, during 2017. All variables were SQRT(X) transformed. Av. Sq. Dist: Average squared distance. Sq Dis/SD: Ratio of the average squared distance to the standard deviation.

May 30 vs June 21				
Average Squared Distance = 4.96				
Variable	Av.Sq.Dist	Sq.Dist/SD	Contribution (%)	Cumulative (%)
Chlorophyll <i>a</i> Concentration (mg/m ²)	3.13	0.56	63.1	63.10
Organic Matter Content (%)	1.83	0.76	36.9	100
May 30 vs July 20				
Average Squared Distance = 5.18				
Variable	Av.Sq.Dist	Sq.Dist/SD	Contribution (%)	Cumulative (%)
Chlorophyll <i>a</i> Concentration (mg/m ²)	2.89	0.57	55.7	55.70
Organic Matter Content (%)	2.30	0.79	44.3	100
June 21 vs July 20				
Average Squared Distance = 2.28				
Variable	Av.Sq.Dist	Sq.Dist/SD	Contribution (%)	Cumulative (%)
Organic Matter Content (%)	2.10	0.81	91.74	91.74
Chlorophyll <i>a</i> Concentration (mg/m ²)	0.19	0.89	8.26	100

Supplemental Material

Table A.1. Mean abundance (individuals /m²) and standard error (n = 27) of the infaunal invertebrate community at four locations at the intertidal Cassiar Cannery mudflat in Inverness Passage during the summer of 2017.

Species	Location	May 30	June 21	July 20
<i>Eogammarus confervicolus</i>	Dock Location	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	Resort Location	0.00 ± 0.00	0.00 ± 0.00	28.88 ± 28.88
	North Reference	0.00 ± 0.00	28.88 ± 28.88	115.53 ± 87.84
	South Reference	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
<i>Americorophium salmonis</i>	Dock Location	346.59 ± 178.63	173.30 ± 96.87	462.12 ± 104.14
	Resort Location	404.36 ± 115.53	3,465.90 ± 1,554.23	2,368.37 ± 945.65
	North Reference	548.77 ± 222.79	3,985.79 ± 1,361.77	3,292.61 ± 832.22
	South Reference	173.30 ± 114.62	1,704.07 ± 960.10	982.01 ± 437.07
Oligochaeta	Dock Location	1,646.30 ± 702.59	3,841.38 ± 1,170.37	3,379.26 ± 1,703.46
	Resort Location	144.41 ± 87.84	404.36 ± 341.44	0.00 ± 0.00
	North Reference	548.77 ± 152.83	1,299.71 ± 462.57	231.06 ± 133.14
	South Reference	837.59 ± 372.13	1,126.42 ± 354.62	28.88 ± 28.88
<i>Nippoleucon hinumensis</i>	Dock Location	86.65 ± 43.32	346.59 ± 137.00	1,299.71 ± 794.14
	Resort Location	28.88 ± 28.88	346.59 ± 178.63	259.94 ± 86.65
	North Reference	57.77 ± 57.77	664.30 ± 474.81	202.18 ± 84.21
	South Reference	144.41 ± 76.42	635.42 ± 256.71	722.06 ± 305.66
<i>Cumella vulgaris</i>	Dock Location	404.36 ± 130.77	86.65 ± 43.32	28.88 ± 28.88
	Resort Location	57.77 ± 57.77	28.88 ± 28.88	202.18 ± 72.21
	North Reference	28.88 ± 28.88	0.00 ± 0.00	0.00 ± 0.00
	South Reference	0.00 ± 0.00	28.88 ± 28.88	375.47 ± 241.65
<i>Abarenicola pacifica</i>	Dock Location	0.00 ± 0.00	57.77 ± 57.77	0.00 ± 0.00
	Resort Location	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	North Reference	231.06 ± 133.14	115.53 ± 45.67	0.00 ± 0.00
	South Reference	0.00 ± 0.00	231.06 ± 146.56	0.00 ± 0.00
<i>Capitella</i> Species Complex	Dock Location	982.01 ± 266.28	693.18 ± 252.62	231.06 ± 91.33
	Resort Location	1,906.25 ± 872.95	1,617.42 ± 838.71	1,155.30 ± 586.25
	North Reference	3,956.91 ± 1,042.28	3,668.08 ± 1,412.81	3,725.85 ± 1,670.64
	South Reference	1,068.65 ± 491.00	2,310.60 ± 1,120.94	404.36 ± 130.77
<i>Pygospio elegans</i>	Dock Location	1,559.66 ± 312.41	5,516.56 ± 2,409.75	2,974.90 ± 1,324.12
	Resort Location	1,906.25 ± 671.17	2,686.08 ± 1,271.98	808.71 ± 339.60
	North Reference	2,888.25 ± 852.77	3,090.43 ± 845.03	2,195.07 ± 464.82
	South Reference	1,357.48 ± 902.32	2,512.78 ± 1,280.80	375.47 ± 290.98
<i>Aricidea hartleyi</i>	Dock Location	866.48 ± 528.83	750.95 ± 507.91	202.18 ± 112.79
	Resort Location	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	North Reference	0.00 ± 0.00	0.00 ± 0.00	28.88 ± 28.88
	South Reference	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
<i>Fabricia stellaris</i>	Dock Location	0.00 ± 0.00	317.71 ± 286.65	0.00 ± 0.00
	Resort Location	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	North Reference	0.00 ± 0.00	259.94 ± 259.94	0.00 ± 0.00
	South Reference	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
<i>Eteone californica</i>	Dock Location	231.06 ± 101.09	346.59 ± 86.65	144.41 ± 62.95
	Resort Location	346.59 ± 167.79	635.42 ± 256.71	433.24 ± 137.00
	North Reference	259.94 ± 106.12	779.83 ± 324.21	577.65 ± 166.54

<i>Paranemertes peregrina</i>	South Reference	375.47 ± 130.77	1,444.13 ± 284.46	433.24 ± 96.87
	Dock Location	115.53 ± 115.53	57.77 ± 38.21	28.88 ± 28.88
	Resort Location	0.00 ± 0.00	57.77 ± 57.77	0.00 ± 0.00
	North Reference	86.65 ± 43.32	28.88 ± 28.88	202.18 ± 84.21
<i>Macoma balthica</i>	South Reference	86.65 ± 86.65	28.88 ± 28.88	0.00 ± 0.00
	Dock Location	866.48 ± 259.94	808.71 ± 133.14	1,126.42 ± 327.09
	Resort Location	1,357.48 ± 417.30	433.24 ± 203.21	577.65 ± 160.81
	North Reference	1,530.77 ± 388.57	1,473.01 ± 375.20	837.59 ± 317.71
Nematoda	South Reference	693.18 ± 225.12	375.47 ± 194.29	664.30 ± 107.10
	Dock Location	2,426.13 ± 556.50	3,783.61 ± 753.03	4,505.68 ± 2,086.75
	Resort Location	2,888.25 ± 859.35	2,426.13 ± 1,118.06	115.53 ± 45.67
	North Reference	2,974.90 ± 1,749.18	3,437.02 ± 1,541.97	2,657.19 ± 1,265.90
Harpacticoida	South Reference	3,552.55 ± 707.92	16,636.34 ± 4,725.87	1,097.54 ± 904.40
	Dock Location	57.77 ± 38.21	288.83 ± 257.93	115.53 ± 76.42
	Resort Location	404.36 ± 123.39	317.71 ± 94.70	519.89 ± 173.30
	North Reference	982.01 ± 493.54	462.12 ± 104.14	577.65 ± 219.96
Ostracoda	South Reference	779.83 ± 293.84	895.36 ± 372.97	3,696.96 ± 2,962.78
	Dock Location	28.88 ± 28.88	0.00 ± 0.00	28.88 ± 28.88
	Resort Location	0.00 ± 0.00	0.00 ± 0.00	28.88 ± 28.88
	North Reference	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Chironomidae Larvae	South Reference	0.00 ± 0.00	28.88 ± 28.88	144.41 ± 87.84
	Dock Location	0.00 ± 0.00	0.00 ± 0.00	86.65 ± 61.27
	Resort Location	57.77 ± 38.21	144.41 ± 144.41	115.53 ± 62.95
	North Reference	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
<i>Isotomidae</i> sp.	South Reference	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	Dock Location	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	Resort Location	0.00 ± 0.00	0.00 ± 0.00	28.88 ± 28.88
	North Reference	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	South Reference	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Table A.2. Mean and standard error (n = 27) of sediment variables collected at each quadrat at four locations at the intertidal mudflat at Cassiar Cannery in Inverness Passage during the summer of 2017.

Variable	Location	May 30	June 21	July 20
aRPD (mm)	Dock Location	1.89 ± 0.63	2.78 ± 1.28	0.89 ± 0.39
	Resort Location	1.00 ± 0.17	0.78 ± 0.32	4.89 ± 2.81
	North Reference	3.56 ± 0.99	4.56 ± 1.26	1.22 ± 0.15
	South Reference	3.44 ± 2.08	2.78 ± 0.97	6.00 ± 2.95
Macro (%)	Dock Location	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	Resort Location	2.67 ± 2.19	3.89 ± 2.17	7.67 ± 6.59
	North Reference	30.11 ± 12.24	20.33 ± 11.47	2.56 ± 1.62
	South Reference	0.22 ± 0.22	1.78 ± 1.66	0.00 ± 0.00
Particle Size	Dock Location	49.44 ± 1.82	41.83 ± 4.20	40.98 ± 3.56
	Resort Location	48.33 ± 3.92	46.43 ± 6.97	59.94 ± 11.16
	North Reference	46.30 ± 5.37	40.54 ± 2.96	37.88 ± 2.75
	South Reference	49.44 ± 7.63	50.39 ± 7.51	34.71 ± 1.86
Penetrability (mm)	Dock Location	41.44 ± 6.74	47.33 ± 5.07	38.11 ± 7.06
	Resort Location	27.33 ± 2.65	26.67 ± 2.88	37.22 ± 5.09
	North Reference	43.11 ± 2.28	37.89 ± 2.91	39.67 ± 4.00
	South Reference	31.44 ± 4.21	35.67 ± 3.90	44.67 ± 3.82
Water Content (%)	Dock Location	34.87 ± 1.12	35.98 ± 1.17	34.56 ± 1.38
	Resort Location	32.97 ± 0.95	33.12 ± 0.82	34.23 ± 1.62
	North Reference	35.80 ± 1.47	34.81 ± 1.18	36.84 ± 1.58
	South Reference	35.33 ± 1.08	34.04 ± 1.06	37.06 ± 0.87
Wood Cover (%)	Dock Location	22.33 ± 10.41	33.89 ± 9.64	23.89 ± 9.27
	Resort Location	1.78 ± 1.16	1.33 ± 0.60	0.11 ± 0.11
	North Reference	0.00 ± 0.00	0.22 ± 0.15	0.11 ± 0.11
	South Reference	0.44 ± 0.24	0.89 ± 0.89	0.00 ± 0.00

Table A. 3. Mean and standard error (n = 27) of nutrient variables measured at each quadrat at four locations at the intertidal mudflat at Cassiar Cannery in Inverness Passage during the summer of 2017.

Variable	Location	May 30	June 21	July 20
Chlorophyll <i>a</i> Concentration (mg/m ²)	Dock Location	14.37 ± 9.16	0.59 ± 0.44	0.75 ± 0.18
	Resort Location	7.31 ± 6.82	0.85 ± 0.50	1.05 ± 0.48
	North Reference	20.66 ± 10.33	0.79 ± 0.43	1.15 ± 0.25
	South Reference	13.84 ± 8.99	0.53 ± 0.23	0.63 ± 0.17
Organic Matter Content (%)	Dock Location	4.07 ± 0.22	4.05 ± 0.13	4.20 ± 0.18
	Resort Location	3.95 ± 0.14	3.78 ± 0.12	4.11 ± 0.16
	North Reference	3.76 ± 0.19	3.66 ± 0.13	4.01 ± 0.19
	South Reference	4.07 ± 0.17	3.73 ± 0.11	4.38 ± 0.15