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4 **Responses of subtidal benthos of the Strait of Georgia,**
5 **British Columbia, Canada to ambient sediment conditions**
6 **and natural and anthropogenic depositions**

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18 **Abstract**

19 Patterns in infaunal biota in the Strait of Georgia are explored relative to water depth, substrate
20 type, organic content of sediments and sedimentation characteristics. The analyses are based on
21 geographically-diverse grab and core data collected over a 19-year period.

22
23 Infaunal abundance and biomass were not predictable by sediment particle size, organic content
24 or water depth. While organic flux was a reasonable predictor of biotic factors, quality of organic
25 material, relative proportions of organic and inorganic input, and source of inputs were also
26 important in this regard. Areas with high accumulation of sediment and high organic flux rates
27 from terrestrial (riverine) sources supported the highest macro-infaunal abundance and biomass
28 found to date in the Strait of Georgia, and were dominated by bivalves. Polychaetes dominated
29 in low organic deposition conditions, and where anthropogenic organic deposition was high.
30 However, biota were severely impoverished in sediments with high organic content from marine
31 deposition, due to low fluxes and poor quality of organic material. Taxa number was related to
32 percent total nitrogen and to the ratio of organic/inorganic flux, both in background conditions
33 and where there was labile organic enrichment. Faunal communities from the Fraser River delta,
34 which experiences considerable bottom-transported riverine material, were very different in
35 composition from those that proliferate in habitats with high deposition and organic flux from the
36 water column.

37
38 **Key words:** marine benthos, sedimentation, Strait of Georgia, infaunal biomass

39 1.0 Introduction

40 In the Pacific northwest, the two most consistently important physical factors affecting marine
41 benthic biota appear to be substrate type and water depth (Striplin, 1996; Llansó et al., 1998;
42 Striplin and Weston, 1999). In general, as water depth increases, biotic communities in coastal
43 marine areas experience reduced organic input, lower currents (and potentially lower oxygen),
44 and more stable temperature, salinity and hydrographic conditions. Globally, benthic
45 invertebrate production and production/biomass ratios tend to decrease with increasing depth
46 (Jumars and Banse, 1989; Cusson and Bourget, 2005). Ellis (1971) found, in his early review of
47 benthic fauna from the Strait of Georgia, that biomass was considerably higher in shallow areas
48 than in deeper stations within the Strait and in the surrounding fjords and channels. On open
49 continental shelves, substrates tend to get finer with water depth and organic flux from coastal
50 sources usually (but not always) decreases (Vinogradov and Tseitlin 1983; Shirayama 1984;
51 Vanaverbeke et al., 1997). However, this generalization can be affected by strong topographic
52 and seasonal drivers (Aller et al., 2002).

53
54 For British Columbia, Canada, which has a diverse and geographically extensive coastline,
55 topography and currents vary widely, such that depth, substrate type and organic loading are
56 spatially and temporally variable and complex. In the inland sea of the Strait of Georgia, there is
57 strong estuarine circulation related to seasonal input of particulates, freshwater and organic
58 carbon (OC) from the Fraser River (Johannessen et al., 2003; Hill et al., in press) and other lesser
59 freshwater sources. Over the past century, discharges from agriculture, industry and urbanized
60 regions in the southern Strait of Georgia have further complicated natural deposition.

61

62 The main objective of this paper is to contribute to the understanding of natural and
63 anthropogenic factors that affect benthic biomass and productivity in the Strait of Georgia.
64 Herein, we examine recent general patterns of benthic macro-invertebrate fauna in the Strait of
65 Georgia and surrounding fjords seeking relationships with depth, substrate type and organic
66 content of sediments. These biotic patterns are then compared with organic and inorganic flux to
67 the sediments as well as the quality and composition of sediments.

68 **2.0 Methods**

69 ***2.1 Data sources and comparisons***

70 The biotic database used herein includes abundance data for benthic invertebrate species from
71 607 grab samples collected between 1988 and 2006, from areas of the Strait of Georgia and
72 surrounding fjords which are remote from anthropogenic discharges (referred to as “background”
73 areas). The database also includes 347 biotic samples from near-field areas of current
74 anthropogenic discharges, where biotic changes related to the discharge have been identified
75 (Table 1). Data from these samples will be referred to herein as “anthropogenic”, to facilitate
76 comparisons with biotic distributions from background areas of the Strait. We recognize that
77 this distinction is somewhat artificial, as contamination from human activities has spread widely
78 throughout the Strait during at least the past century (Macdonald et al., 1991; Johannessen et al.,
79 2005a,b). Anthropogenic input areas for which these same data are available (Fig. 1) include:
80 Iona Island wastewater outfall (off the North Arm of the Fraser River); Lions Gate wastewater
81 outfall (in Burrard Inlet); Macaulay Point wastewater outfall (Juan de Fuca Strait). Although the
82 Macaulay Point outfall is not in the Strait of Georgia (Fig. 1), vigorous currents, high mixing,
83 sediment re-suspension and lack of confounding inputs provides an alternative habitat to

84 examine the effects of sediment conditions on biota in an organically enriched habitat; five pulp
85 and paper mills¹; and Britannia Beach mine in Howe Sound. Anthropogenic data were overlaid
86 on the background data plots to examine biotic changes relative to anthropogenic inputs.

87
88 The data used may be found in various technical reports and unpublished sources listed in Table
89 1; general locations of sampling programs are shown in Fig. 1. All biotic samples were collected
90 using 0.1m² surface area grab (Smith-McIntyre or Van Veen) with stated minimum volume
91 requirements for samples of at least 2/3 capacity. All samples were processed using a 1 mm
92 sieve, with full taxonomic identification to species wherever possible. Detailed sampling
93 protocols and quality control information are described in the original reports. Although quality
94 control likely varied among studies, the data were sufficiently uniform in approach and method
95 of collection to provide assessment of general trends.

96
97 Data for sediment total organic carbon (%TOC) were available for most samples, whereas data
98 for percentage of total nitrogen (%TN) were available for a limited number of samples in the
99 historical database.

100
101 For the analyses presented here, biological data from the sources indicated in Table 1 were
102 assigned consistent taxonomic codes and entered into a master database, along with ancillary
103 sediment measurements of geophysical properties and contaminant concentrations. Data on
104 hydrozoans and bryozoans, which were not included consistently in all studies, were not entered
105 into the database. Meiofauna were not considered to be representatively sampled with a 0.1 mm

¹ Pulp mills included were Catalyst Paper Corporation (Powell River and Crofton), Howe Sound Pulp and Paper Ltd. (Port Mellon), Western Pulp Ltd. (Squamish), Pope and Talbot Ltd. Harmac (Nanaimo),

106 mesh screen (nematodes, harpacticoid copepods) and, therefore, were not entered into the
107 database.

108
109 Summary assessment measures for infaunal benthos typically used in Pacific northwest
110 jurisdictions include taxa number and faunal abundance (Washington State Sediment
111 Management Standards: www.ecy.wa.gov/programs/tcp/smu/sediment.html; Striplin, 1996;
112 Stiplin and Weston, 1999; GVRD, 2004). In addition, Burd (2006) found that bivalves,
113 sedentariate polychaetes, errantiate polychaetes and crustaceans are typically found in most
114 background marine sediments from coastal British Columbia. The abundance of these ubiquitous
115 faunal groups, along with total abundance and taxa number from the historical grab sample were
116 plotted against sediment depth, silt+clay (% fines) and, where available, sediment %TOC and
117 %TN for samples from background locations, with data from samples affected by anthropogenic
118 inputs overlaid for comparison.

119
120 The data include taxa abundance and taxa-specific biomass from triplicate grab samples at nine
121 locations, as part of a dedicated Ambient Monitoring Program (AMP) in the Strait of Georgia
122 (Fig. 2, Table 2, Wright et al., 2008). Methods for biological sampling and processing are
123 described by McPherson et al. (2007a, b). Eight of the AMP locations were from background
124 areas of the Strait; however, one of the AMP sample locations was placed near the largest
125 municipal outfall in the Strait to determine whether there are detectable differences in organic
126 fluxes and biological composition at this location relative to surrounding areas. Surface
127 sediment measurements of total carbon, total organic carbon (%TOC), total inorganic carbon

128 (%TIC), total nitrogen (%TN), organic carbon (OC) and inorganic carbon (IC) fluxes and stable
129 isotopes of carbon and nitrogen ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) were measured from nine cores from the AMP.

130

131 With the exception of seasonal, or intermittent, anoxic events in two peripheral fjords (Saanich
132 Inlet and Howe Sound), bottom waters of the Strait of Georgia are always oxygenated (>2.5
133 $\text{mL}\cdot\text{L}^{-1}$) (Masson, 2002) and support an active benthic community which mixes the surface
134 sediments through bio-turbation (Johannessen et al., 2005b). Sedimentation, and mixing rates in
135 the sediment cores were determined using excess ^{210}Pb profiles in sediments together with
136 advective-diffusive models (Johannessen et al., 2005b). The depth of the surface mixed layer in
137 each core was determined from the ^{210}Pb profile. Organic carbon was calculated as the difference
138 between total carbon and carbonate carbon, based on the method of Calvert et al. (1995). The
139 incident flux of OC, the %OC buried, and the %OC oxidized were estimated from the ^{210}Pb
140 profiles of %OC measured in the sediment cores (for methods, see Johannessen et al., 2008).

141

142 To supplement data from the AMP cores, historical core data for sedimentation rate and organic
143 flux to sediments calculated in the same manner (data sources in Table 2) were included in plots
144 of geographic distribution of sedimentation characteristics using variable-weighted VG gridding
145 in Ocean Data View (Schlitzer, 2006). Similar plots were made for sediment percent fines as
146 well as several biotic factors. Note that the extrapolated values are not valid near shore. The
147 historical data were not used for any further calculations (see below).

148

149 **2.2 Data Analyses**

150 Gaps in the physical/chemical data from the historical database resulting from differences in the
151 suite of sediment variables measured between individual studies, prevented the application of
152 multi-factor comparisons such as multiple regression, ordination or clustering methods.

153

154 However, the AMP data (nine cores and grab sample locations) were examined in greater detail
155 than the historical data, to seek effects of sediment factors and sediment flux trends on biota. In
156 addition to the biotic factors examined for the historical data, total faunal biomass and abundance
157 of several other common biotic groups were analysed (gastropods, ophiuroids and holothuroids)
158 for the AMP data. Although these additional faunal groups are patchy in distribution, they can
159 contribute considerably to faunal biomass, and their presence/abundance may help explain
160 biomass trends.

161

162 Relationships between biotic factors and $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ composition, sedimentation rates and
163 organic flux to sediments were explored initially for the AMP grab/core data using Pearson
164 correlations. In addition to the measured sediment factors, and the modeled sediment flux
165 factors, a “weighted” OC flux, which takes into account the relative lability of organic material,
166 was calculated to correlate with biotic variables. With a consistent organic source, elevations in
167 $\delta^{15}\text{N}$ have been shown to indicate increased trophic reworking in the water column due to
168 preferential use of the lighter isotope (c.f. Burd et al., 2002) and thus, are likely to indicate
169 decreased lability of organic material. Therefore, the weighted organic matter factor used to
170 compare with biotic factors was OC flux divided by $\delta^{15}\text{N}$. Although weighting using $\delta^{15}\text{N}$ is
171 based on a simplistic assumption for the Strait of Georgia, and may be confounded by the

172 relative proportion of terrestrial versus marine organic input (Johannessen et al., 2005b), it does
173 reflect the observed differences in values for the Iona outfall deposits (very low $\delta^{15}\text{N}$), the Fraser
174 River deposits (moderate $\delta^{15}\text{N}$ from agricultural sediment input), and higher $\delta^{15}\text{N}$ from the
175 central deep basin (cores GVRD-1,10; Fig. 2), which is much more distant from major riverine
176 deposits.

177

178 No hypotheses were tested by correlation; rather, this approach helps to identify potential
179 relationships which may be explored further. Where notable correlations were evident, or non-
180 linear patterns suspected from data distribution plots, non-linear regression analyses (Zar, 1984
181 – exponential models) were used to examine variability in biotic versus sediment or sediment
182 flux factors.

183 **3.0 Results**

184 Historical samples, which ranged in substrate type from 0 to 100% fines (=silt+clay), were
185 drawn from depths ranging from 9 to 700 m. The main basin of the Strait is uniformly silty from
186 the south end to the middle of the Strait (around Texada Island), north of which the basin
187 becomes shallower and more mixed in substrate type, with extensive erosional sand and gravel
188 beds along the coastline of eastern Vancouver Island (Burd et al., in press). Samples from the
189 deep basins of the mainland fjords (Jervis, Toba and Bute Inlets) have high percent fines (Burd
190 and Brinkhurst, 1992). The near-shore areas of the fjords tend to have more mixed sand/silt near
191 river deltas. Near-shore substrate detail can be found in the Provincial Physical Shoreline map
192 for British Columbia, (Howes et al., 1994) at URL: <http://maps3.gov.bc.ca/imf406>.

193

194 Historical data showed that faunal abundance and taxa number increased with depth subtidally,
195 peaked between 60 and 80 m, and then declined below 100 m in all samples (Fig.3). This trend
196 was most obvious in bivalves, and less so in polychaetes and crustaceans.

197

198 In the Strait of Georgia, sediment grain size appears to have limited influence on the general
199 benthic faunal indicators used herein (Fig. 4), even though it is expected to affect species
200 distributions. In background samples, total abundance was highest in mixed sediments (60-80%
201 silt/clay), and slightly lower at both lower and higher percent fines (Fig. 4). However, samples
202 taken near the Macaulay outfall showed very high abundance in samples with low percent fines,
203 particularly with respect to polychaetes and crustaceans. Other biotic factors showed no
204 discernible trend with % fines (Figs. 4a,b). Infaunal bivalves tended to be rare where sediment
205 fines were <20%, as in areas disturbed by current anthropogenic inputs.

206

207 In background samples, faunal abundance was highest where %TOC was 1-1.5 (Fig. 5a).
208 However, faunal abundance was moderate to high at much higher %TOC levels in some samples
209 near Macaulay outfall, as well as near the pulp and paper discharges (including some samples
210 used as reference sites during a past pulp mill monitoring program). Taxa numbers declined with
211 increasing %TOC in background and sewage outfall samples (Fig. 5a), but were unpredictable
212 relative to %TOC near pulp mills. Lowest taxa numbers were found in Britannia near-shore
213 sediments, with no discernible relationship to %TOC. Notably, taxa numbers were not unusually
214 low at any location, even where %TOC was high. Bivalves tended to be in low abundance in
215 most of the pulp and paper samples and all of the samples taken near the historical Britannia
216 mine, and, like total abundance, bivalve abundance peaked between 1% and 2% TOC (Fig. 5a).

217 Crustaceans, errantiate and sedentariate polychaete abundance did not show any clear
218 relationship with %TOC (Fig. 5b), except for a slight decline in crustacean abundance with
219 increasing %TOC in background samples. Some samples from near the Macaulay outfall with
220 high %TOC values showed enrichment by opportunistic polychaetes, such as *Capitella capitata*
221 *complex*.

222
223 Sediment %TN provides a simple measure of organic composition and quality. Relatively high
224 nitrogen content implies marine or aquatic food web sources containing protein, whereas low
225 nitrogen content implies terrigenous organic matter (woody or humic material; eg. Webster and
226 Benfield, 1986). Total abundance, bivalve abundance and taxa number tended to decrease with
227 increasing %TN (Fig. 6a), although more variable results for bivalves may have been
228 confounded by the dramatic decline in abundance below 150 m depth, while %TN was higher in
229 deep, background samples. The declining trend with increasing %TN was less clear for
230 crustaceans and not evident for either polychaete group (Fig. 6b) or for samples collected near
231 pulp mills.

232
233 Sediment accumulation rates (Fig. 7a) were highest immediately off the mouth of the south arm
234 of the Fraser River (GVRD-4). Sedimentation rate was too high to measure accurately in this
235 shallow core based on Pb^{210} , and was therefore estimated (see Table 3) based on maximum
236 values in other cores and measurements from the literature. Previous work has shown
237 sedimentation rates near the Fraser delta in the range of 3 -13 cm/year (Evoy et al., 1993; Hart et
238 al., 1998). They were also relatively high in the southern deep basin of the Strait, and tended to
239 decline with distance northward. The pattern for organic flux to sediments, based on fewer data

240 points (Fig. 7b), was similar to that for sediment accumulation, indicating that the material
241 contributed by the Fraser River is an important source of both organic and inorganic matter to the
242 Strait.

243
244 Faunal abundance was highest overall along the bank off the Fraser River discharge, and
245 particularly near the south arm (Fig. 8a). Abundance was moderately high just outside Saanich
246 Inlet in the Satellite Channel area, in the southern-most portion of the main basin of the Strait,
247 and off the south end of Victoria in Juan de Fuca Strait. It was lowest in the deep, mainland
248 fjords along the western margin of the Strait, and in all sample locations in the northern half of
249 the Strait. Although data are limited, faunal abundance appears also to be high within the island
250 archipelago at the north end of the Strait. Bivalve abundance showed a similar pattern to overall
251 abundance (Fig. 8b), with maximum values off the bank and slope spanning the Fraser River
252 discharges. Although taxa numbers (Fig. 9) were high off the south arm of the Fraser River, they
253 were also high in several widely separated areas at the northern and southern ends of the Strait.
254 Taxa numbers were low in the central and northern portions of the main basin.

255
256 A general understanding of the sources and quality of organic matter in sediments may often be
257 gained by examining the distributions of %TOC and %TN, and their stable isotopic compositions
258 ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) (e.g. Johannessen et al., 2005b). An examination of these components for the
259 seven sediment cores from the AMP shows that the northernmost core (GVRD-1) is distinct from
260 all other cores (Fig. 10, Table 3) in having high sediment %TOC and %TN and high $\delta^{13}\text{C}$ and
261 $\delta^{15}\text{N}$, marking it as the core most influenced by marine-derived organic matter. In contrast, low
262 %TOC and %TN values throughout core GVRD-3, near the Iona outfall and for the station off

263 the south arm of the Fraser River (GVRD-4), indicate strong terrigenous input due to a large
264 supply of riverine inorganic material. Recent Iona outfall deposits (after commissioning of the
265 deep-sea outfall in 1989) have a unique, low $\delta^{15}\text{N}$ signature compared with pre-outfall deposits
266 and other core locations in the Strait (Fig. 10) indicating a distinct source of organic matter at
267 that site. The isotopic composition of the sedimentary organic matter suggests that the proportion
268 of terrigenous organic matter is greatest near the Fraser River and decreases northward (see
269 Johannessen et al. (2005b) for a discussion of the application of stable C and N isotopes to
270 discriminate sources of organic matter).

271
272 Sediment accumulation rate, OC flux, inorganic flux and buried OC flux were highly inter-
273 correlated ($r^2 = 0.98$ not shown). These four factors did not always correlate consistently with a
274 given biotic factor, but consistent patterns are notable. For example, biomass, gastropod and
275 crustacean abundance correlated positively with all four of the aforementioned factors. In
276 contrast, the ratio of polychaete abundance to total abundance correlated negatively with the four
277 sediment factors, as well as with oxidized OC flux.

278
279 Total abundance, biomass, ophiuroid, bivalve, gastropod and sedentariate polychaete abundance
280 were moderately to highly positively correlated with total flux, OC flux, OC flux weighted by
281 $\delta^{15}\text{N}$, inorganic and buried OC fluxes. Oxidized OC flux, which would be expected to be a good
282 indicator of biological activity in sediments, was not strongly positively correlated with any
283 biological factor.

284

285 The percent carbonate in surface sediments showed moderate to strong positive correlation with
286 a range of biotic factors, including taxa number, total abundance, abundance of ophiuroids,
287 bivalves, errantiate and sedentariate polychaetes. However, the proportion of both types of
288 polychaetes showed a low negative correlation with %carbonate. A very similar pattern of
289 positive and negative correlations was evident between these biotic factors and organic flux
290 weighted by $\delta^{15}\text{N}$. Percent bivalve abundance was strongly negatively correlated with $\delta^{15}\text{N}$, and
291 $\delta^{13}\text{C}$.

292
293 The number of taxa was most strongly negatively correlated with organic/inorganic flux ratio,
294 %TN and %TOC. A plot of taxa number vs. organic/inorganic flux showed a negative
295 exponential relationship ($r^2 = 0.87$, Fig. 11). The best fit line for this function was superimposed
296 on the scatterplot for taxa number versus %TN for combined historical and AMP data from all
297 background and anthropogenic sites (Fig. 11), which also showed an exponential correlation
298 ($r^2=0.76$). Both of these regressions were highly significant ($P<0.0001$). The two functions show
299 very similar shapes and slopes. Only the data for samples near pulp mills showed unusual
300 deviations from the primary trend.

301
302 The highest faunal biomass was found in cores GVRD-4 and -6, followed by core GVRD-5 (Fig.
303 12). Total biomass was positively exponentially correlated with sediment accumulation rate
304 (Table 4), OC flux, inorganic flux, and buried OC flux. The buried OC flux explained 84% of
305 variance in faunal biomass (Fig. 12). Biotic factors did not show any correlation with AVS
306 concentration (Table 4), and do not show any relationship to biotic factors in the historical
307 database (not shown).

308

309 **4.0 Discussion**310 **4.1 Geographic distribution of sedimentation and biota**

311

312 The highest sediment accumulation rates and organic fluxes occur along the eastern margin of
313 the Strait, off the Fraser River, with the nearby station GVRD-4 having the highest estimated
314 fluxes for this study (Hill et al., in press). Sandy silt from the Fraser River is transported
315 outward from the delta along the bottom northward and downslope (Pharo and Barnes, 1976;
316 Evoy et al., 1993; Hart et al., 1998; Hodgins and Hodgins, 2000;
317 http://gsc.nrcan.gc.ca/marine/gbgi/proj_surf_e.php, 2006; Hill et al., in press). The organic and
318 inorganic sediments from the Fraser River dominate the input to sediments near the Fraser delta
319 (Hodgins and Hodgins, 2000; Hill et al., in press). The Iona Island wastewater outfall, which is
320 the largest volume marine sewage discharge in British Columbia ($145 \times 10^6 \text{ m}^3/\text{yr}$ water), is
321 located about 10 km N of the south arm along the Fraser River foreshore, and discharges through
322 diffusers at 60-90 m depth (Fig. 1). Model results (Hodgins and Hodgins, 2000) indicate that the
323 maximum particle deposition from the Iona outfall ($\sim 0.3 \text{ gcm}^{-2}\text{yr}^{-1}$) occurs within the first km
324 north of the outfall. The sedimentation rate estimated from a core collected at that location
325 (GVRD-3) is $1.34 \text{ gcm}^{-2}\text{yr}^{-1}$. Therefore, about 25% of the total sedimentation just north of the
326 Iona outfall could be accounted for by municipal outfall discharge, with the other 75% coming
327 from the Fraser River. This estimate is relatively close to that noted by Macdonald et al. (in
328 press), using Zn/Cd ratios in effluent and sediments. The suspended particles from the outfall
329 contain about 30% TOC (S. Bertold, Metro Vancouver, pers. comm.). Therefore, with the 75%
330 dilution from the Fraser River particulates, which contain <1% TOC (Johannessen et al., 2003),

331 the sediment %TOC just north of the outfall should be about 7-8%. In fact, the sediments near
332 the outfall are within background levels for %TOC content (<1.5%). There are several possible
333 explanations for the discrepancy; 1) the model overestimates sedimentation to the bottom from
334 the outfall; 2) most of the sedimenting organic material is rapidly broken down within sediments
335 (supported by high oxidation rates in the current study), or; 3) most of the organic material from
336 the outfall does not reach bottom due to biogenic uptake or degradation in the water column.

337
338 Faunal abundance and biomass were highest in the Fraser River frontal area, suggesting that
339 these are highly productive sediments. Bivalves dominated the fauna in this area (40-60% of
340 abundance and biomass - Fig. 8b and Burd, 2003a; McPherson et al., 2007a) more than
341 anywhere else in the Strait. Other authors have noted dominance by infaunal bivalves in marine
342 sediments subject to terrigenous inflow in Arctic and subarctic coastal areas (Thorson, 1957;
343 Wlodarska-Kowalczyk and Pearson, 2004; Wlodarska-Kowalczyk et al., 2007 and references
344 therein). Wlodarska-Kowalczyk (2007) and Wlodarska-Kowalczyk et al. (2004, 2005, 2007)
345 suggested that sediment stability played a major role in structuring faunal type and productivity,
346 with the consequence that the dominant benthic organisms were bivalves in intermediate
347 deposition areas, opportunistic (recolonizing) polychaetes in very high deposition areas (up to
348 $36.5 \text{ g/cm}^2/\text{a}$) with slope instability, and a variety of primarily tube-building polychaetes in low
349 deposition, deep areas. They found that faunal biomass was highest in areas of intermediate
350 deposition, falling off in both the lower and higher deposition areas. Results from the current
351 study support this general pattern. For example, polychaetes tended to be the dominant fauna in
352 areas of the Strait where sedimentation and organic flux were low. Although unstable areas with
353 extremely high deposition were not sampled in this study, the location with the highest

354 deposition (GVRD-4, near the south arm of the Fraser River) has shown a recent increase in
355 dominance by small, rapidly recolonizing polychaetes where bivalves were much more dominant
356 previously (McPherson et al., 2007a). This location could have experienced an increase in
357 particulate deposition from the river in recent years.

358
359 In the southern Strait (core GVRD 6 – 187m deep), fine sand and silt suggest deposition from the
360 river either directly or through resuspension, and/or erosion of material from the southern Gulf
361 Islands via energetic tidal mixing and currents that transport material northward via Haro Strait
362 (Masson and Cummins, 2004; Johannessen et al., 2006). Particulate organic matter, enhanced
363 bacterioplankton production (Albright, 1983) and inorganic particles in the Fraser River plume
364 contribute to the high flux. Biotic abundance and biomass were relatively high at station GVRD-
365 6. The major difference in biota between the delta/slope area and the deeper, southern basin of
366 the Strait, was that the latter had lower overall abundance, a lower proportion of bivalves, and
367 greater dominance by crustaceans and holothurians. However, total biomass in the two areas was
368 similar.

369
370 Sedimentation, organic flux, infaunal abundance, biomass and taxa number were all lowest in the
371 basin north of Texada Island (GVRD-1, GVRD-10). This is not surprising, since evidence from
372 sediment trap (Johannessen et al., 2005b) and multi-beam (Hill et al., this issue) studies indicate
373 a minimal influence of Fraser River particles in the north-central and northern Strait. Long-term
374 monitoring shows that the total water column primary production is greater in the northern Strait
375 than it is in the southern basin (D. Masson, Fisheries and Oceans Canada, personal
376 communication, 2008), and particles that sink in this area have a higher organic content than

377 elsewhere in the Strait (Johannessen et al., 2006). The flux of these organic-rich particles seems
378 to peak in late spring, after the main spring bloom. Consequently, the organic matter in the
379 sediments of the northern Strait is mostly marine (Johannessen et al., 2005b), along with some
380 terrigenous organic matter added by pulp mills within the northern half of the Strait (Macdonald
381 et al., 1991).

382
383 Sedimentation rates for the inlets and fjords seem to be relatively low compared with the Fraser
384 River delta/slope area, based on historical core data for Burrard Inlet and Howe Sound (Table 2).
385 In outer Burrard Inlet, sediment accumulation rates are considerably lower than along the Fraser
386 River delta/slope, whereas faunal abundance and biomass are only moderately lower (McPherson
387 et al., 2007b). Bivalves predominate in outer Burrard Inlet, as they do along the Fraser River
388 foreshore (Je et al., 2003; McPherson et al., 2007b), suggesting moderate deposition rates.

389 Carbon/nitrogen ratios and stable isotopes suggest that sedimenting material in the outer Burrard
390 Inlet comes primarily from the Fraser River (Boyd et al., 1997), however numerous types of
391 anthropogenic discharge contribute unknown quantities of particulate material as well. High
392 flocculent content in the water column observed near the First Narrows bridge (CORI, 2002)
393 suggests that the strong currents re-suspend material from the bottom, reducing the predictability
394 of biotic abundance and biomass based on core-derived flux rates (McPherson et al., 2007b).

395
396 The sediment accumulation rate is lower in the main basin of Howe Sound than in outer Burrard
397 Inlet (Johannessen et al., 2003), as is faunal abundance. However, confounding factors in Howe
398 Sound undoubtedly affect biotic conditions. These include discharges from two pulp mills, acid
399 mine drainage that continues to leak from an abandoned copper mine (Britannia), and

400 intermittent stagnation in the deep basin water behind the sill (Levings et al., 1983; Stucchi,
401 2006).

402

403 Sediments in the deep basin of Jervis Inlet (Burd and Brinkhurst, 1992) are composed of
404 uniformly fine silt (~98%), similar to those in the deepest deposition areas of the main basin of
405 the Strait. This suggests that particulate flux to these sediments is low. Total faunal abundance
406 was lower in samples from the deep basin of Jervis Inlet than in Howe Sound or outer Burrard
407 Inlet.

408

409 Aside from a few measurements from just north of Saanich Inlet (Burd, et al., 2000; Burd and
410 Glaholt, 2000; Seacology, 2001; Glaholt et al. 2002), and from several pulp mill areas, there are
411 few biological or core data available from the near-shore areas along the western margin of the
412 Strait, so fluxes cannot be compared for this region. In Saanich Inlet, historical organic flux data
413 to sediments at the CEPEX site just inside the sill (Whitney and Wong, 1984) suggest rates
414 intermediate between those found at the Iona outfall station (GVRD-3) and at the station outside
415 Burrard Inlet (GVRD-2). However, bottom water hypoxia is the most important factor
416 structuring benthic communities in Saanich Inlet (Tunncliffe 1981; Burd and Brinkhurst, 1984).

417

418 **4.2 Predictability of biotic patterns from ambient and sedimentation conditions**

419

420 Percent fines was not a major factor structuring the biotic indicators measured during this study
421 (see also Levin and Gage, 1998), although it is expected to have a profound effect on community
422 composition and balance of feeding types (Bernard, 1978; Levin and Gage, 1998). The current
423 study shows that biotic declines tended to occur below 100 m depth, and even more dramatically

424 below 300 m depth. This decline with depth, which has also been observed in other high-latitude
425 seas from the continental margin (about 200 m) to abyssal depths (3000 m – Levin and Gage,
426 1998; Wlodarska-Kowalczyk et al., 2004), parallels the observed decline in organic input with
427 depth (Suess, 1980; Vinogradov and Tseitlin, 1983; Shirayama, 1984; Bishop, 1989;
428 Vanaverbeke et al., 1997).

429
430 The data from the current study clearly illustrate that sediment organic content is a poor predictor
431 of benthic macro-infaunal abundance and biomass in the Strait of Georgia. Hyland et al. (2005)
432 suggested that infauna increase in abundance and taxa number as organic content increases, up to
433 a threshold, beyond which they decline (as per Pearson and Rosenberg, 1978). This pattern can
434 be seen near the Macaulay Point outfall south of Greater Victoria (Fig. 1) (Burd, 2003b).
435 However, organic enrichment gradients cannot always be identified by sediment organic content.
436 For example, organic loading from the Iona outfall in the Strait of Georgia is swamped by a
437 large, primarily inorganic deposition from the Fraser River (Hodgins and Hodgins, 2000; Yunker
438 and Macdonald, 2003; McPherson et al., 2007a), so that sediment organic content remains within
439 background ranges along the delta. However, there is evidence of elevated sulphides in
440 sediments and enrichment-related faunal changes near the outfall (Burd, 2003a; McPherson et
441 al., 2007a).

442
443 A further example of the unexpected relationship between sediment organic matter and biotic
444 conditions in the Strait of Georgia was evident in the samples taken from Texada Island
445 northward. Unusually high sediment OC, nitrogen and $\delta^{15}\text{N}$ in the cores (GVRD-1 and 10), and

446 notably impoverished biota suggest that sedimenting marine organic material is recalcitrant in
447 that region of the Strait and contains little of nutritional value by the time it reaches the bottom.

448
449 Organic flux to sediments is a much better indicator of biotic abundance and biomass than
450 organic content of sediments. Similarly, Rowe et al. (1991) pointed out that POC flux to
451 sediments was a much better estimator of infaunal biomass in the western North Atlantic than
452 sediment detrital organic content, and Grebmeier et al. (1988) showed benthic infaunal biomass
453 to be coupled with flux of organic matter to the seabed in the northern Bering and Chukchi Seas.
454 Johnson et al. (2007) also showed that modeled vertical POC flux from surface satellite color
455 imagery accounted for about 2/3 of the variance in benthic standing stock of macrobenthos in the
456 western North Atlantic.

457
458 The quality of organic matter, including contaminant content, in structuring marine infaunal
459 growth and production has not been extensively studied but appears to an important modifier of
460 the aforementioned POC/biotic relationships (Gunnarsson et al., 1999; Aller et al., 2002;
461 Danovaro, 2003). A modified measure of organic flux, which took into account the relative age
462 and lability of organic material, was a better predictor of many biotic factors than unweighted
463 organic flux (Table 4). However, this was not true for total biomass, because the station just
464 north of the Iona outfall skewed the relationship. Despite relatively high sedimentation rates and
465 organic flux at this location (GVRD -3), biomass was low, due to the loss of ophiuroids and the
466 reduction in bivalve abundance. Bivalve abundance is thought to be relatively low near the
467 outfall because of sulphide toxicity from the organic enrichment of sediments (Burd, 2003a;
468 McPherson et al., 2007a; GVRD, 2004). A regression of total biomass on \log_{10} weighted organic

469 flux, calculated without the outfall station, explains 82% (r^2) of the variance in biomass. In the
470 Strait of Georgia, this suggests that infaunal biomass can be well predicted by flux and quality of
471 organic matter to sediments under background conditions of sedimentation, but that sediment
472 toxicity may override the relationship in areas of anthropogenic inputs of organic matter.

473

474 In the Strait of Georgia, river-borne deposits mixed with marine flux appear to provide a more
475 productive substrate for infauna than do marine deposits alone. Many of the abundance factors
476 measured in this study are related to total flux as well as to % carbonates. A high concentration
477 of carbonate in sediments usually indicates river-borne sediments, although over the small scale
478 of the central Strait of Georgia, the carbonate distribution is patchy (Gordon, 1997), so that
479 interpretation is not clear in this case.

480

481 Taxa number was poorly predicted by organic flux and quality. Taxa numbers in background
482 conditions and near sewage outfalls were strongly negatively correlated with %TOC, %TN and
483 the ratio of OC to inorganic flux to sediments (Table 4). These sediment factors were also
484 strongly positively inter-correlated. This is not surprising, since the diversity of benthic marine
485 faunal types is theoretically related to the diversity of substrate habitats and habitat stability
486 within a given area (Gray et al., 2002). Based on results from extensive trawl surveys in the
487 Strait of Georgia, Bernard (1978) suggested that the more consistently fine substrates (without
488 terrigenous debris, shell hash, or a variety of particle sizes) had fewer habitat niches available.
489 Therefore, %TN and relative organic/inorganic composition of sediments appear to be useful
490 surrogates for measuring habitat heterogeneity, and thus predicting taxa number.

491

492 However, taxa number did not show any pattern with sediment organic content near pulp mills.
493 Focused studies outside the government monitoring programs near several of the pulp mills have
494 shown finer-scale bio-diversity impacts related to mill effluents (Jones and Ellis, 1975; Pearson
495 1980 for review; Ostrovsky, 1987), but these patterns are not evident in the federal
496 Environmental Effects Monitoring program data for pulp and paper mills URL:
497 (ec.gc.ca/eem/english/PulpPaper/default.cfm). In addition, the Britannia mine near-field
498 samples had uniformly low taxa numbers over a range of %TOC levels (%TN not measured),
499 possibly due to metal toxicity (Hagan et al., 2004; G3, 2003). This pattern of reduced taxa
500 number but not abundance in the area of historical tailings deposition near the mine was also
501 noted 12 years after the mine closed (Ellis and Hoover, 1990).
502
503 Of the major taxonomic groups that are typically found in infaunal samples in British Columbia
504 (bivalves, errantiate and sedentariate polychaetes, crustaceans), the bivalves in the present study
505 tended to show the clearest responses to ambient and sedimentation gradients, although the
506 reasons for these responses were not always clear. The relative rarity of infaunal bivalves at
507 depths greater than 150-200 m in the Strait of Georgia has been observed coast-wide (Burd,
508 2006). Bivalve percent abundance was very strongly negatively correlated with $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$,
509 which we suggest is indicative of poor food quality. Since bivalves selectively ingest preferred
510 organic material and reject the rest as pseudo-faeces (Taghon, 1982; Newell and Jordan, 1983;
511 Macdonald and Ward, 1994; Bacon et al., 1998), there may simply not be enough food of
512 acceptable quality for infaunal bivalves in the deeper areas of the Strait and fjords (or possibly in
513 areas with very low sediment percent fines). This is supported by the relatively high correlation
514 between bivalve abundance and organic flux weighted by $\delta^{15}\text{N}$.

515

516 The low bivalve abundance in the shallow areas may be an artifact of the limited number of
517 shallow samples included in the database. For example, bivalve abundance was uniformly low
518 in samples from 5 to 20 m depth near the Britannia mine site. Bivalves are known to bio-
519 accumulate metals in their tissues, and a study of intertidal mussels has suggested toxicity
520 responses in proximity to the Britannia mine drainage (Grout and Levings, 2001). A benthic
521 study in Boundary Bay near the Washington border showed that infaunal bivalves were patchily
522 abundant in shallow subtidal stations, but that substrate conditions (such as eel-grass beds) could
523 potentially inhibit bivalve burrowing (Burd, 1992). Such erratic results suggest that more
524 detailed sampling of shallow subtidal areas in the Strait of Georgia is required to understand
525 biotic conditions relative to sedimentation .

526

527 Bivalves were the only group clearly depressed in samples taken near pulp and paper mills,
528 suggesting that pulp mill deposits are not ideal for infaunal bivalve growth. This may be related
529 to difficulty in burrowing through the fibrous organic material, or the low food quality of organic
530 material in sediments. Several earlier studies of the impacts of wood waste in the Strait of
531 Georgia tend to support the hypothesis that burrowing is impeded by wood fibre debris (Conlan,
532 1977; Conlan and Ellis, 1979; Ostrovsky, 1987).

533 **5.0 Conclusions**

534

535 Infaunal abundance and biomass in the Strait of Georgia cannot be readily predicted by static
536 measurements of sediment particle size, organic content or water depth, because these measures
537 do not take into account the rate or quality of organic input. Organic flux and quality are good

538 predictors of biotic abundance and biomass, particularly when outliers affected by sediment
539 toxicity related to organic enrichment are considered separately. Higher deposition rates from
540 terrestrial sources typically translate to higher overall labile organic input, supporting a high
541 macro-faunal abundance and biomass, as well as dominance by infaunal bivalves. Relative
542 proportions of organic and inorganic flux, as well as % carbonate, were also important to biota,
543 suggesting that organic matter and other factors in riverine input support productive benthic
544 assemblages in the Strait of Georgia. It is clear from this study that organic and inorganic flux to
545 sediments and the type of substrate influence infaunal production, and that all of these factors
546 need to be included when modeling biological impacts related to organic deposition (Cromeey et
547 al., 1998).

548
549 Predictions of faunal abundance and biomass based on organic flux and quality to sediments
550 must be approached with caution in complex hydrographic/input areas such as Burrard Inlet, and
551 in fjords where confounding factors such as basin stagnation are primary drivers of benthic
552 productivity. In addition, shallow subtidal areas in the Strait of Georgia have not been
553 adequately studied in terms of infaunal or sedimentation patterns.

554
555 Taxa number can be well predicted by %TN or rate of organic/inorganic flux under background
556 conditions, as well as in situations of labile organic enrichment (Iona and Lions Gate outfalls).
557 Taxa number is much less predictable near pulp mills and in areas receiving acid mine drainage.

558
559 The composition of the benthic fauna varies dramatically throughout the Strait, as do
560 sedimentation dynamics. Fauna that are best suited to continuous bottom transport of material

561 northward and downslope from the Fraser River delta are clearly not the same as those best
562 suited to conditions with high, finer particulate deposition from the water column.

563

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565

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572

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906 **Figure Captions**

907

908 Figure 1. General locations of historical and AMP grab sample data, with overlying bottom
909 bathymetry based on multibeam data (courtesy of Natural Resources Canada) for the main basin
910 of the Strait of Georgia. Multibeam data are not available for the adjacent fjords. The locations of
911 the nine AMP grab sample locations are shown as white dots (which correspond with the AMP
912 core locations; see Fig. 2). Locations of pulp mills, outfalls and the Britannia Beach acid mine
913 drainage site are included. Note FR denotes Fraser River.

914

915 Figure 2. Locations of historical and nine AMP cores from the Strait of Georgia. Historical core
916 names from the original reports are listed in Table 2.

917

918 Figure 3. Total abundance, taxa number and abundance of dominant taxonomic groups for
919 historical and AMP grab samples versus sample depth. Mean background values +/-SE for each
920 biological factor are superimposed for arbitrarily selected depth ranges (points are shown on the
921 plot at the maximum depth for that range). Note that mean values do not include any data for
922 samples taken near anthropogenic discharges.

923

924 Figure 4. Total abundance, taxa number and abundance of dominant taxonomic groups for
925 historical and AMP grab samples versus sample percent silt/clay. Mean background values +/-
926 SE for each biological factor are superimposed for arbitrarily selected depth ranges (points are
927 shown on the plot at the maximum depth for that range). Note that mean values do not include
928 any data for samples taken near anthropogenic discharges.

929

930 Figure 5. Total abundance, taxa number and abundance of dominant taxonomic groups for
931 historical and AMP grab samples versus %TOC. Mean background values +/-SE for each
932 biological factor are superimposed for arbitrarily selected depth ranges (points are shown on the
933 plot at the maximum depth for that range). Note that mean values do not include any data for
934 samples taken near anthropogenic discharges.

935

936 Figure 6. Total abundance, taxa number and abundance of dominant taxonomic groups for
937 historical and AMP grab samples versus sample %TN. Mean background values +/-SE for each
938 biological factor are superimposed for arbitrarily selected depth ranges (points are shown on the
939 plot at the maximum depth for that range). Note that mean values do not include any data for
940 samples taken near anthropogenic discharges.

941

942 Figure 7. a. Geographic distribution of sediment fluxes and, b; sediment organic carbon flux
943 rates from AMP and historical core data (as per Table 2). Locations of cores are shown as black
944 dots on the figure and correspond to core locations shown in Figure 2. Locations of pulp and
945 paper mills, outfalls and the Britannia Beach acid mine drainage are included for reference.

946

947 Figure 8. a; Geographic distribution of total abundance per grab, and b; bivalve abundance per
948 grab for background locations in the Strait of Georgia, including several sample locations off
949 southern Victoria in Juan de Fuca Strait. Locations of pulp and paper mills, outfalls and the
950 Britannia Beach acid mine drainage are included for reference.

951

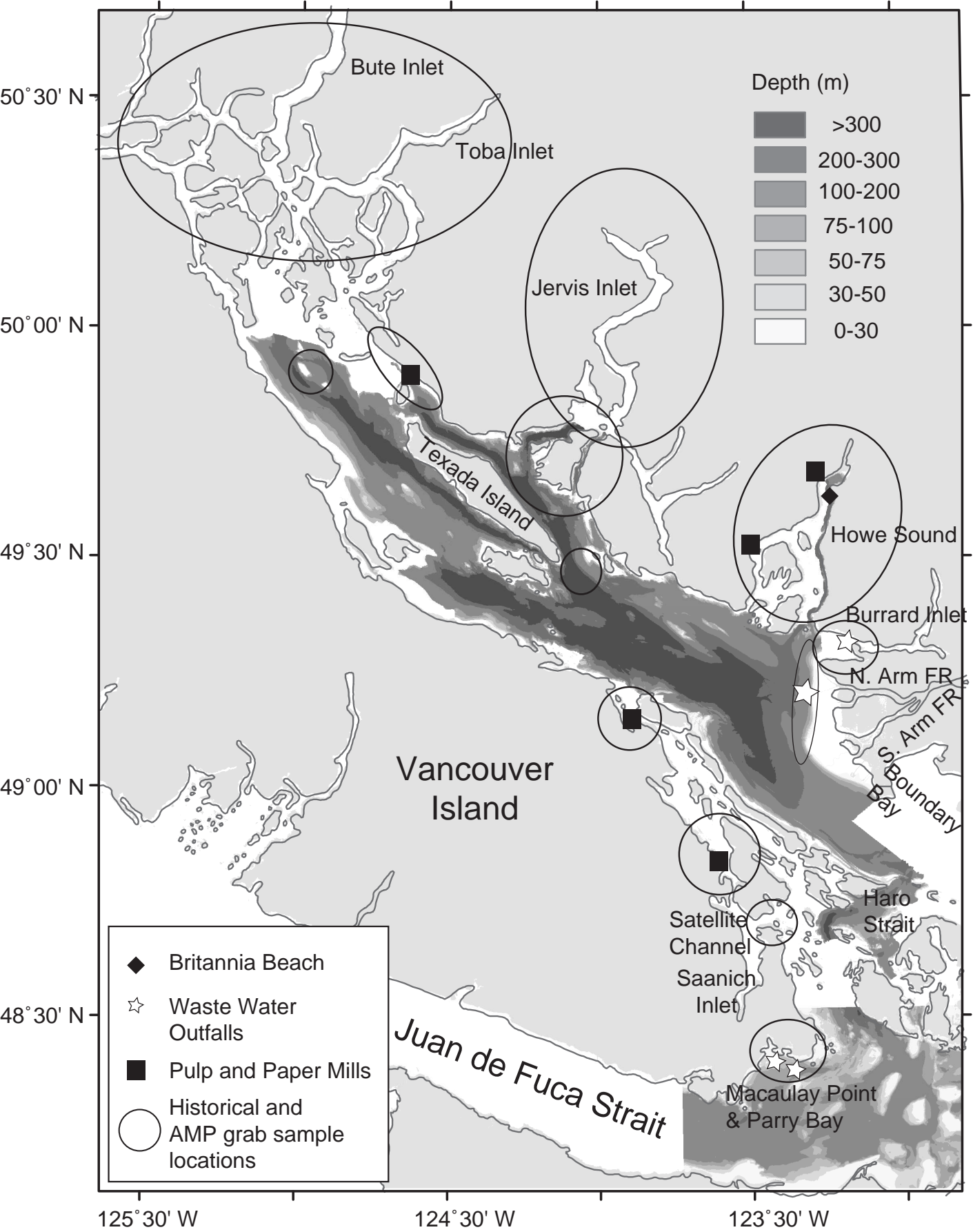
952 Figure 9. Geographic distribution of taxa number per grab for background locations in the Strait
953 of Georgia, including Parry Bay and Macaulay point area in Juan de Fuca Strait. Locations of
954 pulp and paper mills, outfalls and the Britannia Beach acid mine drainage are included for
955 reference.

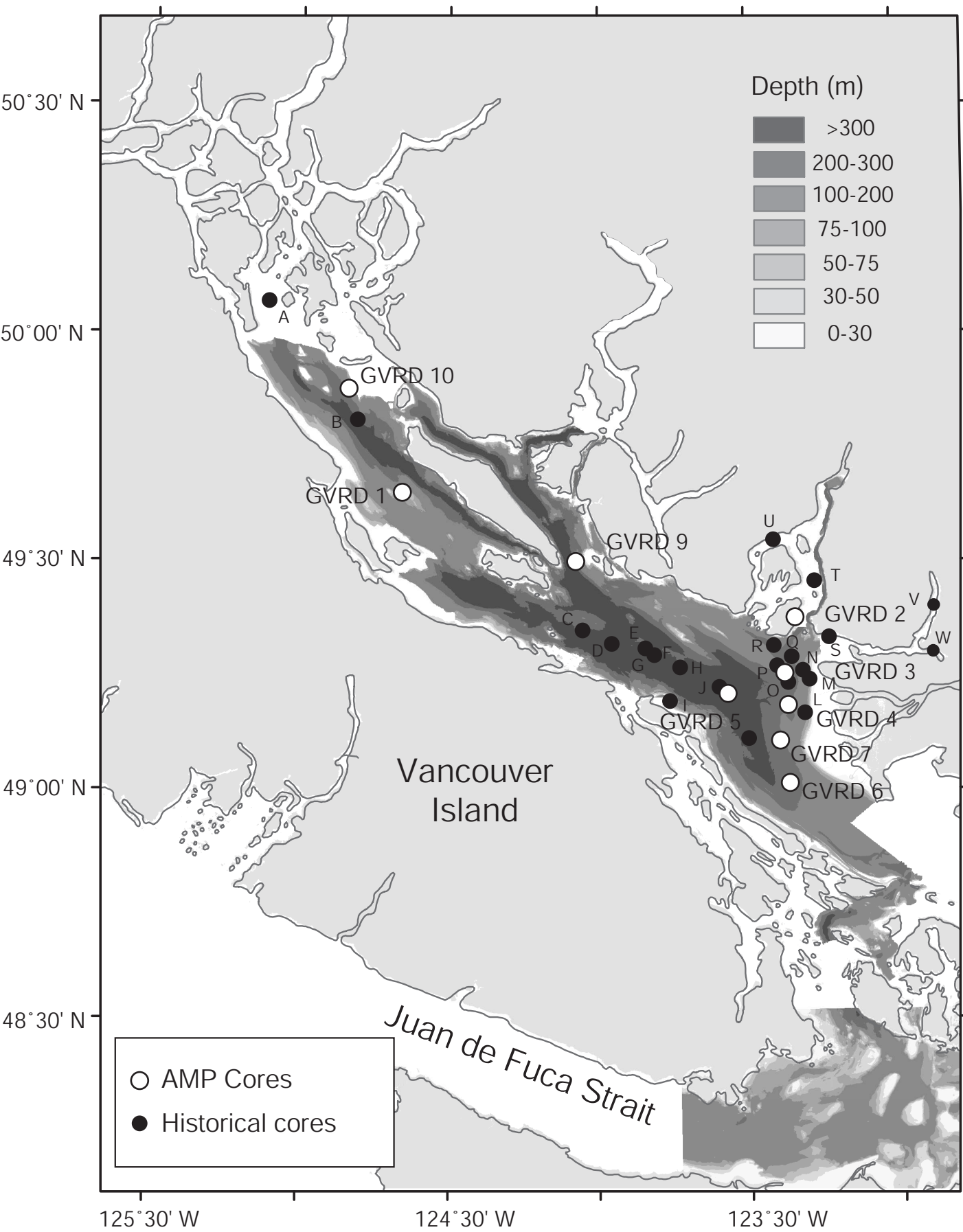
956
957 Figure 10. a; Distribution of carbon stable isotope composition ($\delta^{13}\text{C}$) relative to % TOC, and, b;
958 distribution of nitrogen stable isotope composition ($\delta^{15}\text{N}$) relative to % TN for all depth layers
959 in AMP cores (see Fig. 2 for locations of cores). Outfall samples show a divergence of old
960 sediments deep in the core (pre-outfall) and newer sediments (post-outfall) based on $\delta^{15}\text{N}$
961 values, c; the progression from terrestrial (near the Fraser River) to marine (most northerly part
962 of the Strait) organic deposition sources is shown in increasing $\delta^{15}\text{N}/\delta^{13}\text{C}$ ratios (see arrow in
963 Fig. 10c). Cores 1 and 10 were from the most northern locations in the Strait, whereas cores 2-7
964 and 9 were collected in the southern basin (south of Texada Island – Fig. 1).

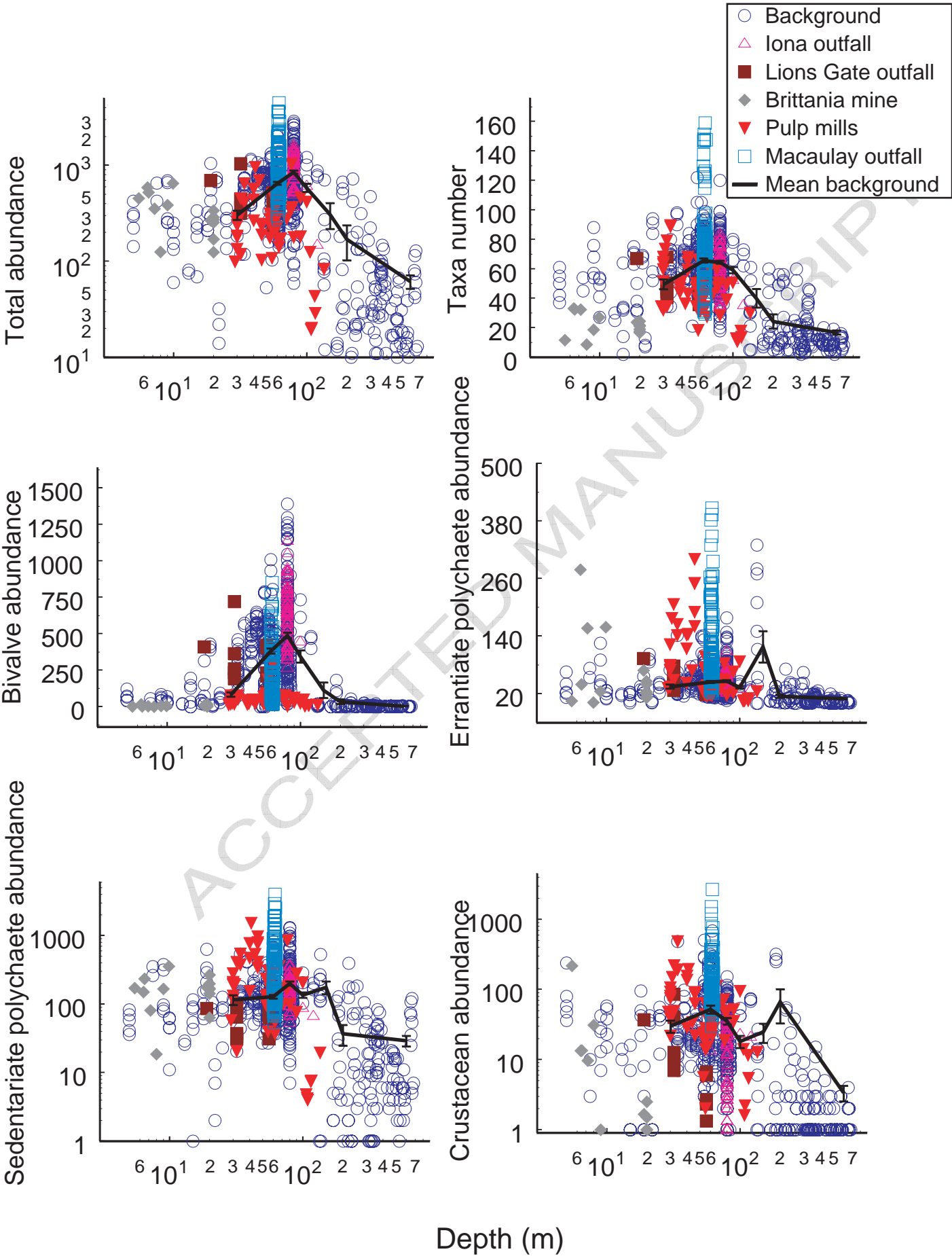
965
966 Figure 11. Best fit exponential regression line for log taxa number per grab versus
967 organic/inorganic flux from AMP grab and core samples ($r^2=0.83$, $p<0.001$). Superimposed are
968 data points for taxa versus %TN from the historical grab data for background locations and
969 anthropogenic sites (exponential regression fits for these data; $r^2=0.66$, $p<0.001$).

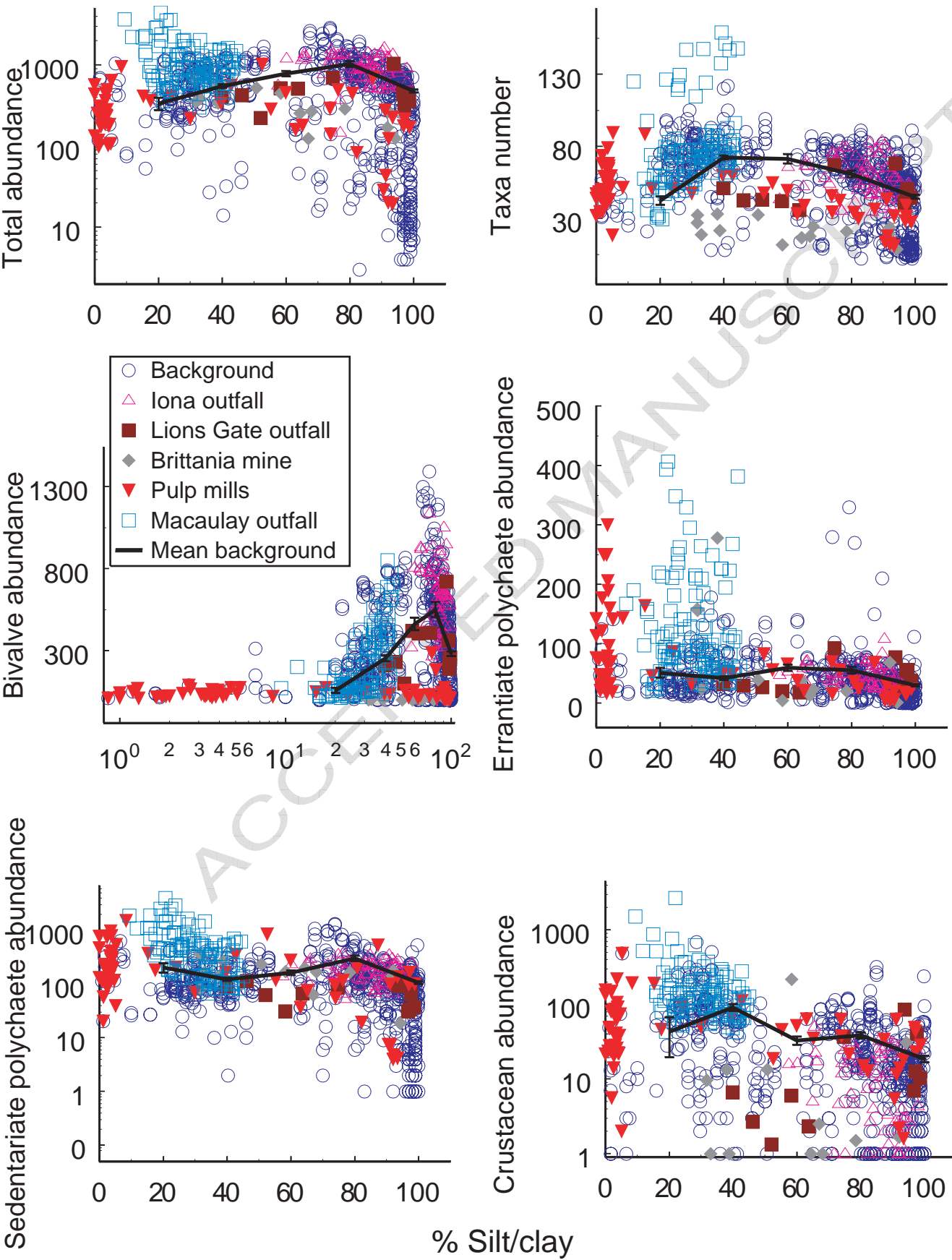
970
971 Figure 12. Best fit regression line ($r^2=0.84$, $p<0.01$) for relationship of mean infaunal biomass
972 versus buried organic carbon flux to sediments for 9 AMP locations (see Fig. 2 for AMP
973 locations).

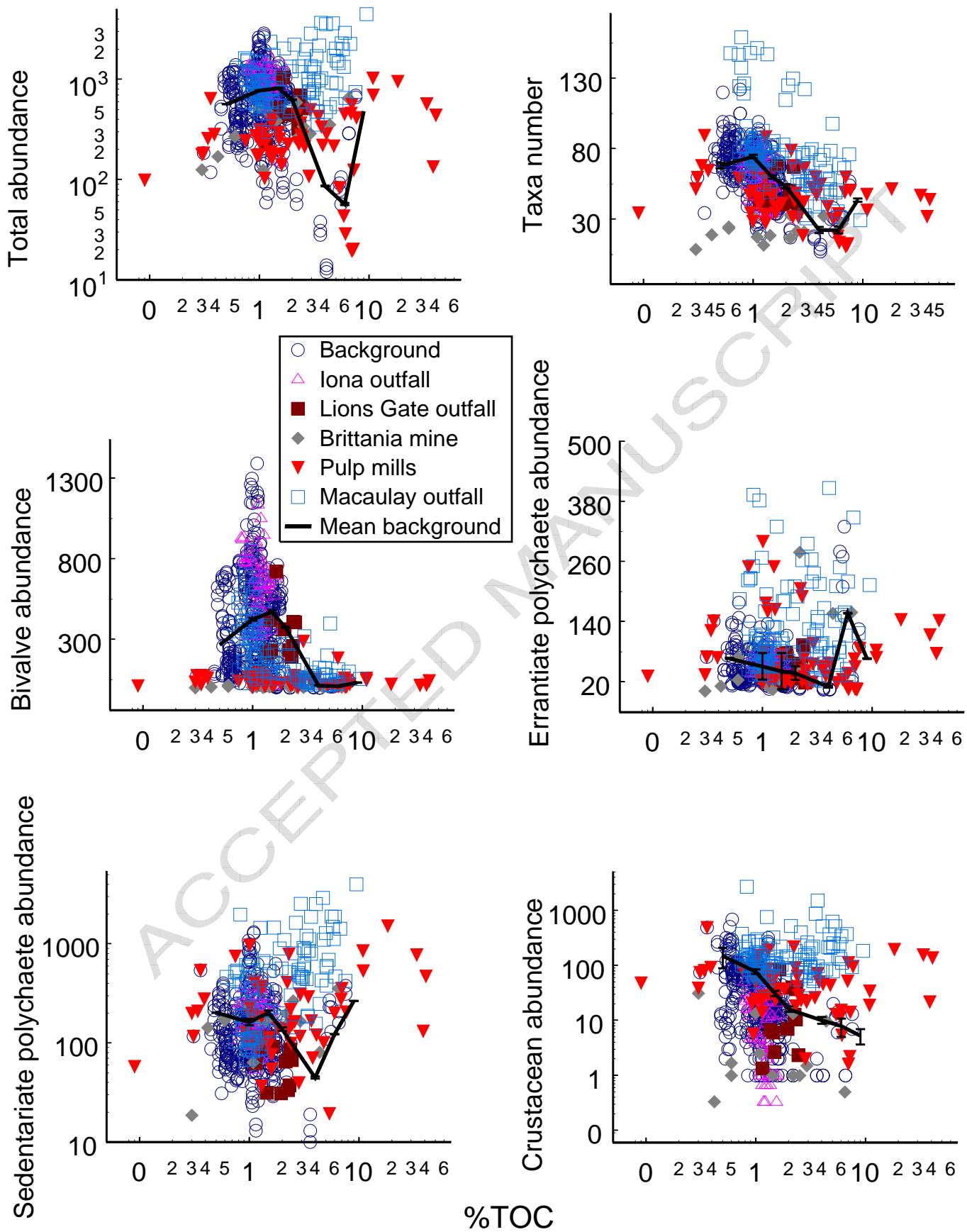
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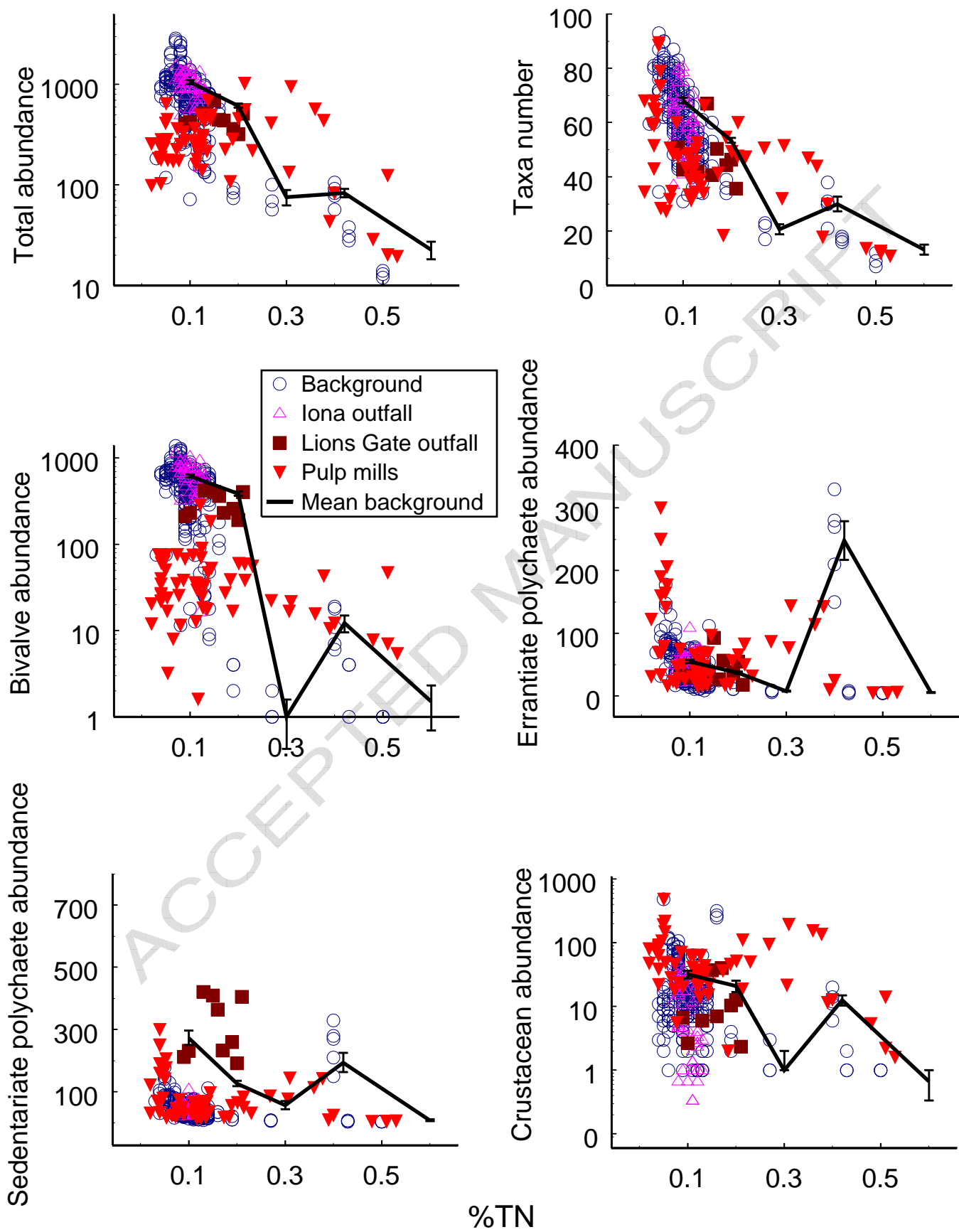




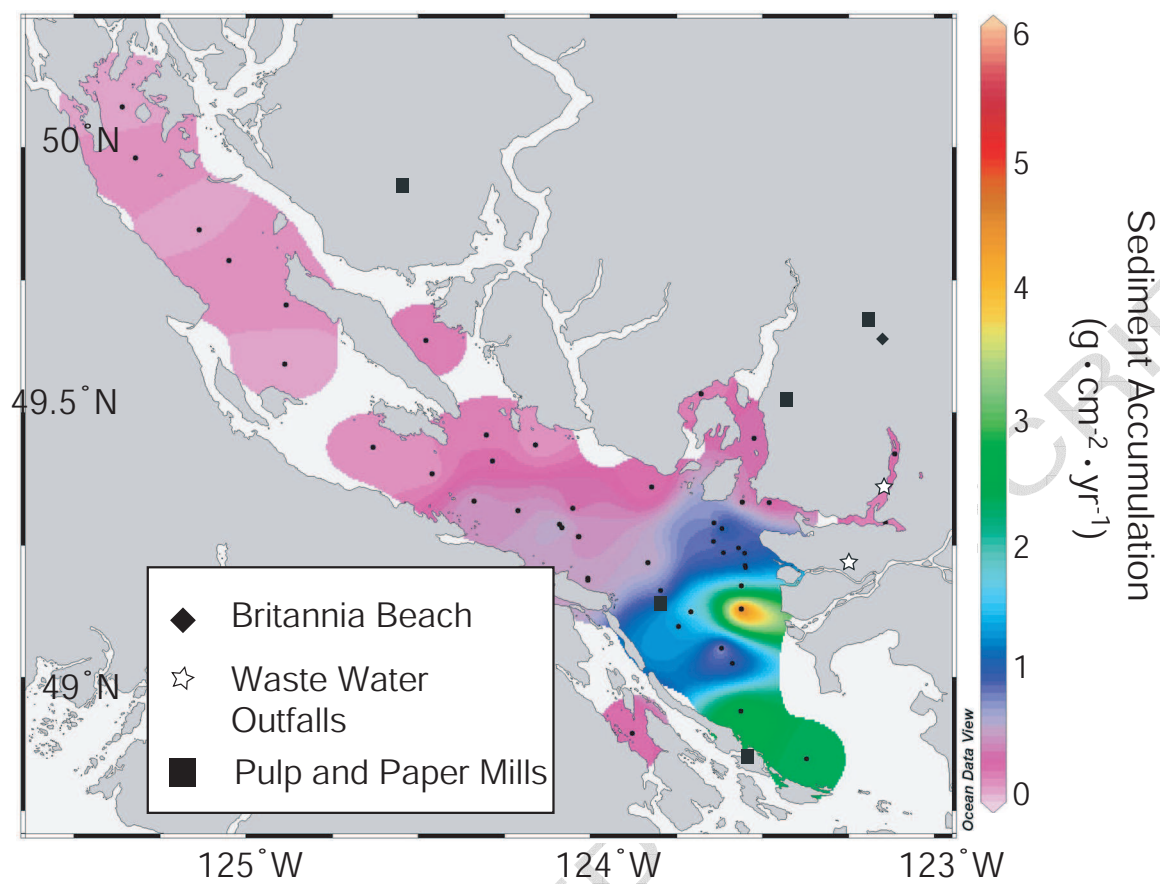




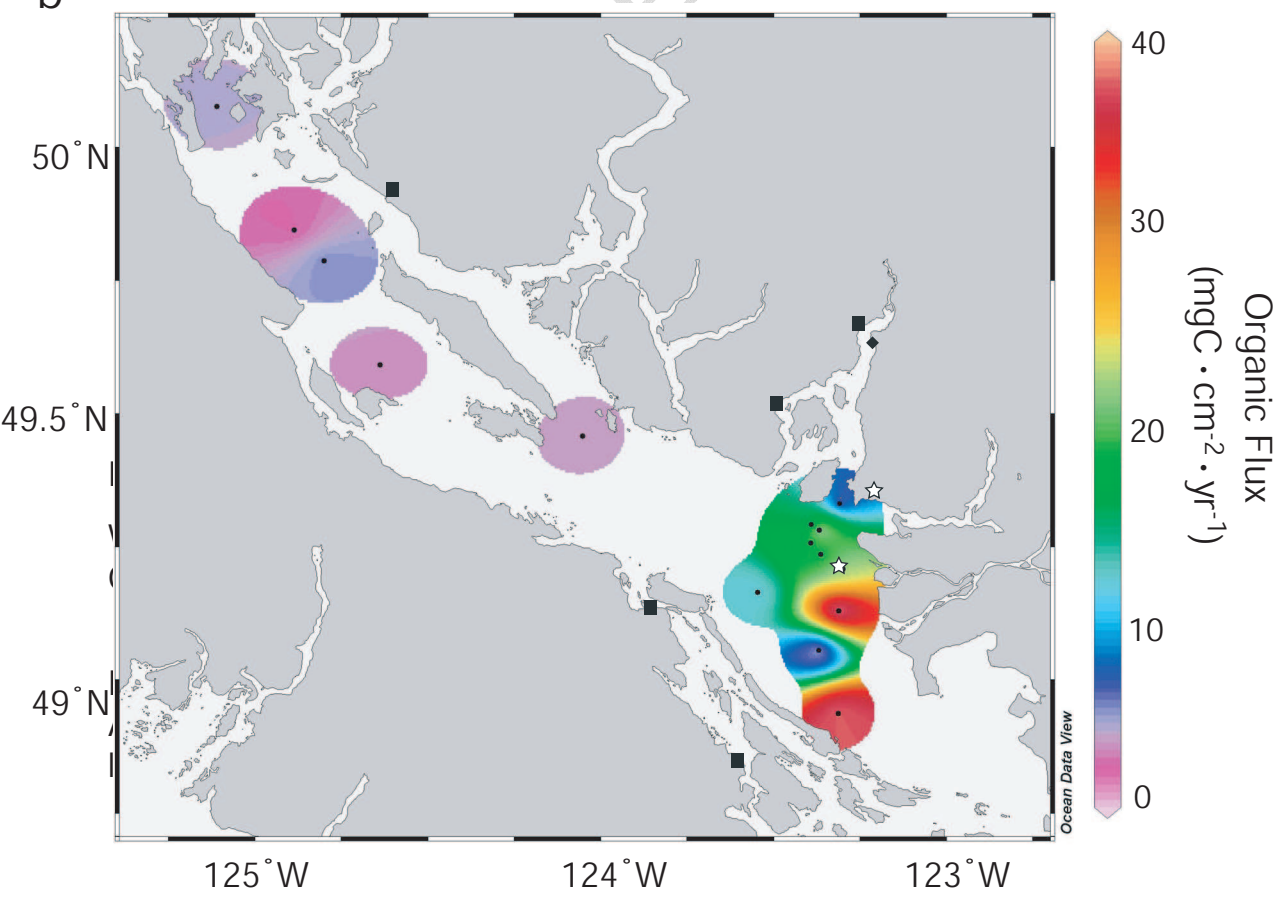




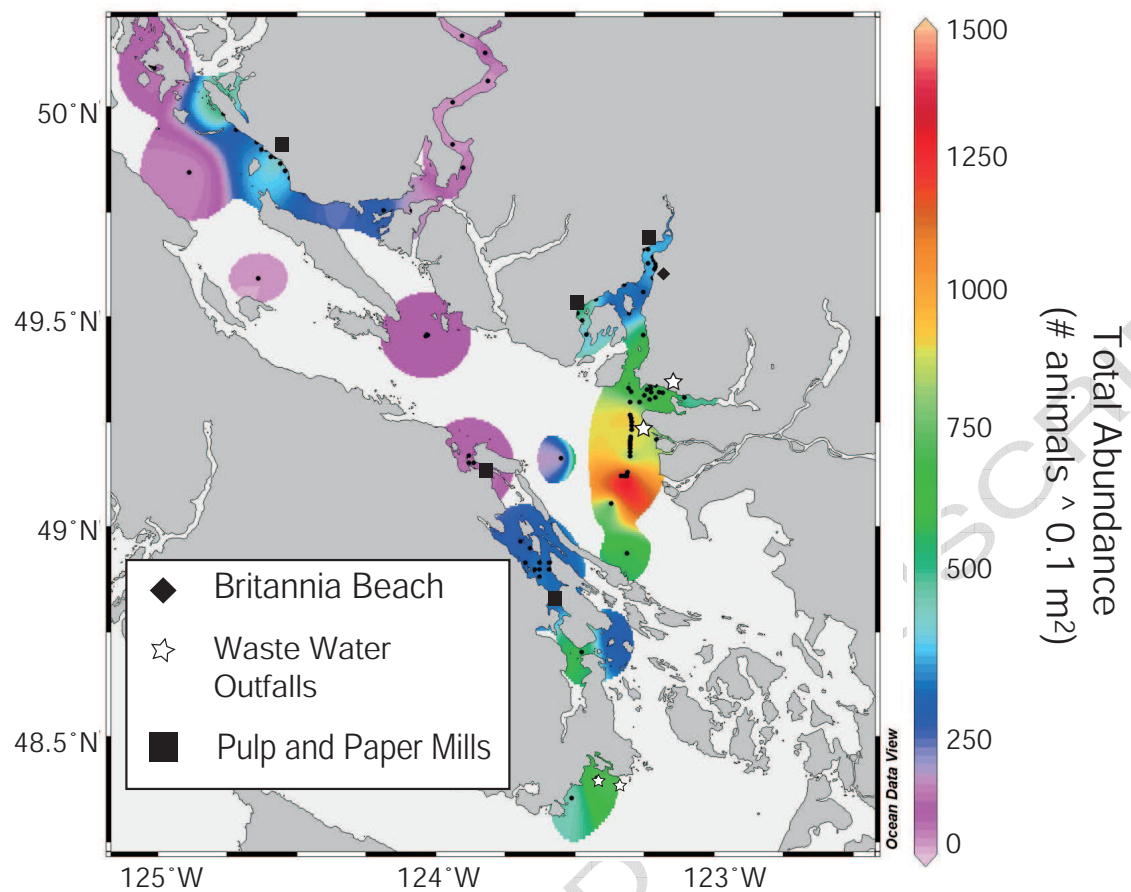
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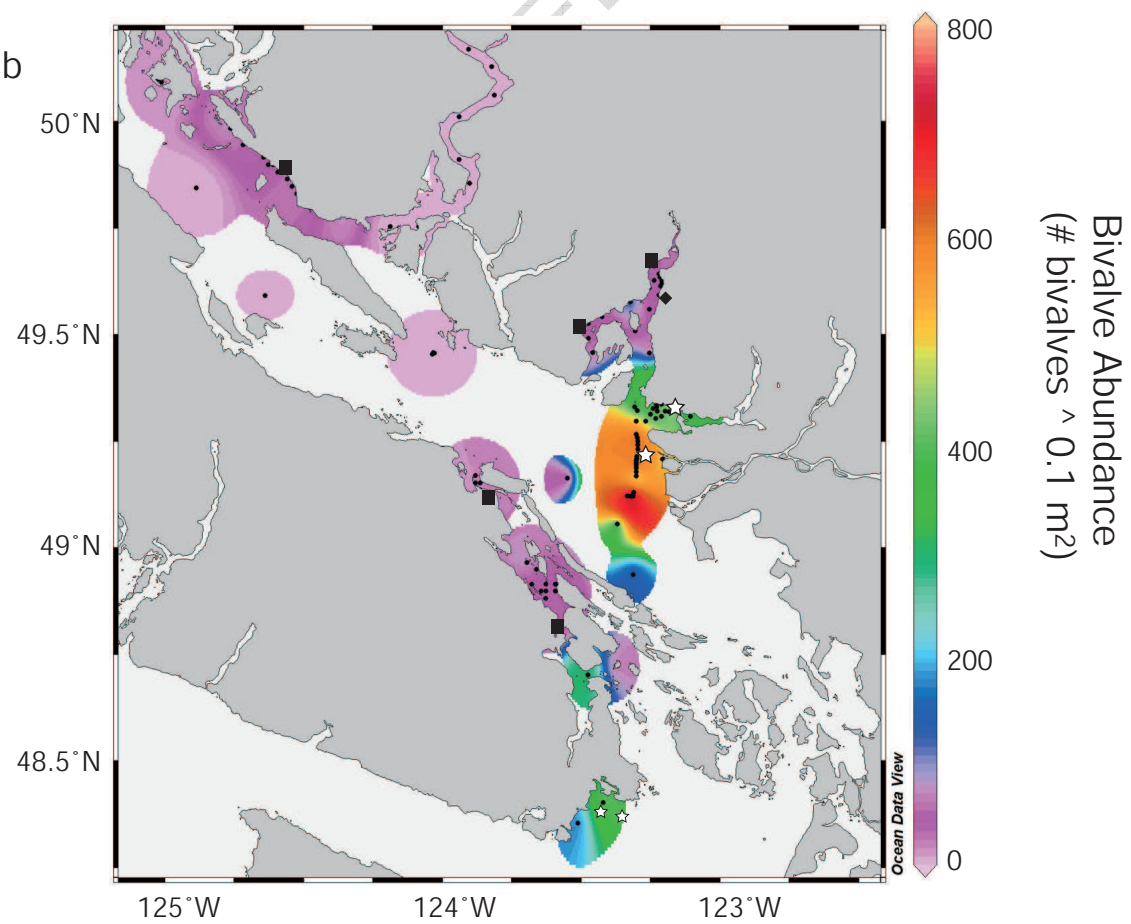
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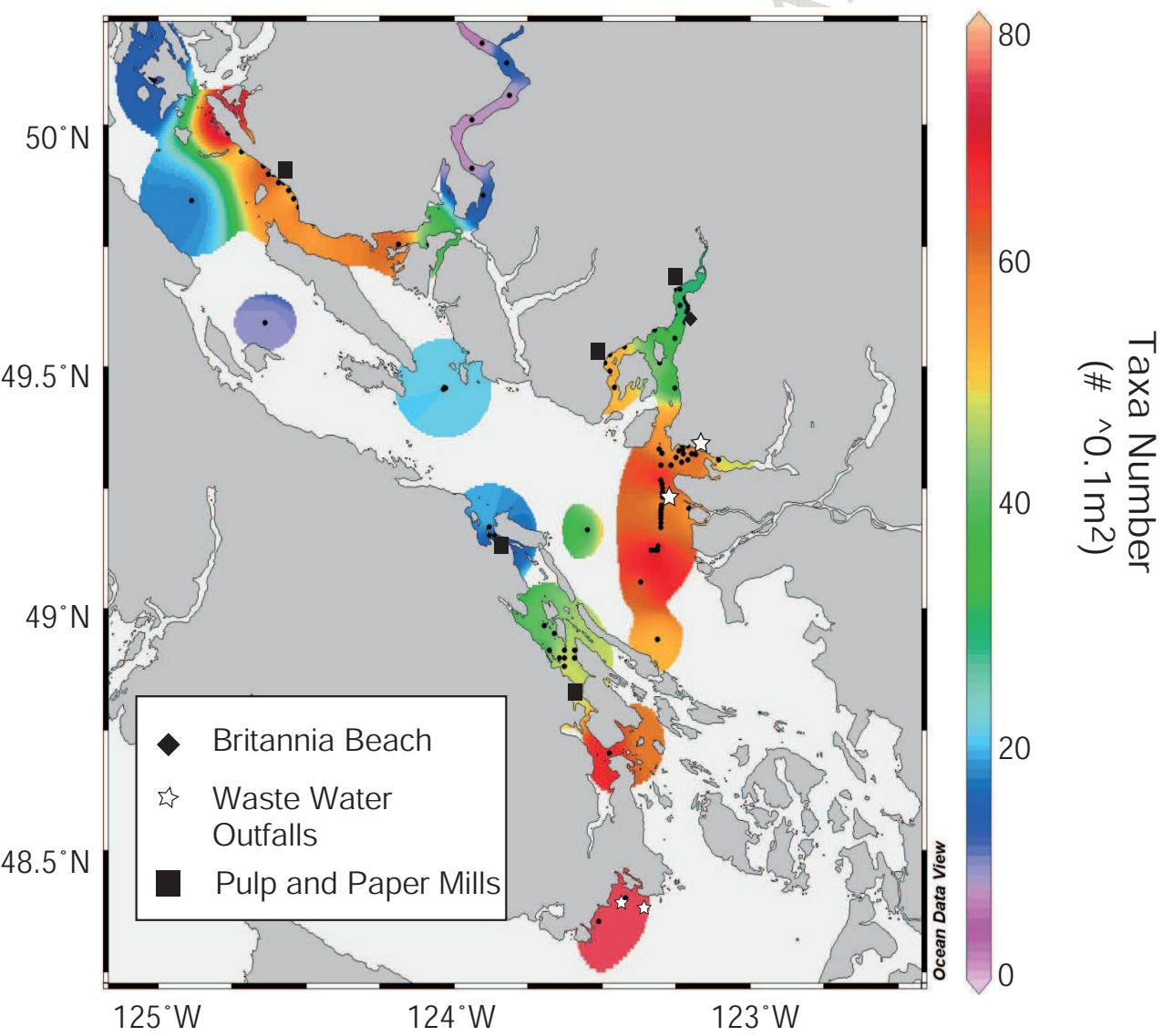


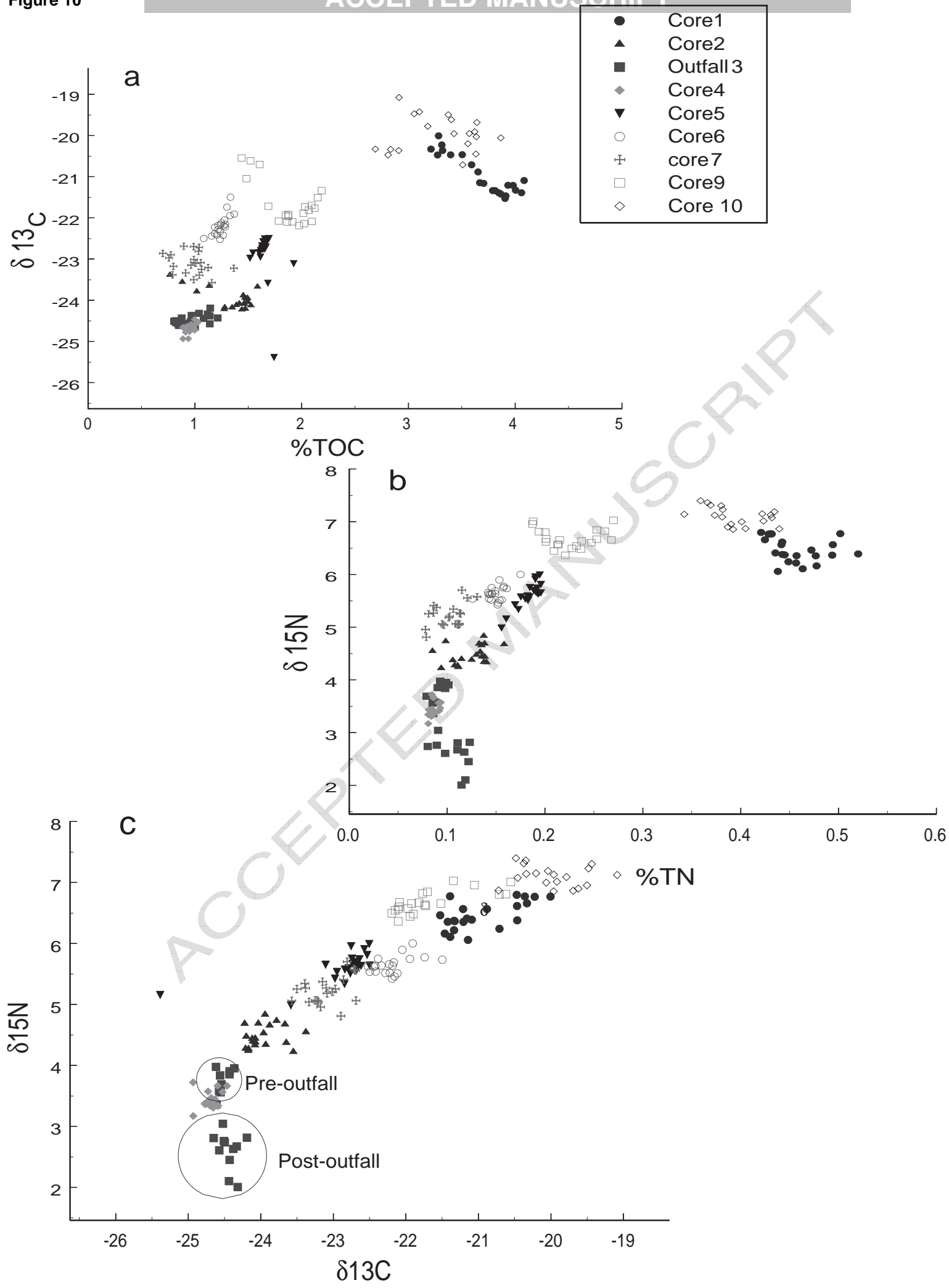
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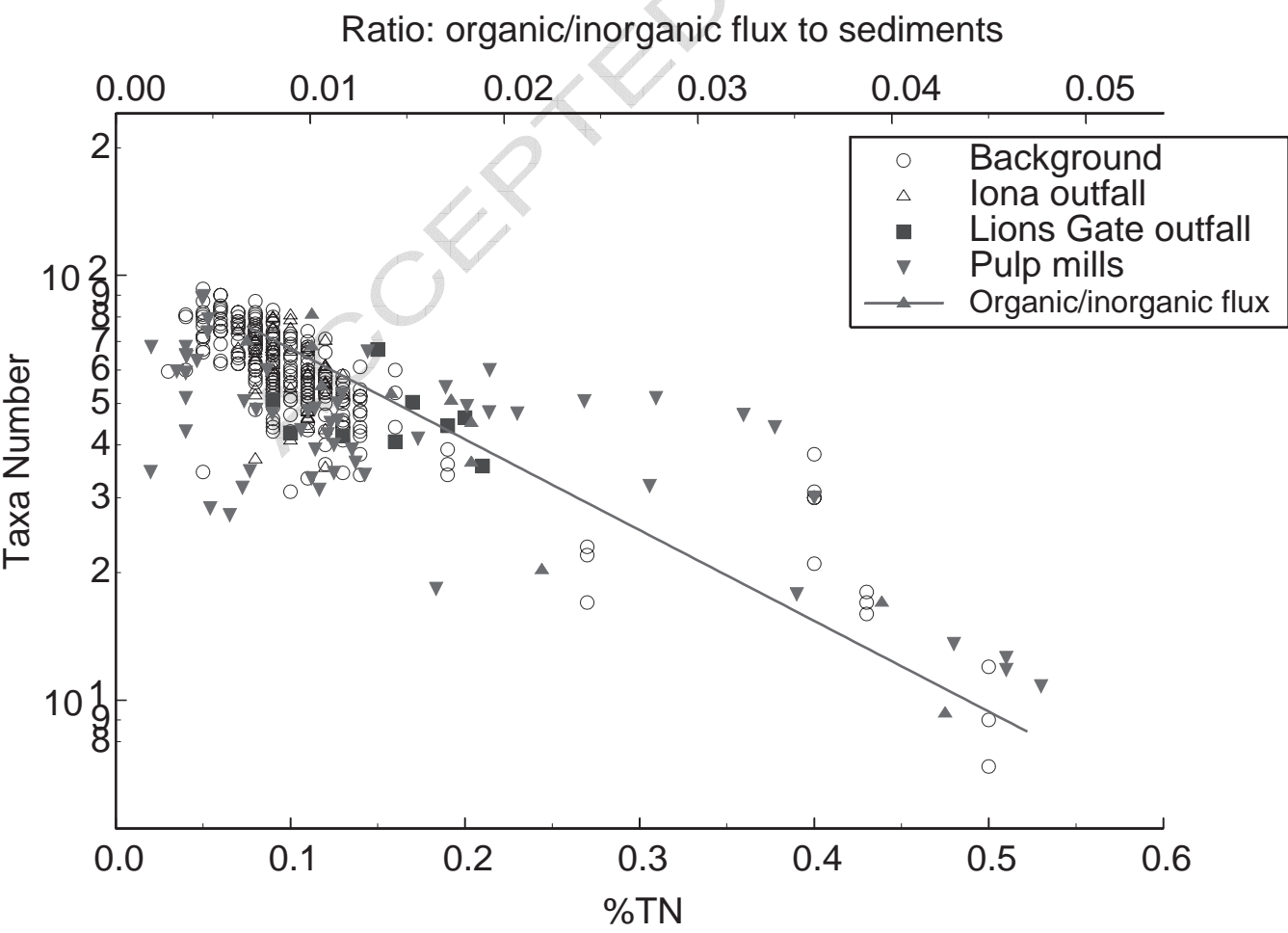


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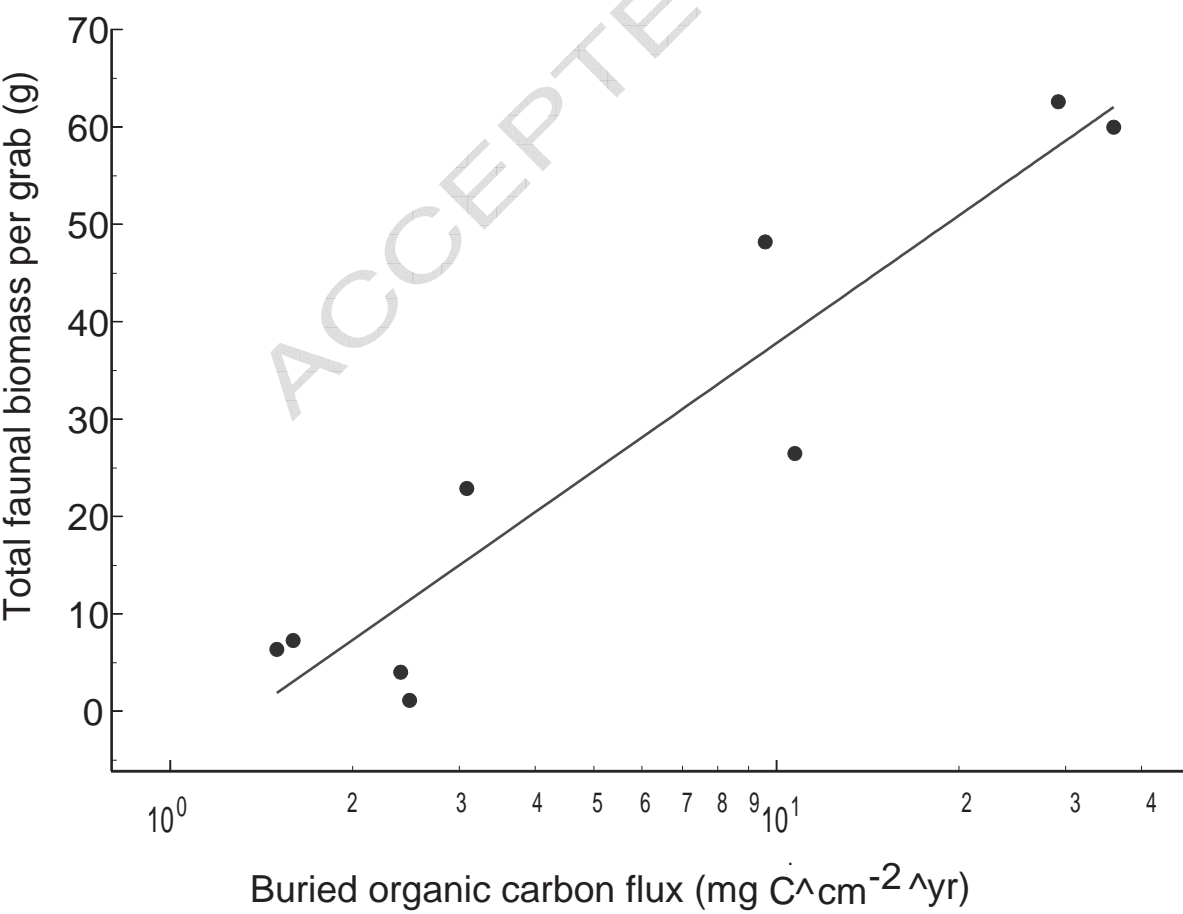


Table 1. Area, Depth, Year, Purpose of study and data source (reference) for historical and AMP grab sample data collected from 1988 to 2007.

Region	Depth (m)	Year	Purpose of study	References
West coast Vancouver Island, Alberni Inlet	25-45	2000	Ambient for pulp mill	Pulp and Paper Environmental Monitoring Program: ec.gc.ca/eem/english/PulpPaper/default.cfm
Southeast Strait of Georgia	60-70	1994-2004	Ambient for Outfall	CRD 2003, 2004, 2005, Paine et al. 2004
Howe Sound	5-20	2000	Brittania Beach, acid mine drainage	G3, 2003
Ecological Reserve 67, Southern Gulf Islands	60-70	1999	Background for pipeline	Burd et al., 2000
Mainland fjords	221-634	1988-1990	Ambient for deep fjords	Burd and Brinkhurst, 1992
Gorge Harbour, Cortes Island; Village Bay, Quadra Island	13-37m	2005	Reference related to oyster farm biodeposition	Barnes, 2007
Southeast Strait of Georgia	80	2000-2005	Ambient for Iona outfall	Bailey et al., 2003, McPherson et al., 2003, 2004a, 2005a, 2006a, 2007a
Outer Burrard Inlet	55-75	2002-2005	Ambient for Lions Gate outfall	McPherson et al., 2004b, 2005b, 2006b, 2007b
Northern Strait of Georgia: Johnstone St	30-100	2000-2002	BCMOE Fish farm monitoring	Wright et al., 2007 a-e,
Southeast Vancouver Island	1-25	2000	Background for pipeline landing	Seacology, 2001; Glaholt et al., 2002; Burd and Glaholt, 2000
Strait of Georgia	80-340	2003, 2004, 2006, 2007	Ambient monitoring for Strait of Georgia	Wright et al., 2008, McPherson et al., 2004c

Table 2. List of AMP cores (GVRD 1-7, 9,10) and historical cores, including original published names and coded labels used in Fig 2, year of collection and source for AMP (GVRD 1-7,9,10) and historical cores. Core locations are shown in Fig. 2.

Station	Code (Fig. 2)	Year Collected	Reference
17	Q	1993	Yunker et al., 1999; Johannessen et al., 2005a, b
21	O	1993	Yunker et al., 1999; Johannessen et al., 2005a, b
31	P	1993	Yunker et al., 1999; Johannessen et al., 2005a, b
A	R	1993	Yunker et al., 1999; Johannessen et al., 2005a, b
BB1	J	1990	Macdonald et al., 1992; Johannessen et al., 2005a, b
BC-2	G		Johannessen et al., 2005a, b
CM-3	K	1997	Johannessen et al., 2005a, b
CM-4	F	1997	Johannessen et al., 2005a, b
FD-12	L	1996	Shang et al., 1999; Johannessen et al., 2005a, b
FD-22	M	1996	Shang et al., 1999; Johannessen et al., 2005a, b
FD-3	N	1996	Shang et al., 1999; Johannessen et al., 2005a, b
HS-1	T	1990	Macdonald et al., 1992; Johannessen et al., 2005a, b
IND-VI	V	1994	Boyd et al., 1997; Johannessen et al., 2005a, b
PEI	S	1994	Boyd et al., 1997; Johannessen et al., 2005a, b
PM-V	W	1994	Boyd et al., 1997; Yunker et al., 1999; Johannessen et al., 2005a, b
SC	A	2001	Johannessen et al., 2005a, b
TC-1	U	1990	Macdonald et al., 1992; Johannessen et al., 2005a, b
TI	B	2001	Johannessen et al., 2005a, b
Vec04A-10	D	2004	Picard et al., 2006
Vec04A-11	I	2004	Picard et al., 2006
Vec04a-15	C	2004	Picard et al., 2006
Vec04A-16	E	2004	Picard et al., 2006
Vec04A-17	H	2004	Picard et al., 2006
GVRD-1	GVRD-1	2003	Wright et al., 2008
GVRD-2	GVRD-2	2003	Wright et al., 2008
GVRD-3	GVRD-3	2002	Wright et al., 2008
GVRD-4	GVRD-4	2002	Wright et al., 2008
GVRD-5	GVRD-5	2002	Wright et al., 2008

GVRD-6	GVRD-6	2003	Wright et al., 2008
GVRD-7	GVRD-7	2003	Wright et al., 2008
GVRD-9	GVRD-9	2007	Wright et al., 2008
GVRD-10	GVRD-10	2007	Wright et al., 2008

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Table 3. Summary data for AMP core and grab samples (Wright et al. 2008). Sample locations are shown in Fig. 2. Biotic values are means for three replicate grabs for each location. All mean abundance values are per grab (0.1m²)

	GVRD-1	GVRD-2	GVRD-3	GVRD-4	GVRD-5	GVRD-6	GVRD-7	GVRD-9	GVRD-10
Sediment accumulation rate (g ^a cm ⁻² a)	0.08	0.26	1.34	4.00 ⁺	0.64	2.70	0.32	0.16	0.059
Organic carbon flux (mg C ^a cm ⁻² yr)	3.18	4.68	22.78	40.00	11.50	37.80	3.31	3.44	1.90
Inorganic flux (mg ^a cm ⁻² yr)	74.42	255.32	1317.22	3960.00 ⁺	627.50	2662.20	311.69	156.56	48.19
Organic carbon/inorganic flux	0.043	0.018	0.017	0.010	0.018	0.014	0.011	0.022	0.038
Buried organic carbon flux (mg C ^a cm ⁻² yr)	2.48	1.60	10.72	36.00	9.59	29.16	3.09	2.4	1.5
Oxidized organic carbon flux (mg C ^a cm ⁻² .yr)	0.70	2.18	12.06	3.60	1.92	8.64	0.22	1.4	0.40
Organic carbon flux/ $\delta^{15}\text{N}$	0.48	1.00	10.00	11.20	1.93	6.57	0.59	0.49	0.27
Water depth of sample (m)	169	76	83	84	388	187	233	365	309
%TN*	0.51	0.15	0.12	0.09	0.19	0.16	0.13	0.27	0.43
%Carbonate*	0.03	0.10	0.15	0.19	0.08	0.09	0.09	0.06	0.07
%TOC*	4.07	1.54	1.15	0.91	1.65	1.32	1.01	2.19	3.60
%TOC/%TN*	8.01	10.41	9.53	10.31	8.55	8.26	8.08	8.11	8.37
Acid-volatile sulphides* ($\mu\text{mol/g}$)	2.00	2.00	11.47	0.20	0.10	1.33	0.10	N/A	N/A
$\delta^{15}\text{N}$ *	6.58	4.69	2.28	3.57	5.95	5.76	5.57	7.00	7.10
$\delta^{13}\text{C}$ *	-21.24	-23.85	-24.43	-24.83	-22.54	-21.62	-22.71	-21.34	-20.30
Mean taxa per grab	9.33	45.00	50.80	77.80	36.33	52.67	55.00	20.3	17.00
Mean total abundance	13	231	788	2015	84	640	233	75.3	32.30
Mean biomass (g \cdot 0.1m ⁻²)	1.13	7.30	26.50	46.60	48.20	62.60	22.90	4.03	6.36
Mean number of holothuroids	2.33	0.33	0.50	2.83	7.67	2.50	22.67	3.33	1.67
Mean number of ophiuroids	0.00	0.00	4.44	18.67	1.67	2.33	1.33	0.00	0.00
Mean number of bivalves	0.00	100.67	521.44	1061.89	3.33	127.00	39.67	1.00	3.00
Mean number of gastropods	0.00	22.67	15.28	102.17	0.67	89.00	2.00	0.00	0.33
Mean number of errantiate polychaetes	4.67	19.33	45.83	56.83	14.67	31.67	36.33	7.66	6.00
Mean number of sedentariate polychaetes	3.00	72.00	197.67	638.06	36.00	91.67	104.67	57.00	14.00
Mean number of crustaceans	0.00	8.67	1.83	78.72	3.00	279.00	15.33	1.00	1.30

+ this value is estimated (see results)

*surface sediment core layers – 1-2 cm

Table 4

Table 4. Pearson correlation coefficients between biotic and sediment factors for core/grab data for AMP locations from the Strait of Georgia; %polychaetes is proportion of abundance made up of all polychaetes; %bivalves is proportion of abundance made up of bivalves. All biotic factors are values per grab (=0.1m²). All values were exploratory only, without any hypothesis testing. For reference, values > 0.755 would be considered significant at p=0.05 for testing the null hypothesis that the correlation coefficient was 0 for any given correlation.

	Number of Taxa	Total Faunal Abundance	Biomass (g)	Number of holothuroids	Number of ophiuroids	Number of bivalves	Number of gastropds	Number of errantiate polychaetr	Number of sedentariate polychaetes	Number of crustaceans	% polychaetes	% bivalve
Sedimentation rate (g ^{cm} ⁻² yr)	0.74	0.92	0.85	-0.20	0.86	0.83	0.94	0.78	0.84	0.64	-0.45	0.7
Organic carbon flux (mg C ^{cm} ⁻² yr)	0.71	0.90	0.87	-0.27	0.73	0.75	0.92	0.76	0.72	0.73	-0.58	0.6
Organic/inorganic flux	-0.90	-0.63	-0.66	-0.35	-0.45	-0.47	-0.51	-0.76	-0.54	-0.35	0.51	-0.5
Buried organic carbon flux (mg C ^{cm} ⁻² yr)	0.69	0.86	0.89	-0.19	0.80	0.74	0.94	0.71	0.76	0.72	-0.46	0.5
Oxidized organic carbon flux (mg C ^{cm} ⁻² yr)	0.47	0.63	0.46	-0.38	0.20	0.46	0.45	0.58	0.27	0.46	-0.68	0.5
Water depth of sample (m)	-0.53	-0.66	-0.13	0.29	-0.45	-0.63	-0.50	-0.62	-0.52	-0.18	0.65	-0.7
%TN*	-0.92	-0.67	-0.62	-0.24	-0.46	-0.53	-0.49	-0.80	-0.56	-0.29	0.54	-0.6
%Carbonate*	0.85	0.93	0.60	-0.10	0.85	0.94	0.63	0.92	0.91	0.16	-0.35	0.9
%TOC*	-0.92	-0.66	-0.64	-0.29	-0.45	-0.51	-0.49	-0.79	-0.54	-0.32	0.54	-0.6
%TOC/%TN*	0.58	0.62	0.22	-0.39	0.58	0.70	0.42	0.55	0.64	-0.07	-0.35	0.8
δ ¹⁵ N*	-0.74	-0.80	-0.39	0.16	-0.56	-0.79	-0.40	-0.84	-0.66	-0.03	0.61	-0.9
δ ¹³ C*	-0.79	-0.74	-0.40	0.03	-0.64	-0.77	-0.39	-0.81	-0.72	0.06	0.54	-0.8
Organic carbon flux/δ ¹⁵ N	0.71	0.96	0.69	-0.31	0.78	0.90	0.73	0.86	0.81	0.41	-0.52	0.8
Acid -volatile sulphides (umol/g)	-0.04	0.06	-0.23	-0.40	-0.07	0.21	-0.20	0.26	-0.02	-0.21	-0.36	0.6

* Surface sediment core layers – 1-2 cm