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Fatty acid composition and concentration of alternative food of Semipalmated Sandpipers
(*Calidris pusilla*) in the upper Bay of Fundy, Canada

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13 **ABSTRACT**

14 Semipalmated Sandpipers (*Calidris pusilla* L., 1766) that migrate through the upper Bay of
15 Fundy, Canada, depend on a rich food supply to fuel their continued migration. Although past
16 studies have reported a diet dominated by the amphipod *Corophium volutator* (Pallas, 1766), an
17 animal rich in n-3 polyunsaturated fatty acids (PUFAs), recent evidence suggests that sandpiper
18 diets are broad. This is beneficial in that it allows Semipalmated Sandpipers to respond to a
19 changing food base, but quality of food is also important. PUFAs are important in providing the
20 energy required by migrating birds and may play a role in migratory preparation. We assessed
21 fatty acid concentrations and proportions in three common food items. We found that
22 polychaetes should adequately meet the needs of migrating sandpipers in terms of fatty acid
23 composition. Concentrations of fatty acids in biofilm were low, but proportionally, n-3 PUFAs
24 were well represented, particularly in biofilm collected in Shepody Bay, where it forms a
25 substantial part of the sandpiper diet. Therefore, provided that birds can consume a sufficient
26 volume of biofilm, it is also probably a suitable source of essential fatty acids. Our results
27 suggest that Semipalmated Sandpipers in the Bay of Fundy can meet their fatty acid needs with a
28 variety of dietary options.

29 **Keywords:** Semipalmated Sandpiper, *Calidris pusilla*, diet flexibility, Bay of Fundy, *Corophium*
30 *volutator*, biofilm, fatty acid, PUFA

31 INTRODUCTION

32 Long distance migration is energetically costly, and migratory birds require substantial energy
33 reserves before undertaking these large-scale annual movements. Energy in the form of
34 carbohydrates, protein, and fat are accumulated in different ratios depending on diet composition
35 (Bairlein 1990), and are not all equally used by avian migrants (Jenni and Jenni-Eiermann 1998).
36 Fat is an energy-dense fuel source that provides the majority of energy for migrating birds
37 (Gannes 1991; Lindström 1991; Stevens 1996; McWilliams et al. 2004), and includes important
38 fatty acids used to fuel high endurance migration (McWilliams et al. 2004).

39 Even with the diversity of migratory bird diets, most of the fat stored consists of three
40 fatty acids, palmitic acid (C16:0), oleic acid (C18:1n-9c), and linoleic acid (C18:2n-6c)
41 (McWilliams et al. 2004). These are saturated (SFAs, no double bonds between carbon atoms),
42 monounsaturated (MUFAs, single double bond), and polyunsaturated fatty acids (PUFAs,
43 multiple double bonds) respectively. PUFAs, particularly the short-chained varieties, have been
44 shown to be more easily mobilized than others across a range of taxa, including mammals
45 (Raclot 2003) and both a songbird and shorebird (Price et al. 2008). Both n-3 and n-6 PUFAs are
46 essential fatty acids; there is phylogenetic consistency in the fact that they cannot be efficiently
47 synthesized by vertebrate consumers (Hulbert and Abbott 2011) and must be obtained through
48 dietary sources (Arts et al. 2001). Although limited, existing evidence for birds is consistent with
49 these findings (Iverson et al. 2007; Twining et al. 2016a). Iverson et al. (2007) investigated fatty
50 acids in captive seabirds fed a controlled diet and found little difference in the fatty acid profiles
51 of food and bird tissues, demonstrating little modification of dietary FA profiles by seabirds.
52 Birds with primarily marine diets may have greater access to n-3 PUFAs than birds with
53 terrestrial or fresh-water diets (Hulbert and Abbott 2011; Klaassen et al. 2012; Twining et al.

2016a). According to the adaptive modulation hypothesis (Karasov 1992), pathways for the synthesis of a potentially limiting nutrient, e.g. n-3 PUFA, may be down-regulated in organisms inhabiting environments where nutrient availability is high, e.g. marine ecosystems. This may contribute to dependence on dietary sources of n-3 PUFAs in seabirds. However, reliance on dietary sources of fatty acids in terrestrial birds has also been observed. Twining et al. (2016a) found that Tree Swallow (*Tachycineta bicolor* (Vieillot, 1808)) chicks (like other vertebrates, see Twining et al. 2016b) have a limited ability to elongate and desaturate possible precursor fatty acids to make long carbon-chain PUFA. Dietary sources of these PUFAs were necessary to meet the physiological requirements of chicks. Dietary fatty acids also play an important role in regulating the fatty acid composition of fat tissue used by birds during migration. There is evidence (reviewed in Pierce and McWilliams 2014) that some songbirds select foods that allow them to achieve particular fatty acid profiles, and that during migration n-6 PUFAs increase in fat stores.

Semipalmated Sandpipers (*Calidris pusilla* L., 1766) travel to the upper Bay of Fundy, Canada each year and use the site as an important stopover location before their trans-oceanic migration to South America (Hicklin 1987). *Corophium volutator* (Pallas, 1766), a small burrowing amphipod inhabiting intertidal mudflats in the region, has been considered the dominant prey item for these shorebirds (Hicklin and Smith 1984). *C. volutator* has a high fatty acid content and is a rich source of n-3 PUFAs, specifically EPA (eicosapentaenoic acid, C20:5n3) and DHA (docosahexaenoic acid, C22:6n3), which make up ~45% of their total fatty acid composition (Ackman et al. 1979; Maillet and Weber 2006). Semipalmated Sandpipers make use of n-3 PUFAs as an easily mobilized fuel for migration, and it has been suggested that these fatty acids provide a metabolic signal to prepare flight muscles for endurance (Maillet and

77 Weber 2006, 2007; Nagahuedi et al. 2009; Weber 2009; but see Guglielmo 2010 and Price
78 2010).

79 Although *C. volutator* is undoubtedly a high quality food source, recent evidence
80 suggests that it may not be as important a part of the Semipalmated Sandpiper diet as previously
81 thought. Populations of this amphipod are highly variable among sites (Barbeau et al. 2009;
82 Gerwing et al. 2015) and have declined substantially in some areas (reviewed in Gerwing et al.
83 2016). However, birds continue to feed on mudflats, using alternate prey and alternate foraging
84 behaviours, even when *C. volutator* is rare (MacDonald et al. 2012). Gerwing et al. (2016)
85 concluded that Semipalmated Sandpipers have broad diets and forage opportunistically while in
86 the Bay of Fundy. This is not surprising and has also been documented in other areas of their
87 range (e.g., Skagen and Oman 1996). In the Bay of Fundy, both polychaete worms and biofilm
88 (consisting primarily of diatoms and the extracellular polymeric substances they produce (Trites
89 et al. 2005)) now appear to contribute substantially to the diet (Quinn and Hamilton 2012), and
90 other prey such as ostracods can be important if present in sufficient quantities (MacDonald et al.
91 2012). The inclusion of biofilm is consistent with recent studies of related shorebird species
92 (Kuwae et al. 2008, 2012; Jardine et al. 2015), in which it has been found to be an important
93 dietary component.

94 A broad diet is beneficial to Semipalmated Sandpipers when faced with a variable prey
95 base. However, prey quality is as important as quantity. Although adapting to an available prey
96 base may have short term and seasonal benefits, allowing individuals to exploit whatever food
97 source is present, there may be unknown long-term impacts. If alternate prey are of inferior
98 quality and birds are faced with a “Hobson’s choice” of consuming poor quality prey or going
99 hungry (*sensu* Hebert et al. 2008), the result can be declines in body condition and/or

reproductive endpoints, as has been observed with some gull and passerine species (Hebert et al. 2002, 2008; Blight 2011; Twining et al. 2016a). Insufficient prey quantity or reduced prey quality, combined with other stressors, may have important implications for migratory avian species (Klaassen et al. 2012). Understanding the relative value of available prey is therefore essential to understand the long-term conservation implications of a variable diet in a species traditionally thought to focus on a high quality food source.

We know the inherent value of *C. volutator* in terms of both energy and fatty acid composition (Ackman et al. 1979; Maillet and Weber 2006), and studies in other areas have shown that biofilm and polychaetes all contain some level of n-3 PUFAs (Bühning and Christiansen 2001; Huggins et al. 2004). However, we lack such information about alternative food found in the Bay of Fundy. To address this knowledge gap, we assessed the fatty acid composition of common alternative foods, and compared these values with *C. volutator*. Although other aspects of food quality such as protein and carbohydrate content are also important, we focused on fatty acids because of the documented link between Semipalmated Sandpipers and *C. volutator* (Hicklin and Smith 1979, 1984; Hamilton et al. 2003; Sprague et al. 2008), and the importance of n-3 PUFAS found in this prey item (Maillet and Weber 2006, 2007).

METHODS

Study Sites

We collected prey samples in summer 2010 from three intertidal mudflats in the Upper Bay of Fundy, chosen based on foraging habits of Semipalmated Sandpipers. We worked in Shepody Bay (the western segment of Chignecto Bay), and in the southern bight of Minas Basin. In

Shepody Bay, mudflats sampled were Mary's Point (45.72°N; 64.67°W) and Grande Anse (45.82°N; 64.50°W). In the Minas Basin we sampled at Avonport (45.11°N; 64.24°W) (Figure 1). In these areas, tides rise and fall by up to 15 m (Desplanque and Mossman 2004), exposing large mudflats extending ~ 800 to 2000 m from shore at low tide. These are the mudflats used by Gerwing et al. (2016) in their molecular diet analysis. See Gerwing et al. (2015) for details of site characteristics.

Food Collection

Sediment was collected from the top 5 cm of mud from a minimum of three locations within ~ 300 m of shore on each mudflat. Areas with suitable substrate and evidence of invertebrate activity were targeted to ensure that sufficient organisms were collected for analysis. After collection, sediment samples were sieved through a 250 µm mesh (Crewe et al. 2001). Retained invertebrates were live sorted into broad taxonomic groups with the aid of a dissecting microscope. Information on relative abundance of the different taxa at each site is provided in Gerwing et al. (2015). We collected biofilm by scraping it from the surface in areas in which it was visible (appearing as a thin green or green-brown mat on the surface of the mud) using a thin spatula and stored it in scintillation vials (Quinn and Hamilton 2012). Some sediment was unavoidably collected with the biofilm, but this was minimized as much as possible, and birds are also known to consume considerable sediment while feeding (Reeder 1951) so what was sampled likely resembles what birds would consume.

Fatty Acid Analysis

Invertebrates and biofilm from each sample were frozen (grouped as *C. volutator*, polychaetes, and biofilm) in liquid nitrogen vapor at the time of collection. Polychaetes within each sample were pooled because individuals of the different taxa present (see Gerwing et al. 2015) were not

numerous enough to provide sufficient biomass for separate analyses. Each sample assayed was thus a combination of many individuals, and as such, the result would reflect consumption of multiple individuals by each bird. Samples were transported in a cryoshipper (Taylor-Wharton CX500) to the National Wildlife Research Center in Ottawa, ON, Canada, where they were stored at -80°C until processing and analysis. Fatty acid methyl esters (FAME) were obtained in a three-step process: extraction, derivatization, and quantification on a gas chromatograph (GC). Details regarding these steps can be found in Hebert et al. (2006) and McMeans et al. (2012). Briefly, samples were homogenized and lipids extracted in chloroform-methanol, centrifuged, and dried. Derivatization was done using BF₃-methanol. Resulting FAMES were measured by GC (Hewlett Packard model 6890N with sampler-tray 7683B) equipped with flame-ionization detector and fused silica column (Supelco SP2560, 100m X 0.25mm, 0.2 µm film thickness). Unknown FAMES were identified by comparing retention times to standards. Final FAME concentrations are based on an internal standard (5α-cholestane) and calculated using ChemStation software (Agilent Technologies, Santa Clara, California, USA). Results are reported as µg FAME/mg dry weight tissue and as proportions of total FAME concentrations.

Statistical Analysis

Data were analysed using R 3.1.1 (R Core Team 2014). We assessed parametric statistical assumptions using Shapiro-Wilk normality tests and visual analysis of Q-Q plots, and Levene's test of homogeneity of variance. Multivariate homogeneity of variance was assessed using the Box's M test. Although an arcsine transformation is frequently required for proportion data, most data met assumptions without it, and in the few cases where violations occurred, we corrected them with log transformations. Multivariate analyses of variance (MANOVAs) were used to investigate differences in fatty acid concentrations and proportions among potential food types

and locations. SFAs, MUFAs, and PUFAs were dependent variables, and fixed independent factors were each possible food type and the two arms of the Bay of Fundy: Shepody Bay and Minas Basin. For this analysis, samples from Grande Anse and Mary's Point were combined to represent Shepody Bay because Semipalmated Sandpipers move regularly between the two areas (Sprague et al. 2008; Neima 2017) and therefore their combination best represents what is available to birds in this region of the Bay of Fundy. We further examined PUFAs by running additional MANOVAs using EPA and DHA concentrations and proportions as dependent variables. Multivariate results were evaluated using Pillai's Trace, the most robust of multivariate test statistics available (Tabachnick and Fidell 2007). Significant interactions between food type and arm of the bay were investigated by examining data from each arm of the bay separately. We followed each significant MANOVA with individual univariate ANOVAs. Dunnett's post hoc tests (Hothorn 2008) were used to compare concentrations and proportions of fatty acids in alternative food items to levels observed in *C. volutator*.

RESULTS

Overall fatty acid concentrations varied with food type (MANOVA $F_{[6,44]} = 38.9$; $p < 0.001$), but not location (MANOVA $F_{[3,21]} = 1.0$; $p = 0.41$), and differences among foods were not substantially different between arms of the bay (MANOVA interaction $F_{[6,44]} = 1.7$, $p = 0.15$). All fatty acid groups (SFA, MUFA, PUFA) differed among foods (Table 1). *C. volutator* had significantly higher concentrations of MUFAs than all other potential food items ($p \leq 0.003$), and higher concentrations of SFAs and PUFAs than biofilm ($p < 0.001$; Fig. 2a). However, concentrations of PUFAs and SFAs were similar between *C. volutator* and polychaetes ($p > 0.3$, Fig. 2a). The overall fatty acid composition (proportion of each fatty acid group within each food

type) varied with a combination of bay and food type (MANOVA interaction $F_{[6,44]} = 3.7$, $p=0.004$). In Shepody Bay, the proportions of SFAs, MUFAs, and PUFAs did not differ significantly among food types (MANOVA $F_{[6,24]} = 1.0$, $p=0.47$, Fig. 2b). In Minas Basin, there were differences among foods (MANOVA $F_{[6,18]} = 20.5$, $p<0.001$), and these were present in all categories of fatty acids (Table 1 and Fig. 2b). There were proportionally less SFAs in *C. volutator* than in polychaetes or biofilm ($p\leq 0.002$, Fig. 2b). However, *C. volutator* contained proportionally more MUFAs than did polychaetes ($p=0.003$) and more PUFAs than did biofilm ($p<0.001$, Fig. 2b).

There was an overall multivariate difference among food types in concentrations of the n-3 PUFAs EPA and DHA (MANOVA $F_{[4,46]} = 30.7$; $p \leq 0.001$) but no effect of arm of the bay (MANOVA $F_{[2,22]} = 0.1$; $p = 0.93$). Differences among food types were present for both fatty acids (Table 2). *C. volutator* had significantly higher concentrations of DHA than other food types ($p \leq 0.002$), and higher concentrations of EPA than biofilm ($p \leq 0.001$), but not polychaetes ($p=0.49$, Fig. 3a). Proportions of DHA and EPA (relative to total fatty acid concentration per food item) varied with a combination of bay and food type (MANOVA interaction $F_{[4,46]} = 8.0$, $p<0.001$). In Shepody Bay, food types differed in fatty acid composition (MANOVA $F_{[4,26]} = 3.3$, $p=0.03$). This was driven by EPA (Table 2), with the EPA proportion higher in both polychaetes and biofilm than in *C. volutator* ($p\leq 0.002$, Fig. 3b). Proportion of DHA was similar among food items (Table 2). In Minas Basin, food types also differed in fatty acid composition (MANOVA $F_{[4,20]} = 30.2$, $p<0.001$), but in this case both DHA and EPA contributed to the differences (Table 2). *C. volutator* and polychaetes had higher proportions of EPA than did biofilm ($p<0.001$), but *C. volutator* and polychaetes were similar ($p=0.92$, Figure 3b). DHA was present in higher proportions in *C. volutator* than either biofilm ($p<0.001$) or

215 polychaetes ($p=0.001$, Fig. 3b).

216

217 **DISCUSSION**

218 *Corophium volutator* is a well-recognized prey item for Semipalmated Sandpipers in the upper
219 Bay of Fundy (Hicklin and Smith 1984), and is a rich source of n-3 PUFAs, which may be
220 important to Semipalmated Sandpipers in preparation for migration (Maillet and Weber 2006,
221 2007). *C. volutator* fatty acid levels in our study correspond well with those found in previous
222 work (Ackman et al. 1979; Maillet and Weber 2006), suggesting that these animals are a
223 consistent source of essential fatty acids in the Bay of Fundy. Given recent evidence that
224 Semipalmated Sandpipers in the region consume a broad diet (MacDonald et al. 2012; Quinn and
225 Hamilton 2012; Gerwing et al. 2016), fatty acid concentrations and profiles of alternate food
226 items, relative to *C. volutator*, should be considered.

227 **Quality of alternative foods**

228 **Polychaetes.** Although they have historically been a limited part of the diet of Semipalmated
229 Sandpipers in the Bay of Fundy region (Hicklin and Smith 1979, 1984), recent work suggests
230 that polychaetes now form a large component of the sandpiper diet (Ginn 2009; Quinn and
231 Hamilton 2012; Neima 2017). This is not surprising because relative availability of *C. volutator*
232 and polychaetes has changed over the past several decades. Whereas *C. volutator* used to be the
233 most abundant invertebrate at many feeding sites, it is now less abundant in some areas, and
234 polychaetes have increased (reviewed in Gerwing et al. 2016). Further, given the considerable
235 evidence that these prey are also used at other stopover sites (Michaud and Ferron 1986;
236 Tsipoura and Burger 1999), knowing the quality of polychaetes is particularly important.

237 Our results suggest that a diet rich in polychaetes will provide Semipalmated Sandpipers

foraging in the Bay of Fundy with essential fatty acids needed for migration, making this prey item a suitable alternative to *C. volutator*. Fatty acid concentrations and proportions in polychaetes varied only slightly from *C. volutator*. MUFA concentrations were lower, but the essential n-3 PUFA values were comparable in concentration and in proportion. Specific makeup varied, with polychaetes lower in DHA concentration and proportion than *C. volutator*, but similar or higher in EPA (Fig. 3). EPA and DHA have been suggested to be especially important in preparation for migration, stimulating an increased oxidative capacity of muscles and acting as a natural doping agent for these birds as they rapidly prepare for a long endurance flight (Maillet and Weber 2006; Nagahuedi et al. 2009; Weber 2009; but see Guglielmo 2010 and Price 2010); however, all high PUFA diets are known to increase membrane fluidity and permeability (Ernst 1989).

Biofilm. Semipalmated Sandpipers foraging in the Bay of Fundy are incorporating biofilm into their diet (MacDonald et al. 2012; Quinn and Hamilton 2012; Gerwing et al. 2016). Use of biofilm by these birds is consistent with work on other shorebirds (Mathot et al. 2010; Kuwae et al. 2012). Kuwae et al. (2008) suggested that biofilm made up 45-49% of the diet of Western Sandpipers (*Calidris mauri* (Cabanis, 1857)), and contributed 50% of sandpipers' daily energy requirement. Jardine et al. (2015), using stable isotope analyses of droppings, estimated the biofilm contribution to the diet at 22 to 53%.

The biofilm collected at our study sites appears to offer less than 2% of the concentrations of SFA, MUFA, and PUFA provided by *C. volutator*. This is a surprising result, as diatoms are known to be an important source of fatty acids (Huggins et al. 2004), particularly some longer-chain PUFAs (Ackman et al. 1964; Dunstan et al. 1993), and diatoms make up the majority of microphytobenthos on mudflats in the Bay of Fundy (Trites et al. 2005).

261 Concentration and quality of fatty acids in diatoms varies with season, ultraviolet radiation, light,
262 and species (Dunstan et al. 1993; Huggins et al. 2004; Guihéneuf et al. 2010; Chen 2012), so it is
263 possible that the conditions present on our mudflats are not conducive to high fatty acid
264 concentrations. However, it is far more likely that our sampling method substantially
265 underestimated concentrations of fatty acids in biofilm samples. We scraped biofilm off the mud
266 surface, and although every effort was made to avoid picking up sediment, small amounts of it
267 were incorporated into each sample. Sediment may thus have diluted the fatty acid concentration
268 measured in biofilm. However, shorebirds also take in sediment when foraging; it forms up to
269 75% of stomach contents in some cases (Reeder 1951; Tsipoura and Burger 1999; Kuwae et al.
270 2008; Mathot et al. 2010). Thus, the fatty acid values of biofilm determined here may reflect
271 what is ingested by shorebirds. In this case, birds may need to consume large quantities of
272 biofilm to obtain quantities of fatty acids comparable to what they get from consuming *C.*
273 *volutator*.

274 Kuwae et al. (2008) found that individual Western Sandpipers could consume ~190 g of
275 wet biofilm per day, seven times their body mass. Therefore, high volume consumption is clearly
276 possible. Given this, food quality in terms of relative proportions of fatty acids, and in particular
277 the proportion of n-3 PUFAs, is an important consideration. Overall, biofilm consisted of ~40%
278 SFAs (myristic acid C14:0, pentadecanoic acid C15:0, palmitic acid, stearic acid C18:0), 20%
279 MUFAs (palmitoleic acid C16:1n7, oleic acid) and 40% PUFAs (linoleic acid, alpha-linolenic
280 acid C18:3n3, arachidonic acid C20:4n6, docosapentaenoic acid C22:5n3, EPA, and DHA) (see
281 Appendix Table A1). Although spatially variable, n-3 PUFAs were well represented among fatty
282 acids in biofilm. Within Shepody Bay, this distribution of fatty acids was consistent with *C.*
283 *volutator* (see Fig. 2b). In Minas Basin, biofilm contained proportionally more SFAs and less

PUFAs than did *C. volutator*, perhaps driven by a combination of lower DHA and EPA proportions. Our results suggest that if birds consume enough biofilm, it may be appropriate to meet their dietary needs with respect to fatty acids.

It is notable that during the period when these data were collected, biofilm comprised a substantially higher proportion of the diet of sandpipers foraging in Shepody Bay than in Minas Basin (Quinn and Hamilton 2012). Differences between the arms of the bay in biofilm quality may reflect different species composition or growing conditions (Dunstan et al. 1993; Huggins et al. 2004; Guihéneuf et al. 2010). Although assessment of that is outside the scope of this study, future work should include a more detailed study of local biofilm composition and fatty acid profiles relative to dietary proportions in shorebirds using these areas.

Implications of a Changing Food Base

While we used to view *C. volutator* as a critical resource that was an important basis for habitat selection and foraging activity by Semipalmated Sandpipers (Hicklin and Smith 1979, 1984; Hamilton et al. 2003; Sprague et al. 2008), we now recognize that it was probably just a widely available high quality food source for birds. Sandpipers appear to be opportunistic foragers with diverse diets (MacDonald et al. 2012; Quinn and Hamilton 2012; Gerwing et al. 2016). The change in food habits, particularly the increase in importance of polychaetes, may simply reflect the changing prey base. Consumption of biofilm is probably not a new phenomenon for this species; historical diet studies (Hicklin and Smith 1979, 1984) did not report it, but those studies focused on invertebrate prey. Western Sandpipers are known to graze on biofilm (Kuwaie et al. 2008; Jardine et al. 2015), and Semipalmated Sandpipers engage in similar behaviour, particularly at night (Hebert 2011; Quinn 2011). Recent observations (S.G. Neima personal communication) suggest that Semipalmated Sandpipers possess the same tongue adaptations

307 observed in related species that consume biofilm (described in Elner et al. 2005). Therefore, it
308 seems highly unlikely that these birds have only recently acquired a biofilm foraging habit.
309 However, it is possible that proportions in the diet have shifted as the food base has changed.
310 Regardless, additional work to accurately quantify concentrations of n-3 PUFAs, as well as other
311 energy sources, in biofilm is warranted.

312 Our results suggest that a diet rich in polychaetes, and incorporating biofilm, could
313 provide the necessary fatty acid profile to prepare birds for migration and thus is not a “Hobson’s
314 Choice” for sandpipers- at least not in the context of limiting fatty acid availability. Our findings
315 should not be surprising if Semipalmated Sandpipers select for diets high in specific fatty acids,
316 as seen in other birds (Bairlein and Gwinner 1994; Pierce et al. 2005). Such selection could be
317 assessed by examining fatty acid profiles in a broader range of possible food items. An analysis
318 of energetic content of food would also be informative, as would further investigation into other
319 energy sources such as protein and carbohydrates, as recent evidence suggests some level of
320 protein in diets is important to transport fatty acids to working muscles (Guglielmo 2010). Our
321 findings are encouraging in that it appears that Semipalmated Sandpipers foraging in the Bay of
322 Fundy have the capacity to obtain essential fatty acids from a range of food types, offering them
323 foraging flexibility as they prepare for migration.

324

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REFERENCES

- Ackman, R.G., Nash, D.M., and McLaughlin, J. 1979. Lipids and fatty-acids of *Corophium volutator* from Minas Basin. *Proc. Nova Scotia Inst. Sci.* **29(4)**:501-516.
- Ackman, R.G., Jangaard, P.M., Hoyle, R.J., and Brockerhoff, H. 1964. Origin of marine fatty acids. I. Analyses of the fatty acids produced by the diatom *Skeletonema costatum*. *J. Fish. Res. Board Can.* **21(4)**:747-756. doi: 10.1139/f64-067.
- Arts, M.T., Ackman, R.G., and Holub, B.J. 2001. "Essential fatty acids" in aquatic ecosystems: a crucial link between diet and human health and evolution. *Can. J. Fish. Aquat. Sci.* **58(1)**:122-137. doi: 10.1139/cjfas-58-1-122.
- Bairlein, F. 1990. Nutrition and food selection in migratory birds. *In* Bird migration: physiology and ecophysiology. *Edited by* E. Gwinner. Spring, New York, pp. 198-213.
- Bairlein, F., and Gwinner, E. 1994. Nutritional mechanisms and temporal control of migratory energy accumulation in birds. *Annu. Rev. Nutr.* **14**:187-215. doi: 10.1146/annurev.nu.14.070194.001155.
- Barbeau, M.A., Grecian, L.A., Arnold, E.E., Sheahan, D.C., and Hamilton, D.J. 2009. Spatial and temporal variation in the population dynamics of the intertidal amphipod *Corophium*

- 353 *volutator* in the Upper Bay of Fundy, Canada. J. Crustac. Biol. **29**:491-506. doi:
354 10.1651/08-3067.1.
- 355 Blight, L.K. 2011. Egg production in a coastal seabird, the Glaucous-Winged Gull (*Larus*
356 *glaucescens*), declines during the last century. PLoS One, **6**(7):e22027. doi:
357 doi:10.1371/journal.pone.0022027.
- 358 Bühring, S.I., and Christiansen, B. 2001. Lipids in selected abyssal benthopelagic animals: links
359 to the epipelagic zone? Prog. Oceanogr. **50**(1-4):369-382.
- 360 Chen, Y.C. 2012. The biomass and total lipid content and composition of twelve species of
361 marine diatoms cultured under various environments. Food Chem. **131**(1):211-219.
362 doi:10.1016/j.foodchem.2011.08.062.
- 363 Crewe, T.L., Hamilton, D.J., and Diamond, A.W. 2001. Effects of mesh size on sieved samples
364 of *Corophium volutator*. Estuar. Coast. Shelf Sci. **53**(2):151-154.
365 doi:10.1006/ecss.2001.0795.
- 366 Desplanque, C., and Mossman, D.J. 2004. Tides and their seminal impact on the geology,
367 geography, history, and socio-economics of the Bay of Fundy, eastern Canada. Atl. Geol.
368 **40**:1-130.
- 369 Dunstan, G.A., Volkman, J.K., Barrett, S.M, Leroi, J.M., and Jeffrey, S.W. 1993. Essential
370 polyunsaturated fatty acids from 14 species of diatom (Bacillariophyceae). Phytochemistry,
371 **35**(1):155-161. doi:10.1016/S0031-9422(00)90525-9.
- 372 Elner, R.W., Beninger, P.G., Jackson, D.L, and Potter, T.M. 2005. Evidence of a new feeding
373 mode in western sandpiper (*Calidris mauri*) and dunlin (*Calidris alpina*) based on bill and
374 tongue morphology and ultrastructure. Mar. Biol. **146**(6):1223-1234. doi:10.1007/s00227-
375 004-1521-5.

- 376 Ernst, E. 1989. Effects of n-3 fatty acids on blood rheology. J. Intern. Med. Suppl.
377 **225(S731)**:129-132. doi: 10.1111/j.1365-2796.1989.tb01446.x.
- 378 Gannes, L.Z. 2001. Comparative fuel use of migrating passerines: effects of fat stores, migration
379 distance, and diet. Auk, **118(3)**:665-677. doi: [http://dx.doi.org/10.1642/0004-](http://dx.doi.org/10.1642/0004-8038(2001)118[0665:CFUOMP]2.0.CO;2)
380 8038(2001)118[0665:CFUOMP]2.0.CO;2.
- 381 Gerwing, T.G., Gerwing, A.M.A., Drolet, D., Barbeau, M.A., and Hamilton, D.J. 2015.
382 Spatiotemporal variation in biotic and abiotic features of eight intertidal mudflats in the
383 upper Bay of Fundy, Canada. Northeast. Nat. **22(m12)**:1-44. doi:
384 <http://dx.doi.org/10.1656/045.022.m1201>.
- 385 Gerwing, T.G., Kim, J.H., Hamilton, D.J., Barbeau, M.A., and Addison, J.A. 2016. Diet
386 reconstruction using next-generation sequencing increases the known ecosystem usage by
387 a shorebird. Auk, **133(2)**:168-177. doi: <http://dx.doi.org/10.1642/AUK-15-176.1>.
- 388 Ginn, M.G. 2009. Flexibility in foraging behaviour and use of alternative food sources by
389 semipalmated sandpipers (*Calidris pusilla*) during migratory stopover in the upper Bay of
390 Fundy. M.Sc. thesis, Mount Allison University, Sackville, NB, Canada.
- 391 Guglielmo, C.G. 2010. Move that fatty acid: fuel selection and transport in migratory birds and
392 bats. Integr. Comp. Biol. **50(3)**:336-345. doi: 10.1093/icb/icq097.
- 393 Guihenéuf, F., Fouqueray, M., Mimouni, V., Ulmann, L., Jacquette, B., and Tremblin, G. 2010.
394 Effects of UV stress of the fatty acid and lipid class composition in two marine microalgae
395 *Pavlova lutheri* (Pavlovphyceae) and *Odontella aurita* (Bacillariophyceae). J. Appl.
396 Phycol. **22(5)**:629-638. doi:10.1007/s10811-010-9503-0.

- 397 Hamilton, D.J., Barbeau, M.A., and Diamond, A.W. 2003. Shorebirds, mud snails, and
398 *Corophium volutator* in the upper Bay of Fundy, Canada: predicting bird activity on
399 intertidal mud flats. Can. J. Zool., **18**:1358-1366. doi: 10.1139/Z03-13.
- 400 Hebert, C.E., Shutt, J.L., and Ball, R.O. 2002. Plasma amino acid concentrations as an indicator
401 of protein availability to breeding Herring Gulls (*Larus argentatus*). Auk, **119**(1):185-200.
402 doi: [http://dx.doi.org/10.1642/0004-8038\(2002\)119\[0185:PAACAA\]2.0.CO;2](http://dx.doi.org/10.1642/0004-8038(2002)119[0185:PAACAA]2.0.CO;2).
- 403 Hebert, C.E., Arts, M.T., and Weseloh, D.V. 2006. Ecological tracers can quantify food web
404 structure and change. Environ. Sci. Technol. **40**(18):5618-5623. doi: 10.1021/es0520619.
- 405 Hebert, C.E., Weseloh, D.V.C., Idrissi, A., Arts, M.T., O’Gorman, R., Gorman, O.T., Locke, B.,
406 Madenjian, C.P., and Roseman, E.F. 2008. Restoring piscivorous fish populations in the
407 Laurentian Great Lakes causes seabird dietary change. Ecology, **89**(4):891-897. doi:
408 10.1890/07-1603.1.
- 409 Hebert, M.A. 2011. Diurnal and nocturnal foraging activities of Semipalmated Sandpipers
410 (*Calidris pusilla*) in the upper Bay of Fundy. B.Sc. Hons thesis, Mount Allison University,
411 Sackville, NB, Canada.
- 412 Hicklin, P.W. 1987. The migration of shorebirds in the Bay of Fundy. Wilson Bull. **99**(4):540-
413 570.
- 414 Hicklin, P.W., and Smith, P.C. 1979. The diets of five species of migrant shorebirds in the Bay
415 of Fundy. Proc. Nova Scotia Inst. Sci. **29**(4):483-488.
- 416 Hicklin, P.W., and Smith, P.C. 1984. Selection of foraging sites and invertebrate prey by migrant
417 Semipalmated Sandpipers, *Calidris pusilla* (Pallas), in Minas Basin, Bay of Fundy. Can. J.
418 Zool. **62**(11):2201-2210. doi: 10.1139/z84-321.

- 419 Hothorn, T., Bretz, F., and Westfall, P. 2008. Simultaneous inference in general parametric
420 models. *Biometrical J.* **50(3)**:346-363. doi: 10.1002/bimj.200810425.
- 421 Huggins, K., Frenette, J.J., and Arts, M.T. 2004. Nutritional quality of biofilms with respect to
422 light regime in Lake Saint-Pierre (Québec, Canada). *Freshw. Biol.* **49(7)**:945-959. doi:
423 10.1111/j.1365-2427.2004.01236.x.
- 424 Hulbert, A.J., and Abbott, S.K. 2011. Nutritional ecology of essential fatty acids: an evolutionary
425 perspective. *Aust. J. Zool.* **59(6)**:369-379. doi: <http://dx.doi.org/10.1071/ZO11064>.
- 426 Iverson, S.J., Springer, A.M., and Kitaysky, A.S. 2007. Seabirds as indicators of food web
427 structure and ecosystem variability: qualitative and quantitative diet analyses using fatty
428 acids. *Mar. Ecol. Prog. Ser.* **352**:235-244. doi:10.3354/meps07073.
- 429 Jardine, C.B., Bond, A.L., Davidson, P.J.A., Butler, R.W., and Kuwae, T. 2015. Biofilm
430 consumption and variable diet composition of Western Sandpipers (*Calidris mauri*) during
431 migratory stopover. *PLoS One*, **10(4)**:e0124164. doi:10.1371/journal.pone.0124164
- 432 Jenni, L., and Jenni-Eiermann, S. 1998. Fuel supply and metabolic constraints in migrating birds.
433 *J. Avian Biol.* **29**:521-528.
- 434 Karasov, W.H. 1992. Tests of the adaptive modulation hypothesis for dietary control of intestinal
435 nutrient transport. *Am. J. Physiol. Regul. Integr. Comp. Physiol.* **263(3)**:496-502.
- 436 Klaassen, M., Hoyer, B.J., Nolet, B.A., and Buttemer, W.A. 2012. Ecophysiology of avian
437 migration in the face of current global hazards. *Philos. Trans. R. Soc. Lond. B Biol. Sci.*
438 No. **367**:1719-1732. doi: 10.1098/rstb.2012.0008.
- 439 Kuwae, T., Beninger, P.G., Decottignies, P., Mathot, K.J., Lund, D.R., and Elner R.W. 2008.
440 Biofilm grazing in a higher vertebrate: the Western Sandpiper (*Calidris mauri*). *Ecology*,
441 **89(3)**:599-606. doi: 10.1890/07-1442.1.

- 442 Kuwae, T., Miyoshi, E., Hosokawa, S., Ichimi, K., Hosoya, J., Amano, T., Moriya, T., Kondoh,
443 M., Ydenberg, R.C., and Elner, R.W. 2012. Variable and complex food web structures
444 revealed by exploring missing trophic links between birds and biofilm. *Ecol. Lett.*
445 **15(4)**:347-356. doi: 10.1111/j.1461-0248.2012.01744.x.
- 446 Lindström, Å. 1991. Maximum fat deposition rates in migrating birds. *Ornis Scand.* **22(1)**:12-19.
447 doi: 10.2307/3676616.
- 448 MacDonald, E.C., Ginn, M.G., and Hamilton, D.J. 2012. Variability in foraging behaviour and
449 implications for diet breadth among Semipalmated Sandpipers staging in the upper Bay of
450 Fundy. *Condor*, **114(1)**:135-144. doi: <http://dx.doi.org/10.1525/cond.2012.100246>.
- 451 Maillet, D., and Weber, J.M. 2006. Performance-enhancing role of dietary fatty acids in a long-
452 distant migrant shorebird: the Semipalmated Sandpiper. *J Exp. Biol.* **209**:2686-2695. doi:
453 10.1242/jeb.02299.
- 454 Maillet, D., and Weber, J.M. 2007. Relationship between n-3 PUFA content and energy
455 metabolism in the flight muscles of a migrating shorebird: evidence for natural doping. *J.*
456 *Exp. Biol.* **210**:413-420. doi: 10.1242/jeb.02660.
- 457 Mathot, K.J., Lund, D.R., and Elner, R.W. 2010. Sediment in stomach contents of Western
458 Sandpipers and Dunlin provide evidence of biofilm feeding. *Waterbirds*, **33(3)**:300-306.
459 doi: <http://dx.doi.org/10.1675/063.033.0305>.
- 460 McMeans, B.C., Arts, M.T., Rush, S.A., and Fisk, A.T. 2012. Seasonal patterns in fatty acids and
461 stable isotopes of *Calanus hyperboreus* (Copepoda, Calanoida) from Cumberland Sound,
462 Baffin Island. *Mar. Biol.* **159(5)**:1095-1105. doi: 10.1007/s00227-012-1889-6.

- 463 McWilliams, S.R., Guglielmo, C., Pierce, B., and Klassen, M. 2004. Flying, fasting, and feeding
464 in birds during migration: a nutritional and physiological ecology perspective. *J. Avian*
465 *Biol.* **35(5)**:377-393. doi: 10.1111/j.0908-8857.2004.03378.x.
- 466 Michaud, G., and Ferron, J. 1986. Etude comparative des techniques de quete alimentaire de
467 quatre especes d'oiseaux limicoles. *Nat. Can. (Qué)* **113**:281-292.
- 468 Nagahuedi, S., Popesku, J.T., Trudeau, V.L., and Weber, J.M. 2009. Mimicking the natural
469 doping of migrant sandpipers in sedentary quails: effects of dietary n-3 fatty acids on
470 muscle membranes and PPAR expression. *J. Exp. Biol.* **212**:1106-1114. doi:
471 10.1242/jeb.027888.
- 472 Neima, S.G. 2017. Stopover ecology of Semipalmated Sandpipers (*Calidris pusilla*) during fall
473 migration through the upper Bay of Fundy, Canada. M.Sc. thesis, Mount Allison
474 University, Sackville, NB, Canada.
- 475 Pierce, B.J., McWilliams, S.R., O'Connor, T.P., Place, A.R., and Guglielmo, C.G. 2005. Effect
476 of dietary fatty acid composition on depot fat and exercise performance in a migrating
477 songbird, the Red-Eyed Vireo. *J. Exp. Biol.* **208**:1277-1285. doi: 10.1242/jeb.01493.
- 478 Pierce, B.J., and McWilliams, S.R. 2014. The fat of the matter: how dietary fatty acids can affect
479 exercise performance. *Integr. Comp. Biol.* **54(5)**:903-912. doi:10.1093/icb/icu098.
- 480 Price, E.R., Krokfors, A., and Guglielmo, C.G. 2008. Selective mobilization of fatty acids from
481 adipose tissue in migratory birds. *J. Exp. Biol.* **211**:29-24.
- 482 Price, E.R. 2010. Dietary lipid composition and avian migratory flight performance:
483 development of a theoretical framework for avian fat storage. *Comp. Biochem. Physiol. A*
484 *Mol. Integr Physiol.* **157(4)**:297-309. doi: <http://dx.doi.org/10.1016/j.cbpa.2010.05.019>.

- 485 Quinn, J.T. 2011. Dietary flexibility and diurnal and nocturnal foraging behaviour of
486 Semipalmated Sandpipers (*Calidris pusilla*) in the upper Bay of Fundy, Canada: Links to
487 prey availability and quality. M.Sc. thesis, Mount Allison University, Sackville, NB,
488 Canada.
- 489 Quinn, J.T., and Hamilton, D.J. 2012. Variation in diet of Semipalmated Sandpipers (*Calidris*
490 *pusilla*) during stopover in the upper Bay of Fundy, Canada. *Can. J. Zool.* **90(9)**:1181-
491 1190. doi:10.1139/Z2012-086.
- 492 R Core Team 2014. R: A language and environment for statistical computing. R Foundation for
493 Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.
- 494 Raclot, T. 2003. Selective mobilization of fatty acids from adipose tissue triacylglycerols. *Prog.*
495 *Lipid Res.* **42**:257-288.
- 496 Reeder, W.G. 1951. Stomach analysis of a group of shorebirds. *The Condor*, **53(1)**:43-45. DOI:
497 10.2307/1364586.
- 498 Skagen, S.K. and Oman, H.D. 1996. Dietary flexibility of shorebirds in the western hemisphere.
499 *Can. Field-Nat.* **110(4)**:419-444.
- 500 Sprague, A. J., Hamilton, D.J., and Diamond, A.W. 2008. Site safety and food affect movements
501 of Semipalmated Sandpipers (*Calidris pusilla*) migrating through the upper Bay of Fundy.
502 *Avian Conserv. Ecol.* **3**:4. Available from <http://www.ace-eco.org/vol3/iss2/art4/> [accessed
503 15 December 2008].
- 504 Stevens, L. 1996. *Avian Biochemistry and Molecular Biology*. Cambridge University Press,
505 Cambridge.
- 506 Tabachnick, B.G., and Fidell, L.S. 2007. *Using multivariate statistics*, 5th edition. Pearson
507 Education, Boston, Massachusetts.

- 508 Trites, M., Kaczmarska, I., Ehrman, J.M., Hicklin, P.W., and Ollerhead, J. 2005. Diatoms from
509 two macro-tidal mudflats in Chignecto Bay, Upper Bay of Fundy, New Brunswick,
510 Canada. *Hydrobiologia*, **544**:299. doi:10.1007/s10750-005-1696-x.
- 511 Tsipoura, N., and Burger, J. 1999. Shorebird diet during spring migration stopover on Delaware
512 Bay. *Condor*, **101(3)**:635-644. doi: 10.2307/1370193.
- 513 Twining, C.W., Brenna, J.T., Lawrence, P., Shipley, J.R., Tollefson, T.N., and Winkler, D.W.
514 2016a. Omega-3 long-chain polyunsaturated fatty acids support aerial insectivore
515 performance more than food quantity. *Proc. Natl. Acad. Sci. U.S.A.* **113(39)**:10920-10925.
516 doi:10.1073/pnas.1603998113.
- 517 Twining, C.W., Brenna, J.T., Hairston, N.G., and Flecker, A.S. 2016b. Highly unsaturated fatty
518 acids in nature: what we know and what we need to learn. *Oikos*, **125**:749-760.
519 doi:10.1111/oik.02910.
- 520 Weber, J-M. 2009. The physiology of long-distance migration: extending the limits of endurance
521 metabolism. *J. Exp. Biol.* **212**:593-597. doi: 10.1242/jeb.015024.
- 522
- 523

Table 1. Results of univariate ANOVAs conducted following significant MANOVA results (reported in the text) for analyses of concentrations and proportions of SFAs, MUFAs, and PUFAs in food items collected in Shepody Bay and Minas Basin. For proportions, a significant multivariate interaction required separate analyses for the two areas. There were no significant multivariate effects in Shepody Bay (see text), so univariate analyses are not reported. For significant main effects, post hoc comparisons among food types are presented in the text.

Measure	Fatty acid group	Factor	df	<i>F</i>	<i>P</i>
concentration	SFA	location	1,23	0.7	0.43
		food type	2,23	269.6	<0.001
		location*food type	2,23	1.5	0.25
	MUFA	location	1,23	0.7	0.42
		food type	2,23	137.6	<0.001
		location* food type	2,23	0.6	0.55
	PUFA	location	1,23	0.1	0.82
		food type	2,23	301.9	<0.001
		location* food type	2,23	0.2	0.84
proportion	SFA – Minas Basin	food type	2,10	49.6	<0.001
	MUFA – Minas Basin	food type	2,10	24.5	<0.001
	PUFA – Minas Basin	food type	2,10	66.7	<0.001

Table 2. Results of univariate ANOVAs conducted following significant MANOVA results (reported in the text) for analyses of concentrations and proportions of the n-3 PUFAs EPA and DHA in food items collected in Shepody Bay and Minas Basin. For proportions, a significant multivariate interaction required separate analyses for the two areas. For significant main effects, post hoc comparisons among food types are presented in the text.

measure	Fatty acid group	factor	df	<i>F</i>	<i>P</i>
concentration	EPA	location	1,23	0.1	0.70
		food type	2,23	478.0	<0.0001
		location*food type	2,23	0.1	0.95
	DHA	location	1,23	<0.1	0.90
		food type	2,23	474.5	<0.0001
		location* food type	2,23	0.1	0.87
proportion	EPA – Shepody Bay	food type	2,13	11.9	0.001
	DHA – Shepody Bay	food type	2,13	1.6	0.23
proportion	EPA – Minas Basin	food type	2,10	60.2	<0.0001
	DHA – Minas Basin	food type	2,10	35.5	0.0001

FIGURE CAPTIONS

Figure 1. Locations of sampled mudflats within the upper Bay of Fundy, New Brunswick and Nova Scotia, Canada. See also Figure 1 in Gerwing et al. (2016).

Figure 2. **a)** Concentration ($\mu\text{g FAME/mg dry weight}$) and **b)** proportions (relative to total FA composition) of saturated (SFA), monounsaturated (MUFA), and polyunsaturated fatty acids (PUFA) for each food type from Shepody Bay and Minas Basin. $n=3-8$ (see Appendix Table A1). Within each boxplot, the horizontal line represents the median, margins of the box the interquartile range (IQR), and whiskers all points that are within $1.5 * \text{IQR}$ of the hinge. Points beyond that range are plotted individually. Results of statistical comparisons are presented in Table 1 and in the text.

Figure 3. **a)** Concentration ($\mu\text{g FAME/mg dry weight}$) and **b)** proportions (relative to total FA composition) of DHA and EPA for each food type from Shepody Bay and Minas Basin. $n=3-8$ (see Appendix Table A1). Within each boxplot, the horizontal line represents the median, margins of the box the interquartile range (IQR), and whiskers all points that are within $1.5 * \text{IQR}$ of the hinge. Points beyond that range are plotted individually. Results of statistical comparisons are presented in Table 2 and in the text.

555 APPENDICES

556

557 Table A1: Fatty acid composition of three available food options for Semipalmated Sandpipers (*Calidris*
 558 *pusilla* L., 1766) averaged over each arm of the Bay of Fundy. Results are reported as $\mu\text{g FAME/mg}$
 559 dry weight tissue $\pm$ SD. When a particular fatty acid was not detected in any samples, a value of
 560 0 is entered. Sample size indicates the number of samples processed separately for each food
 561 type. Each sample consisted of a combination of multiple individual organisms (continued on
 562 next page).

	Minas Basin			Shepody Bay		
	<i>C.volutator</i> (n=3)	Polychaetes (n=4)	Biofilm (n=3)	<i>C.volutator</i> (n=5)	Polychaetes (n=8)	Biofilm (n=6)
Saturated fatty acids						
C13:0	0	0	0.003 $\pm$ 0.01	0.02 $\pm$ 0.05	0	0
C14:0	0.53 $\pm$ 0.24	0.86 $\pm$ 0.58	0.05 $\pm$ 0.01	0.88 $\pm$ 0.44	0.42 $\pm$ 0.38	0.04 $\pm$ 0.01
C15:0	0.16 $\pm$ 0.06	0.47 $\pm$ 0.32	0.03 $\pm$ 0.01	1.44 $\pm$ 1.80	0.74 $\pm$ 0.43	0.02 $\pm$ 0.01
C16:0	5.99 $\pm$ 1.60	3.49 $\pm$ 2.19	0.14 $\pm$ 0.04	7.28 $\pm$ 2.47	3.72 $\pm$ 1.24	0.10 $\pm$ 0.04
C17:0	0.17 $\pm$ 0.04	0.58 $\pm$ 0.15	0	0.58 $\pm$ 0.33	1.09 $\pm$ 0.56	0
C18:0	0.99 $\pm$ 0.15	2.20 $\pm$ 0.70	0.02 $\pm$ 0.01	1.18 $\pm$ 0.35	2.30 $\pm$ 0.77	0.02 $\pm$ 0.01
C20:0	0	0	0	0.05 $\pm$ 0.05	0	0
C21:0	0	0	0	0.01 $\pm$ 0.02	0	0
C22:0	0	0	0	0.07 $\pm$ 0.06	0	0
C23:0	0	0	0	0.01 $\pm$ 0.01	0	0
C24:0	0	0	0	0.01 $\pm$ 0.02	0	0
Σ SFAs	7.83 $\pm$ 2.03	7.60 $\pm$ 2.20	0.24 $\pm$ 0.07	11.53 $\pm$ 3.66	8.27 $\pm$ 2.20	0.18 $\pm$ 0.08
Monounsaturated fatty acids						
C15:1n5c	0	0.29 $\pm$ 0.19	0	0	0.02 $\pm$ 0.05	0
C16:1n7	2.46 $\pm$ 1.16	0.99 $\pm$ 0.22	0.12 $\pm$ 0.02	3.62 $\pm$ 1.77	0.83 $\pm$ 0.32	0.07 $\pm$ 0.02
C18:1n9t	0	0.49 $\pm$ 0.73	0	0	1.05 $\pm$ 0.65	0

C18:1n9c	2.29±0.28	0.53±0.48	0.01±0.01	2.57±0.63	0.68±0.33	0.02±0.01
C20:1n9c	0.42±0.04	0.06±0.12	0	0.51±0.15	0.37±0.27	0
C22:1n9	0	0	0	0.08±0.07	0	0
C24:1n9	0	0	0	0.01±0.01	0	0
ΣMUFAs	5.18±1.38	2.36±1.19	0.13±0.03	6.77±2.52	2.95±1.10	0.09±0.02
Polyunsaturated fatty acids						
C18:2n6c	0.61±0.20	0.23±0.15	0.01±0.002	0.83±0.44	0.16±0.16	0.02±0.002
C18:3n6	0.04±0.07	0	0	0.18±0.08	0	0
C18:3n3	0.12±0.06	0.38±0.26	0.02±0.01	0.12±0.06	0.55±0.35	0.01±0.01
C20:2n6c	0.14±0.03	0.05±0.10	0	0.15±0.04	0.18±0.16	0
C20:3n6	0	0	0	0.06±0.06	0.01±0.02	0.01±0.01
C20:3n3	0	0	0	0.07±0.06	0.05±0.09	0
C20:4n6	1.44±0.27	1.38±0.12	0.02±0.004	1.71±0.34	0.97±0.29	0.01±0.01
C20:5n3 (EPA)	8.63±2.40	6.75±2.64	0.11±0.02	10.53±4.66	8.00±2.65	0.11±0.03
C22:5n3	0.26±0.06	1.37±0.65	0	0.35±0.07	1.47±0.57	0
C22:6n3 (DHA)	3.84±0.60	1.26±0.51	0.02±0.003	3.92±0.82	1.49±0.67	0.02±0.01
ΣPUFAs	15.09±3.48	11.42±3.40	0.19±0.03	17.91±6.34	12.87±4.21	0.18±0.06

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564

Bay