DIFFERENCES IN USE OF NORTHUMBERLAND STRAIT HABITAT AND FATTENING RATES AMONG MIGRATORY SHOREBIRD SPECIES

BY

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Abstract

Migratory shorebirds rely on stopover sites to rebuild fat stores during migration. The habitat used within each stopover site, and the strategies used to build fat, can vary between species and stopover. In the Canadian Maritimes, the Bay of Fundy has been the focus of migratory shorebird research given the large population of shorebirds it supports. Though less used, other sites on the New Brunswick and Nova Scotia coast, including the Northumberland Strait, also host a diverse shorebird assemblage. A variety of shorebird species use the mudflats, sandflats, and saltmarshes along the Northumberland Strait coast during their fall migration. It is unknown whether species in this region are using the available habitat on a mudflat-by-mudflat basis in this region, and how much fat they are building. We predicted that due to the different pressures associated with long- and short-distance migrations, short-distance migrant species will adhere to a slowly fattening, short stay, many movement strategy, while long-distance migrant species will build fat quickly over a longer period of time with few movements. We investigated duration of stay, habitat use and plasma metabolites of Least Sandpipers (*Calidris minutilla* Vieillot), Semipalmated Sandpipers (*Calidris pusilla* L.), White-rumped Sandpipers (*Calidris fuscicollis* Vieillot), and Semipalmated Plovers (*Charadrius semipalmatus* Bonaparte) to characterize their use of the Northumberland Strait, and to compare said use between species. Usage of habitat and length of stay were determined through radio telemetry, and plasma metabolites were investigated by measuring plasma triglyceride and *B*-hydroxybutyrate concentrations. Least Sandpipers had the lowest plasma triglyceride and highest *B*-hydroxybutyrate concentrations suggesting that they were fattening the slowest. Semipalmated Sandpipers and Semipalmated Plovers both had high triglyceride and low *B*-hydroxybutyrate, while White-rumped Sandpipers occupied an intermediate position with low triglyceride and *B*-hydroxybutyrate. All sandpiper species in this study had similar mean minimum stopover durations, between 14-19 days, while the plovers stay for up to a week longer. The species also exhibited differences in the habitat they used. Semipalmated Sandpipers ranged more widely than did the other species, though there was a universal preference for habitat nearest to our catching site. These findings provide evidence that shorebirds using the Northumberland Strait are not adhering to the predictions associated with expected stopover behaviour in short- and long-distance migrants. Instead, each species is using unique and variable strategies to build fat stores during their stopover. We also highlight the need for continued research of multiple species stopover strategies and the use of the Northumberland Strait as migratory shorebird habitat as limited movements between sites suggest region wide protection may be needed to conserve shorebirds.

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Chapter 1: Introduction

Migration and Stopover Sites

Many animals move seasonally between a breeding ground and a wintering ground. This migration provides animals with the opportunity to exploit seasonal resources at the cost of energy expenditures and risks associated with relocation (Myers 1983). Many shorebird species perform yearly migrations between the low predator and resource abundant nesting sites in the Arctic, and warm wintering grounds in South America or the Caribbean (Myers et al. 1987). Migration on this magnitude is very energy intensive (O'Reilly & Wingfield 1995) and many birds do not complete their entire migration in a single flight. Instead, shorebirds fly between multiple stopover sites over the course of their migration (Warnock 2010). These stopover sites are habitat used by shorebirds to rebuild their fuel stores and roost (Schaub & Jenni 2000). High-quality habitat, with low predation pressures and predictable food abundances is limited across shorebirds' migratory ranges (Myers et al. 1987; Fiala 2009). Therefore, identifying, protecting, and monitoring the high-quality stopover sites used by shorebirds is critical in the conservation of these migratory birds.

The Maritime Provinces of Canada host a high number of mudflats, sandflats, and salt marshes that act as stopover sites for migratory shorebirds. The shorebirds using the Maritimes are a wide variety of species, with some specifically originating from eastern breeding populations of the Arctic (Brown et al. 2017). The Bay of Fundy, located between Southern Nova Scotia and New Brunswick, is designated as a landscape of hemispheric importance by the Western Hemisphere Shorebird Reserve Network (McKellar et al. 2020). Overall, the shorebird population in the Bay of Fundy consists of approximately 95% Semipalmated Sandpipers (*Calidris pusilla* L.) and a much smaller suite of other species (Hicklin 1987). Conversely, the Northumberland Strait, located just north of the Bay supports a much wider diversity of species (ACSS 2017). Recent investigations into the differences between the two regions concluded that environmental heterogeneity along the Northumberland Strait allows for the niche partition among species that is absent in the Bay of Fundy (Bellefontaine 2020). Additionally, populations of Semipalmated Sandpipers and White-rumped Sandpipers (*Calidris fuscicollis* Vieillot) that solely utilize coastal habitat outside of the Bay of Fundy have been identified (Arenseault 2020; R. Linhart, unpublished data). However, the differences in use of heterogeneous habitat along the

Northumberland Strait and stopover strategies of migratory shorebirds have yet to be investigated for other species. Intraspecific local habitat use of shorebirds is highly specific to the population in question. Nearby populations of Semipalmated Sandpipers in the Maritimes and along the Gulf of Maine have been found to exhibit discrete use of habitat during their stopover (Holberton et al. 2019; Neima et al. 2020; R. Linhart, unpublished data). An investigation into the intraspecific local habitat use of other shorebirds species has yet be conducted. Additionally, exploration of local scale movements by the various species along the Northumberland Strait would be a novel endeavor.

Study Species

The Northumberland Strait provides habitat to a diversity of shorebirds species. Least Sandpipers (*Calidris minutilla* Vieillot), Semipalmated Sandpipers, White-rumped Sandpipers, and Semipalmated Plovers (*Charadrius semipalmatus* Bonaparte) are common species found throughout this region (Atlantic Canada Shorebird Survey 2017).

Semipalmated Sandpipers are an opportunistic, small species that breeds throughout the North American Arctic (Skagen 1997; Gratto-Trevor et al. 2012). From their Arctic breeding grounds, they fly between 5 000 and 7 000 km to winter along the northern South American coast (Anderson et al. 2019). Over 30% of Semipalmated Sandpipers eastern biogeographical population stops at the Bay of Fundy to build fat stores (Hicklin 1987; McKellar et al. 2020). The median passage date for these birds in the upper Bay of Fundy is around August 9-10 (Bliss et al. 2019). Semipalmated Sandpipers are known to perform non-stop transoceanic flights from the Maritimes to their wintering grounds (Hicklin and Gratto-Trevor 2010). They are considered near threatened on the IUCN Red List of Threatened Species with decreasing population trends (BirdLife International 2016a).

White-rumped Sandpipers are some of the longest distance shorebird migrants, with their total distance flown estimated between 9 000-11 500 km to their wintering grounds (Anderson et al. 2019). These sandpipers breed in the central high Arctic and on the various Arctic Islands (Parmelee et al. 1968; Morrison 1984). It is thought that these birds use stopover sites along the Atlantic coast to build fat before performing a non-stop transoceanic flight to the north South American coast (Harrignton et al. 1991). Once in South America, White-rumped Sandpipers continue their southbound migration along the coast until they reach wintering grounds in

Argentina (Harrison et al. 1991; Anderson et al. 2019). White-rumped Sandpipers are categorized as a species of least concern by the IUCN, decreases in these sandpipers' population have been noted (BirdLife International 2017).

Least Sandpipers are the smallest *Calidris* species (Nebel and Cooper. 2008). They mostly breed in the sub-Arctic, with some breeding populations extending south to Sable Island, Nova Scotia (Miller 1983a, Miller 1983b). On average, adult Least Sandpipers migrate between July 6 and August 15, flying 5 000 km to northern South America and the Caribbean (Morrison et al. 1994; Anderson et al. 2019). Least Sandpipers are not known to perform transoceanic migration, and instead use stopover sites in the south eastern United States (Lehnen & Krementz 2007). The IUCN considers Least Sandpipers populations to be of least concern, but they are in decline (BirdLife International 2016b).

The breeding range of Semipalmated Plovers extends from the Canadian Arctic into the sub-Arctic (Baker & Baker 1973). Using multiple stopover sites during their migration, these plovers fly to their wintering ground 5 000 km away along the North American coast, or overland (Nol & Blanken 2014, Anderson et al. 2019). They then spend the winter along a large swath of coast, extending from South Carolina to northeastern Brazil (Rose & Nol 2010). Semipalmated Plovers have stable populations, and of listed as a species of least concern (BirdLife International 2016c).

Fattening Rate and Plasma Metabolites

To meet the high energy demands of prolonged flight, shorebirds accumulate large deposits of energy-rich adipose tissue (Schaub & Jenni 2000). This fat can be transported by the circulatory system to muscles. Here, the fat is catabolized into fatty acids, which are used by muscle cells for energy (Robinson & Williamson 1980; McWilliams et al. 2004). Fats have been found to store up to ten times more energy per unit of wet mass than other fuel types like proteins (McWilliams et al. 2004). This makes fat the ideal fuel source for migratory birds during prolonged flight, as they can build rich energy-stores without compromising their ability to fly due to weight.

The amount of fat a bird builds before departure from a stopover site is dependent on the distance to the next destination, as longer flights require more energy (Anderson et al. 2019). It has also been found in Red Knots (*Calidris canutus*) that the more fat a bird builds, the higher the likelihood that bird will survive migration (Duijns et al. 2017). Fat stores may also affect the departure time of shorebirds from a stopover site in that they cannot leave before they have accumulated sufficient reserves, though most findings suggest that other environmental factors like wind conditions determine exact departure timing (Åkesson & Hedenström 2000; Neima 2017; Anderson et al. 2019). Some birds remaining at a stopover site for up to 2 to 3 weeks after they have accumulated sufficient fat (Dunn et al. 1988).

The fattening rate of a bird can be inferred by the concentrations of lipid storing and mobilizing metabolites found in their plasma (McWilliams et al. 2004). In fat accumulating settings, diet-derived fatty acids saturate free glycerol to be transported to and stored in adipose tissues. Therefore, a strong positive correlation between plasma triglyceride concentrations and fattening rate has been found in shorebirds (Seaman et al. 2005; Cerasale & Guglielmo 2006; Covino & Holberton 2011). Likewise, a correlation between the ketone body *B*-hydroxybutyrate and mobilization of fats to muscles has been found (Cerasale & Guglielmo 2006). Therefore, high concentrations of *B*-hydroxybutyrate in the blood is indicative of birds that are fasting and also breaking down their fat stores for energy (Jenni-Eiermann et al. 2002; Yoshida 2016). Using these two metabolites, we inferred the fattening rate among migratory shorebird species.

Study Objectives and Relevance

Overall shorebird populations have declined between 37-40% since 1970 (Rosenberg et al. 2019; Environment and Climate Change Canada 2019). Long-distance migratory shorebirds have been estimated to have declined by an additional 12% in the same time (Environment and Climate Change Canada 2019. Although some species that have had increases in their population reported over time, Andres et al. (2012) found that 98% of these cases were the discovery of new populations and not an increase of the previously known population. Declines in shorebird population are thought to stem from wintering grounds (Newton 2004). Even so, for the conservation of declining shorebirds, protection across their entire range is needed. Specifically, critical stopover sites that provide high quality habitat to shorebirds should be identified and protected from extensive perturbation by humans.

To meet this objective, we investigated habitat use among the diverse species of migratory shorebirds along the Northumberland Strait. We determined the use of Northumberland Strait habitat by various species and related this to their inferred fattening rate with the aim of determining whether shorebird species that have different migration strategies are utilizing habitat along the Northumberland Strait differently. We hypothesize that species will use habitat along the Northumberland Strait differently according to the different energetic requirements of long- and short-migrants. Therefore, we predict White-rumped Sandpipers will have a high fattening rate (high plasma triglyceride, low *B*-hydroxybutyrate), long length of stay, and little movement between sites. Semipalmated Sandpipers are also long-distance migrants and therefore should show similar characteristics. For the short-distance migrants, Semipalmated Plovers and Least Sandpipers, we predict that they will have lower fattening rates (low plasma triglyceride, high *B*-hydroxybutyrate), stay for fewer days, and more move between sites.

Chapter 2: Methods

Catching and Sampling Captured Shorebirds

From July 27 to September 6, 2020, we captured Semipalmated Sandpipers (SESA), Semipalmated Plovers (SEPL), Least Sandpipers (LESA), and White-rumped Sandpipers (WRSA) at Petit-Cap (46.19°N, -64.50°W), a barrier beach situated along the Northumberland Strait coast (Figure 2.1; Table 2.1). To capture birds, we opened an array of 18 m mist nets between 19:30 and 00:45 on either the interior or exterior intertidal flats of the barrier beach on days when weather and tides were conducive to bird capture. Birds caught in the mist nets were manually extracted and processed immediately. If too many birds were caught at a single time for immediate processing, we placed the excess birds in an enclosed pen for later processing. All birds were processed and released within 2-3 hrs.

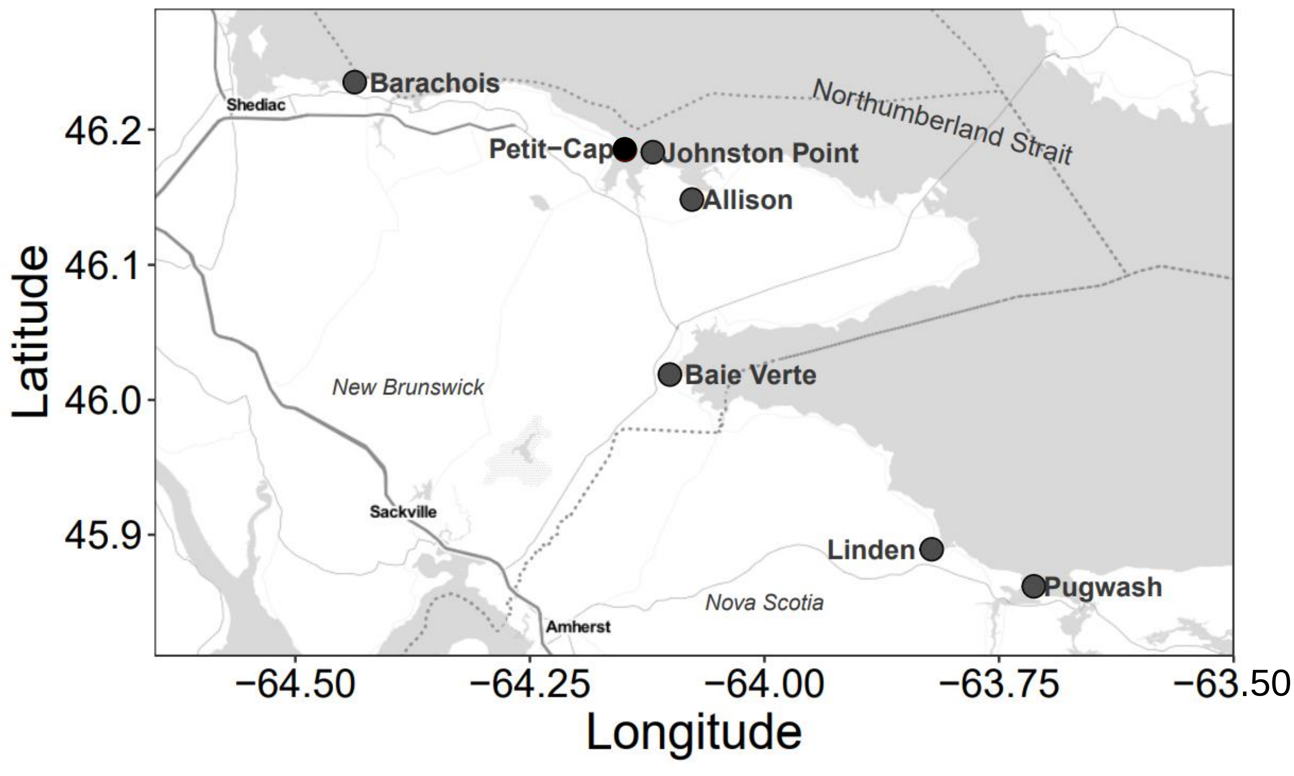

Figure 2.1. Location of capture (black) and habitat use study sites (grey) along the Northumberland Strait coast. Coordinates for sites in Table 2.1.

Table 2.1. Coordinates of capture (Petit-Cap) and habitat use study sites along the Northumberland Strait.

Site	Latitude	Longitude
Barachois	46°14 N	64°26 W
Johnston Point	46°11 N	64°7 W
Allison	46°9 N	64°5 W
Baie Verte	46°1 N	64°6 W
Linden	45°53 N	63°49 W
Pugwash	45°52 N	63°43 W
Petit-Cap	46°11 N	64°9 W

We began processing birds by collecting a weight measurement. If their weight met or exceeded the minimum bleed weight for that species (Table 2.2), we pricked their branchial vein with a 27.5-gauge needle and collected up to 140μL of blood in two 70 μL capillary tubes, which was then transferred to a 0.2 mL Eppendorf tube and put on ice until later processing. We noted both the time at which bird were captured and when blood samples were collected, that way the effects of handling stress on plasma metabolites can be taken into consideration. All blood samples used for plasma metabolite analyses were collected within 20 min of capture to minimize stress effects (Guglielmo et al. 2002). Birds from which we collected blood samples also had a drop of their blood placed onto a Whatman FTA card for future PCR analysis of sex. Once blood samples were collected, we applied gentle pressure to the puncture site until bleeding stopped. Upon returning from the field, we separated the red blood cells and plasma by centrifuging the blood at 10 000 rpm for 1 minute in a mySPIN12 Mini Centrifuge (Thermo Scientific). We then pipetted the plasma into a new 0.2 mL Eppendorf tube. Both red blood cell and plasma samples were stored at -20°C until further analysis.

Table 2.2. Required minimum weight of birds for safe collection of blood samples and band sizes.

Species	Minimum Bleed Weight (g)	Band size
Least Sandpiper	19	1
Semipalmated Sandpiper	22	1B
White-rumped Sandpiper	35	1A
Semipalmated Plover	35	1A

We outfitted the upper left leg of each bird with an identifying stainless steel (SESA, SEPL, and WRSA) or aluminum (LESA) USGS band, the size of which depends on the species (Table 2.1). Additionally, a white 3-digit alphanumeric plastic flag that is readable in the field was fitted to the upper right leg of each bird. For each bird we also measure their flattened straightened wing chord with a ruler, as well as their bill and tarsus length with calipers. We determined and noted the age of each bird according to plumage and feather quality as either hatch year (HY), second year (SY), or after second year (ASY).

We attached a 0.65 g radiotracking tag (Lotek Wireless Inc., NTQB2-3-2) with cyanoacrylate glue (following Sprague et al. 2008) to a subset of birds from each species. Most tagged birds had low weights for their species to ensure that they were recent arrivals and would remain in the region for a period of time, facilitating tracking. Feathers on a small area just above the uropygial gland were clipped with scissors to facilitate attachment. These tags detach from the birds and are lost over the course of their next molt.

Bird Tracking

In total, we deployed 119 radiotracking tags on four species and two age classes (Figure 2.3). Each of these tags emits a signal in bursts every 10.1 seconds at 166.38 MHz. Encoded in this transmission is a unique identifier for each tag. On average, these tags have a battery life of 124 days which ensures that the tag will be active over the course of their migration.

Table 2.3. Number of NanoTags deploy per species and age along the Northumberland Strat.

	Adult	Juvenile
Least Sandpiper	0	18
Semipalmated Sandpiper	20	20
White-rumped Sandpiper	30	0
Semipalmated Plover	6	24

Transmissions from these tags are detected by an array of Motus radio tracking towers and each detection is recorded in an associated receiver. These receivers make up the Motus Wildlife Tracking System (motus.org), which is a network of towers bearing 9-element Yagi-Uda antennas wired to a GPS and a basic computer called a sensorgnome. Data collected by these towers belong to a large number of projects working in collaboration. Therefore, the detection data collected on tagged birds on any of the Motus radio tracking towers is returned to the researchers that deployed that tag. Along the Northumberland Strait there is extensive coverage of shorebird habitat by these towers with each tower having a detection range between 10 and 20 km depending on weather conditions (Taylor et al. 2017). Many of these towers are oriented directly at foraging habitat, while others range from being directed at roosting areas to extensively used flyways.

In the habitat use analysis, we limited the number of Motus tracking towers that we were analyzing to six: Barachois, Johnston Point, Allison, Baie Verte, Linden, and Pugwash (Figure 2.1 Table 2.1). These six towers all overlook coastal mudflats or sandflats which are commonly used foraging habitat by shorebirds. The Atlantic Canada Shorebird Survey (2017), a yearly shorebird count between July 20 and November 20 performed by volunteers since 1974, has records that the habitat associated with these towers have historically supported shorebirds, except for Allison, as no surveys were performed in that area.

Plasma Triglyceride

For this study we used plasma triglyceride concentrations in birds' blood to estimate fattening rate (Covino and Holberton 2011). To measure triglyceride concentration, we used the Sigma Serum Triglyceride Determination Kit (Sigma-Aldrich, TR0100-1KT, Oakville, ON). Two duplicate 5 µL samples of plasma were taken from each birds' blood and placed in to a 96-

well plate. Then, we added a 200 µL solution of glycerol kinase, glycerol-3-phosphate oxidase, and peroxidase to each of the samples. By introducing glycerol kinase to our samples, the glycerol molecules that are not bound to fatty acids are converted into glycerol-3-phosphate. This is the first step in series of reactions facilitated by the enzymes we introduced, that converts unbound glycerol into quinoneimine dye. The full reaction is outlined below:

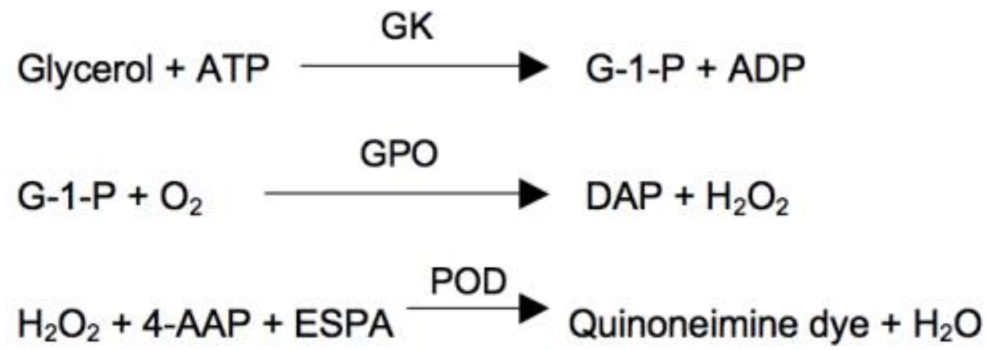

Figure 2.3. Multistep reaction breaking down glycerol and ATP into quinonimine dye and water with the enzymes provided in the Sigma Serum Triglyceride Determination Kit (Sigma). Source: (Sigma-Aldrich, Inc., 2016).

We shook samples for 300 s before measuring the absorbance of dissolved quinoneimine dye at 540 nm using a spectrophotometer (Spectramax Plus 348, Molecular Devices LLC, Sand Jose, CA). After collecting the absorbance measurements, we added 50 µL of lipoprotein lipase to the samples. This lipase removes fatty acids from triglycerides and liberates glycerol in the process. Still diluted in enzymes, the chain reaction described above restarts to increase the concentration of quinoneimine dye. We shook the samples for another 300 s and remeasured the absorbance. Using a standard curve of known glycerol concentrations, we calculate the concentration of glycerol in the first absorbance measurement which represents the free glycerol in the birds' blood, and the second absorbance measurement, which represents the newly released triglyceride and free glycerol in the blood. By taking the difference between the first and second concentration measurement, we calculate the triglyceride concentration in the original sample.

B-Hydroxybutyrate

We estimated the degree of fasting for each bird according to the *B*-hydroxubutyrate (D-3-hydroxybutyrate) concentration in their blood. *B*-hydroxubutyrate concentrations were measure from blood samples taken from each species using the Cayman's *B*-Hydroxubutyrate (Ketone Body) Colorimetric Assay Kit (Cayman Chemical Company, 700190, Ann Arbor, MI). We ran samples of plasma diluted with *B* -HB Assay Buffer to a final volume of 50 µL with plasma to buffer ratios ranging between 1:5 to 1:12. Each bird had two duplicated samples that were ran on the same 96-well plate.

Cayman's *B*-Hydroxubutyrate assay works by oxidizing *B*-hydroxubutyrate in the blood sample into acetoacetate through the introduction of 3-hydroxybutyrate dehydrogenase dissolved in a 50 µL WST-1 solution. The oxidation reaction reduces free floating NAD^+ into NADH. The WST-1 in the solution then reacts with NADH in the presence of diaphorase to form formazan dye, a proxy for *B*-hydroxubutyrate. We let this reaction take place over a 30-minute period in which the plate was kept in a dark, 25°C room.

Using a spectrophotometer (Spectramax Plus 348, Molecular Devices LLC, Sand Jose, CA), we measured the absorbance of the formazan dye solution between 445-455nm. The absorbance between these wavelengths is proportional to the concentration of *B*-hydroxubutyrate in the original 50 µL of diluted solution. Using a standard curve calculated from *B*-HB Standards of known concentrations, we were able to determine the concentration of *B*-hydroxubutyrate in the original blood sample.

Statistical Analysis

Overview

We ran all my analyses in R (version 4.0.3) using the R Studio interface (version 1.3.1093). Normality was tested using Shapiro-Wilk normality test and homogeneity of variance was tested with either Levene's test for homogeneity of variance or the score test for non-constant error variance. If data did not meet assumptions, we transformed the data, and when transformed data did not meet assumptions, we used non-parametric tests.

Tracking Data

To assure the quality of our radiotelemetry data, we assumed that birds which were not detected for three or more days after tagging had lost their tag and were therefore removed from the analysis. Additionally, using the Motus filter in R, any group of detections that did not have more than three detections in quick succession is considered to be unreliable and removed from the analysis (Crewe et al. 2018). Whenever a bird was detected at more than one tower at a given time, the detection with the strongest signal was kept, unless that was a false hit. Finally, we plotted the detections to identify any hits that were obviously false. False hits include those when a bird travels too far too fast (ex. Nova Scotia to Ontario in an hour), returns to the breeding grounds, or flies to wintering grounds and then back.

Length of Stay

Using the radiotelemetry data, we calculated the number of days between when we caught a bird, and the last time it was detected at a tower within the Maritimes but outside of the Bay of Fundy. This minimum measurement of how long birds are staying along the Northumberland Strait and Southern Nova Scotia is called length of stay. The Bay of Fundy was excluded from this analysis as R. Linhart (unpublished data) has found that Semipalmated Sandpiper stopover ecology differs heavily once birds move into the bay, no birds in this study returned to the coast once in the bay.

We tested whether length of stay differed between adults and juveniles using a Wilcoxon rank sum test for Semipalmated Sandpipers, and a two-sample t-test with equal variances for Semipalmated Plovers. In both Semipalmated Sandpipers ($W_{29} = 125$, $p = 0.618$) and Semipalmated Plovers ($t_{26} = -1.214$, $p = 0.236$) there was no difference in the number of days that adults and juveniles stayed along the Maritime coast. Therefore, age was not considered in the length of stay analysis and the ages were pooled within species. We only caught adult White-rumped Sandpipers and juvenile Least Sandpipers, therefore there is no comparison between ages for these species.

We used linear regression to explore the relationship between size-adjusted mass and length of stay for each species, except for Semipalmated Sandpipers who had their relationship tested with a permutational regression (R package permuco, Frossard and Renaud 2019) because of failed parametric assumptions. Size-adjusted mass is a measurement of a bird's fatness, controlling for structural size and was calculated using the following formula:

$$Size\text{-}adjusted\ mass\ \left({}^{g}/_{mm^3}\right) = \frac{mass\ (g)}{wing\ chord\ length\ (mm)^3} \cdot 10\ 000$$

We found that there was no relationship between size-adjusted mass and length of stay for Semipalmated Sandpipers. We did however detect a linear relationship between size-adjusted mass and length of stay in Least Sandpipers, White-rumped Sandpipers, and Semipalmated Plovers. To account for the influence of size-adjusted mass on length of stay, we standardized length of stay for the three species to their species-specific average size-adjusted masses. Then we conducted a one-way ANOVA with species as my fixed independent factor and length of stay as my continuous dependent variable, which for three species is corrected for size-adjusted mass.

Habitat Use

For the analysis of habitat use, we only considered towers overlooking foraging habitat, (either a mudflat, sandflat, or saltmarsh) along the Northumberland Strait. Additionally, we removed any towers that had been visited by fewer than 12 birds or visited on fewer than 12 days. This leaves us with six sites: Barachois, Johnston Point, Allison, Baie Verte, Linden, and Pugwash (Figure 2.1).

For these six sites, we calculated daily habitat use by each species. Daily habitat use is a daily measurement of what proportion of the total tagged population of a given species is present in habitat. Total tagged population is considered to be the number of tagged birds on a given day present somewhere along the Northumberland Strait. We calculated this measure for every day-species combination using the following equation:

$$Daily\ Habitat\ Use = \frac{\#birds\ of\ species\ x\ at\ a\ site\ on\ day\ y}{\#birds\ of\ species\ x\ at\ the\ stopover\ area\ on\ day\ y}$$

To avoid unreliable data based on small samples sizes, we only considered that the Northumberland Strait was being used by a species on days when at least 4 individuals of that species were thought to be along the Northumberland Strait. In this case, a shorebird did not need to be at one of the sites to be counted towards those 4 individuals, but they at needed to have not moved into the Bay of Fundy and were considered gone after their last detection on the Northumberland Strait. To compare the habitat use between species, we ran a two-way analysis of variance of aligned rank transformed data (R package ATRools, Kay et al. 2021) with daily habitat use as my dependent variable, and species and sites as my dependent variables. This analysis and daily habitat use calculations were performed a second time, but instead of looking at different species, only the two age classes of Semipalmated Sandpipers were compared. We didn’t consider Semipalmated Plovers for a similar analysis because there were too few adult plovers tagged (n = 6 before filtering).

Blood Metabolites

As discussed in methods, we restricted analysis of plasma metabolites to samples collected < 20 min following capture. Additionally, if the plasma metabolite concentration between the two duplicates belonging to a bird had a percent difference greater than 15%, we excluded it from the analysis. When the percent difference was equal to or less than 15%, we used the average concentration between the two duplicates as the metabolite's concentration measurement.

Testing each species and plasma metabolite separately, we compared plasma triglyceride and *B*-hydroxubutyrate concentrations between adult and juveniles. For three of the comparisons, we used two-sample t-tests with equal variances but required a log10 transformation for the comparison between *B*-hydroxubutyrate concentrations of adult and juvenile Semipalmated Sandpipers. For comparing *B*-hydroxubutyrate between ages in Semipalmated Plovers we used a Wilcoxon rank sum test. We found that the plasma triglyceride concentrations for both Semipalmated Sandpipers ($t_{45} = 0.016$, $p = 0.987$) and Semipalmated Plovers ($t_{30} = 0.478$, $p = 0.636$) were not statistically different between ages, and therefore can be ignored in the plasma triglyceride analysis. This was also the case for *B*-hydroxubutyrate concentrations of Semipalmated Plovers ($W = 38$, $p = 0.536$). However, ages differed for Semipalmated Sandpipers ($t_{26} = -2.189$, $p = 0.038$). Thus, we separated *B*-hydroxubutyrate concentrations comparison between species by age, comparing Semipalmated Sandpiper, White-rumped Sandpiper and Semipalmated Plover adults, and Semipalmated Sandpiper, Least Sandpiper, and Semipalmated Plover hatch year birds.

Although size-adjusted mass is suitable to assess fat levels within species, the use of only weight and wing chord length in its calculations could lead to biases when compared across species because of differences in morphology. Different species have different body size to wing ratios. To eliminate this possible bias, we converted the size-adjusted mass data into a Z-score within each species. This standardized size-adjusted mass subsequently replaced size-adjusted mass for the metabolite analyses.

Possible covariates standardized size-adjusted mass, handling time, Julian date, and length of stay were assessed against dependent variables *B*-hydroxubutyrate and plasma triglyceride using linear regressions. Only plasma triglyceride and standardized size-adjusted mass had a significant relationship (*B* = 0.300, R^2 = 10.46, $F_{1,106}$ = 10.46, p = 0.002). Following this, we confirmed that there is homogeneity of slopes by plotting the data (see Figure 3.4).

To test if plasma triglyceride concentrations differ between species, we ran an ANCOVA using square root transformed plasma triglyceride concentrations as the dependent variable and species (categorical) and standardized size-adjusted mass (covariate) as predictors. Additionally, we ran two separate ANOVAs comparing *B*-hydroxybutyrate concentrations between species, one for adult birds and one for juveniles.

Chapter 3: Results

Length of Stay

Shorebird length of stay varied between species ($F_{3,94}$ = 9.513, p < 0.001; Figure 3.1). We found that Semipalmated Plovers (SEPL) stayed along the Northumberland Strait for a considerably longer time than other shorebird species (Table 3.1) There was no statistically detectable difference in the length of stay among Least Sandpipers (LESA), Semipalmated Sandpipers (SESA), and White-rumped Sandpipers (WRSA).

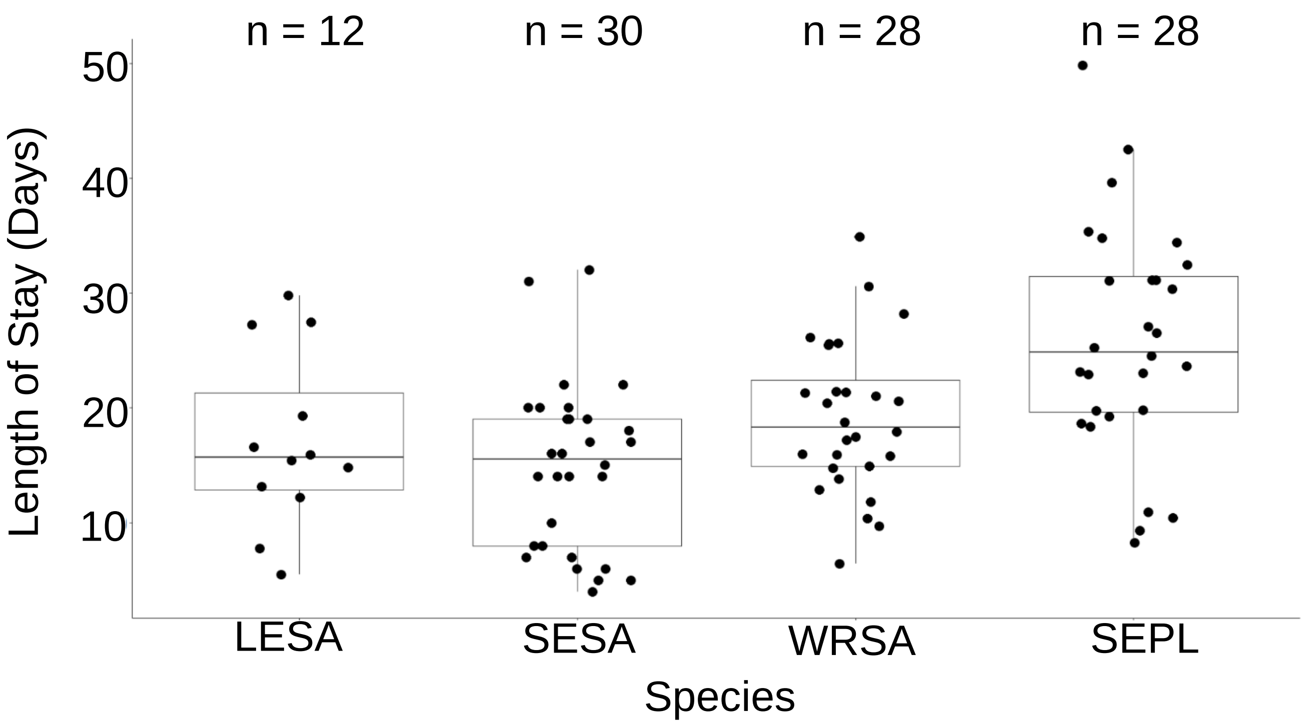

Figure 3.1. Average length of stay (days) of four different shorebird species along the Northumberland Strait and Southern Nova Scotia shore. LESA, WRSA, and SEPL have length of stay values corrected to the mean size-adjusted mass of that species. Boxes represent 1st and 3rd quartiles around the median line, and whiskers represent ± interquartile range, n = sample size. Results of statistical comparisons are provided in the text (Table 3.1).

Table 3.1. Adjusted P-values from pairwise Tukey multiple comparisons of means between length of stay of shorebirds caught on the Northumberland Strait. Significant p-values marked with asterisk (*)

	LESA	SESA	WRSA
LESA			
SESA	0.845		
WRSA	0.879	0.181	
SEPL	0.012*	< 0.001*	0.013*

Habitat Use

Daily habitat use varied with a combination of species and site (species x site interaction, $F_{15,784} = 36.585$, $p < 0.001$). Habitat use varied among sites for each species (Table 3.2).

Table 3.2. Kruskal-Wallis comparisons of daily habitat use between habitat sites divided by each species.

Species	X^2	*df*	*p*
Least Sandpiper	25.071	5	< 0.001
Semipalmated Sandpiper	73.558	5	< 0.001
White-rumped Sandpiper	123.45	5	< 0.001
Semipalmated Sandpiper	187.93	5	< 0.001

Johnston Point was the site most used among all of the species (Figure 3.2). Least Sandpipers exhibited the narrowest range of habitat use. In contrast, we found that Semipalmated Sandpipers used habitat near 5 of the 6 tracking tower sites for a detectable amount of daily habitat use. Both White-rumped Sandpipers and Semipalmated Plovers used habitat near the Allison tower for substantial daily, in addition to Johnston Point (Figure 3.2).

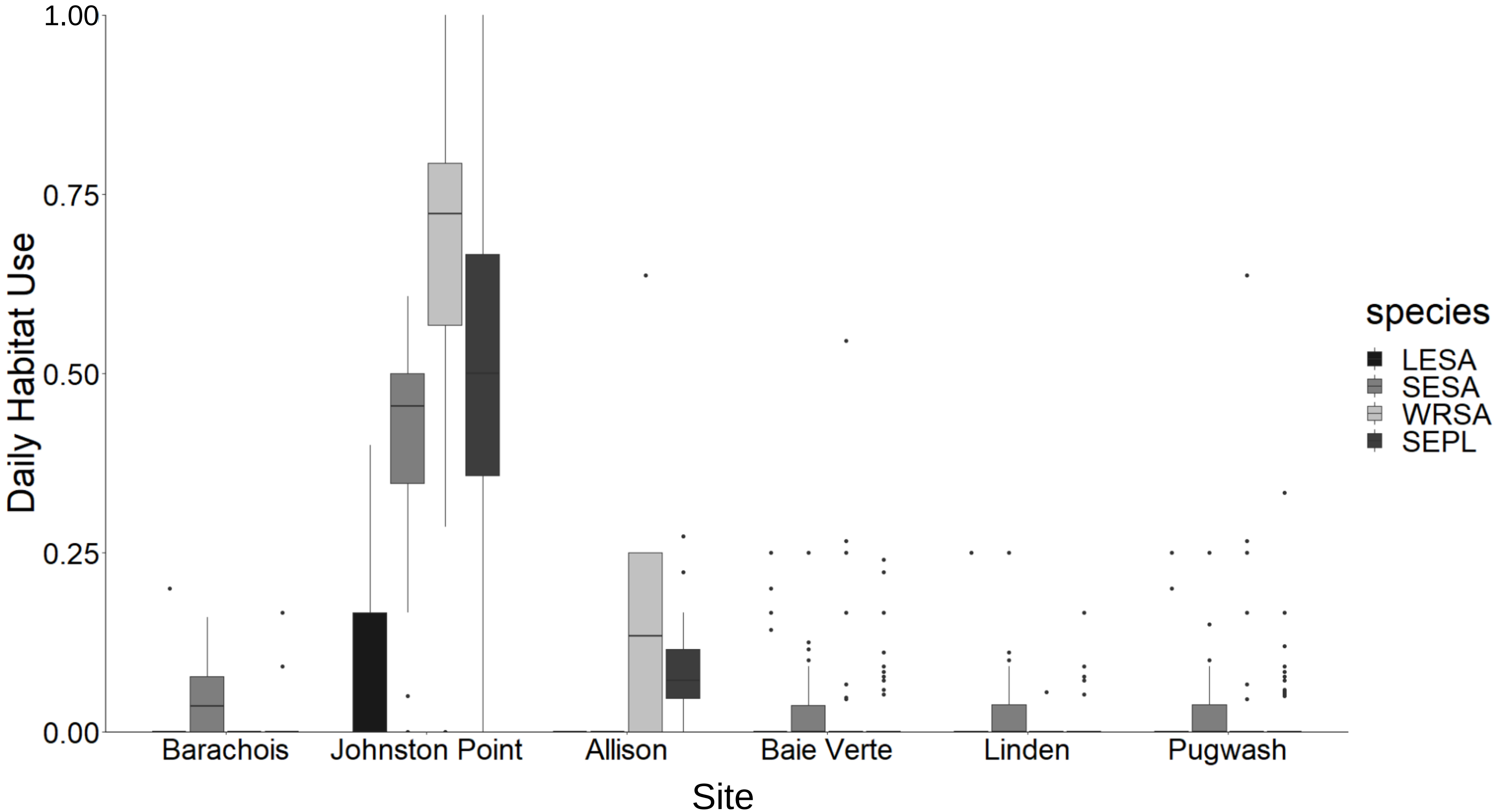

Figure 3.2. Average daily habitat use (proportion) of four shorebird species at 6 habitat sites along the Northumberland Strait. Days in which fewer than 4 individuals of a species were found in the Northumberland Strait region were removed for that species. Boxes represent 1st and 3rd quartiles around the median line, and whiskers represent ± interquartile range.

Daily habitat use also varied with a combination of age and site for Semipalmated Sandpipers (age x site interaction, $F_{4,221}$ = 5.100, $p < 0.001$). With habitat use varying among sites for adults (X^2_4 = 52.315, $p < 0.001$) and juveniles (X^2_5 = 50.237, $p < 0.001$). Similar to the pattern seen with all species, Johnston Point was the most used sites among ages (Figure 3.3). Both adult and juvenile Semipalmated Sandpipers utilized Barachois to a lesser extent. But, juveniles utilized Baie Verte, Linden, and Pugwash while adults did not any sites other than Johnston Point and Barachois (Figure 3.3).

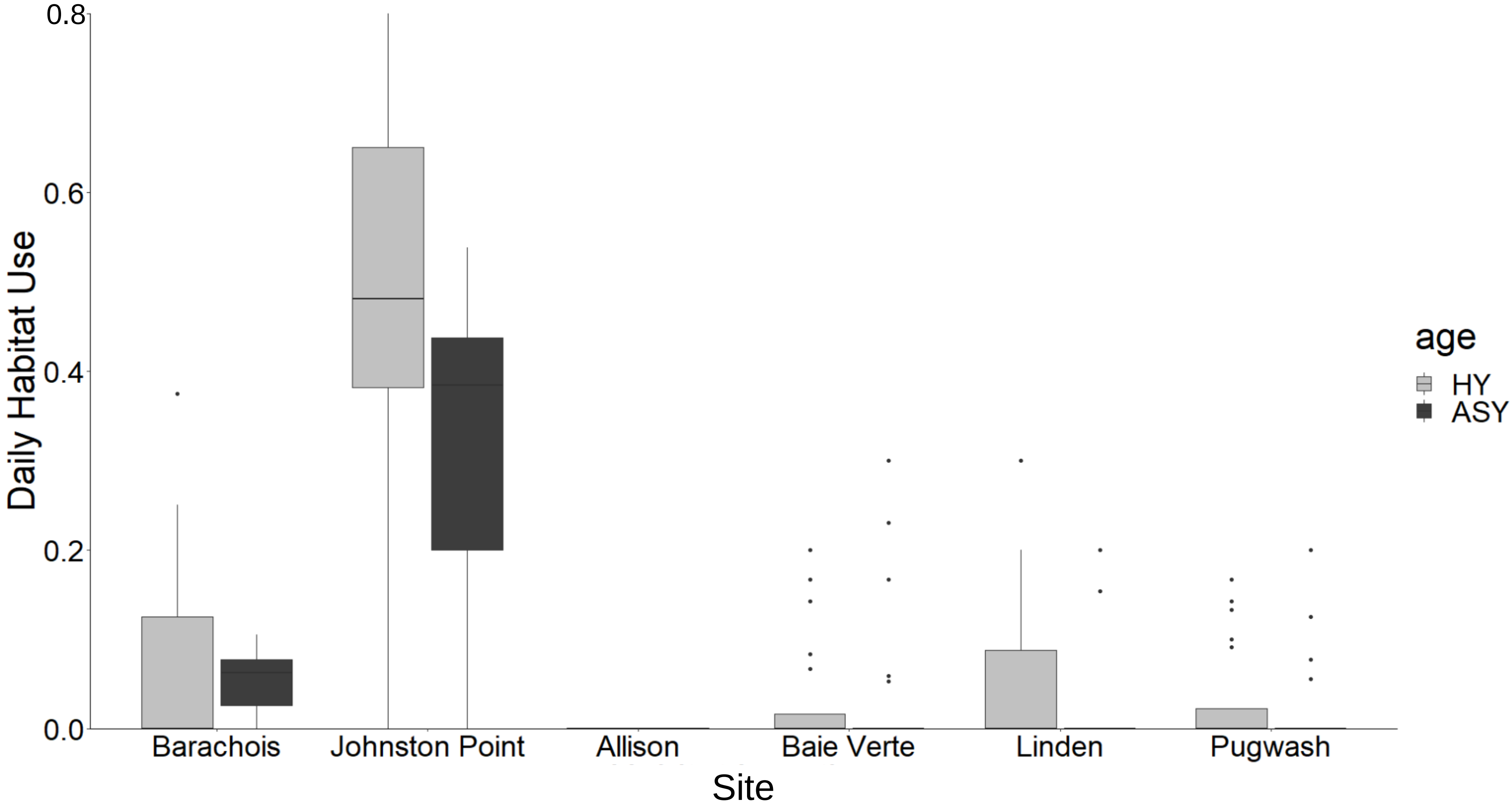

Figure 3.3. Average daily habitat use (proportion) of two Semipalmated Sandpiper age classes at 6 habitat sites along the Northumberland Strait. Days in which fewer than 4 individuals of an age class were found in the Northumberland Strait region were removed for that age class. Boxes represent 1st and 3rd quartiles around the median line, and whiskers represent ± interquartile range.

Plasma triglyceride analysis

We found a positive relationship between standardized size-adjusted mass and plasma triglyceride concentrations that was consistent across species (mass x species interaction $F_{3,100}$ = 0.156, p = 0.926; Figure 3.4). Controlling for this covariate, we found that plasma triglyceride concentrations varied significantly among species (ANCOVA $F_{3,103}$ = 14.682, p < 0.001; Figure 3.5). Semipalmated Sandpipers and Semipalmated Plovers had higher triglyceride concentrations than the other species, suggesting that they are fattening quicker than Least and White-rumped Sandpipers (Table 3.3). We found no difference in triglyceride concentrations between Semipalmated Sandpipers and Plovers (Table 3.3).

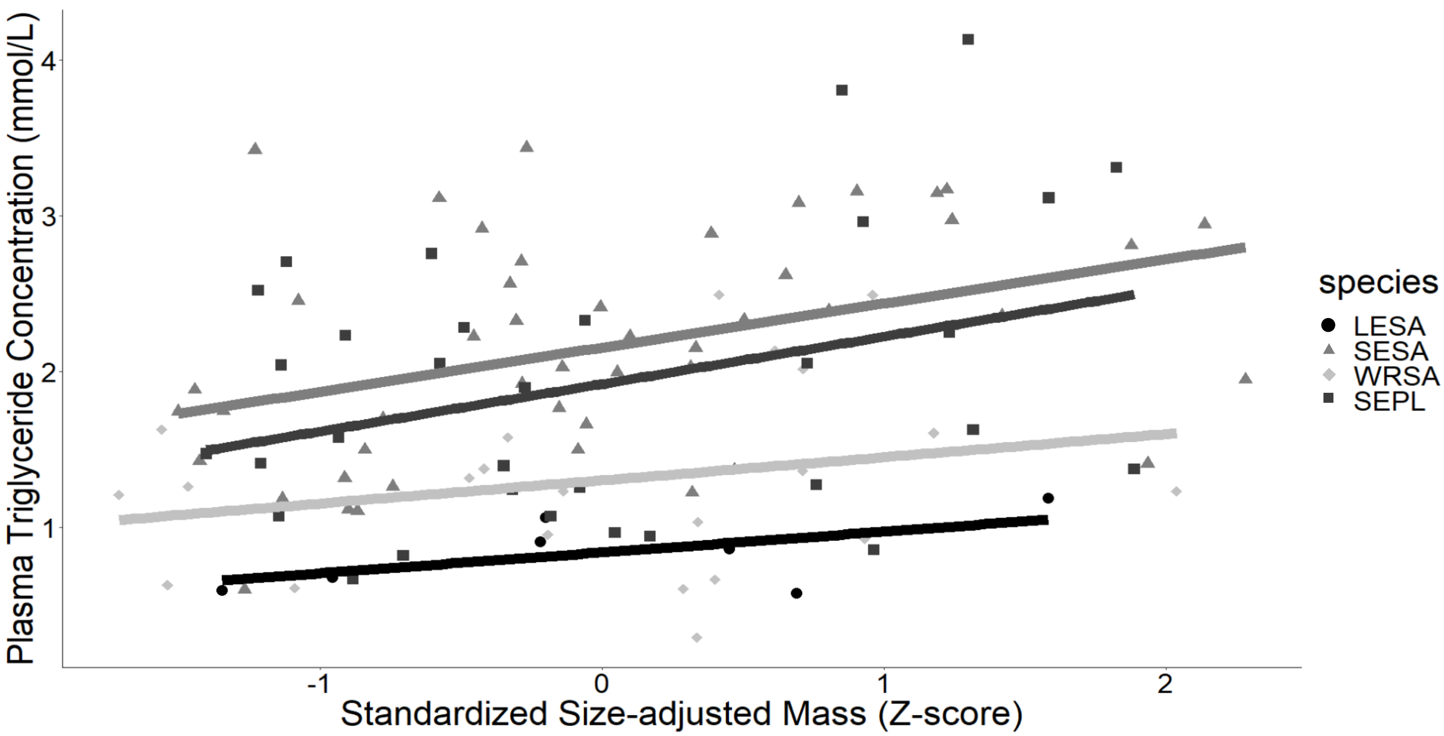

Figure 3.4. Linear relationships of standardized size-adjusted mass (Z-score) and plasma triglyceride concentration (mmol/L) in four species of shorebird.

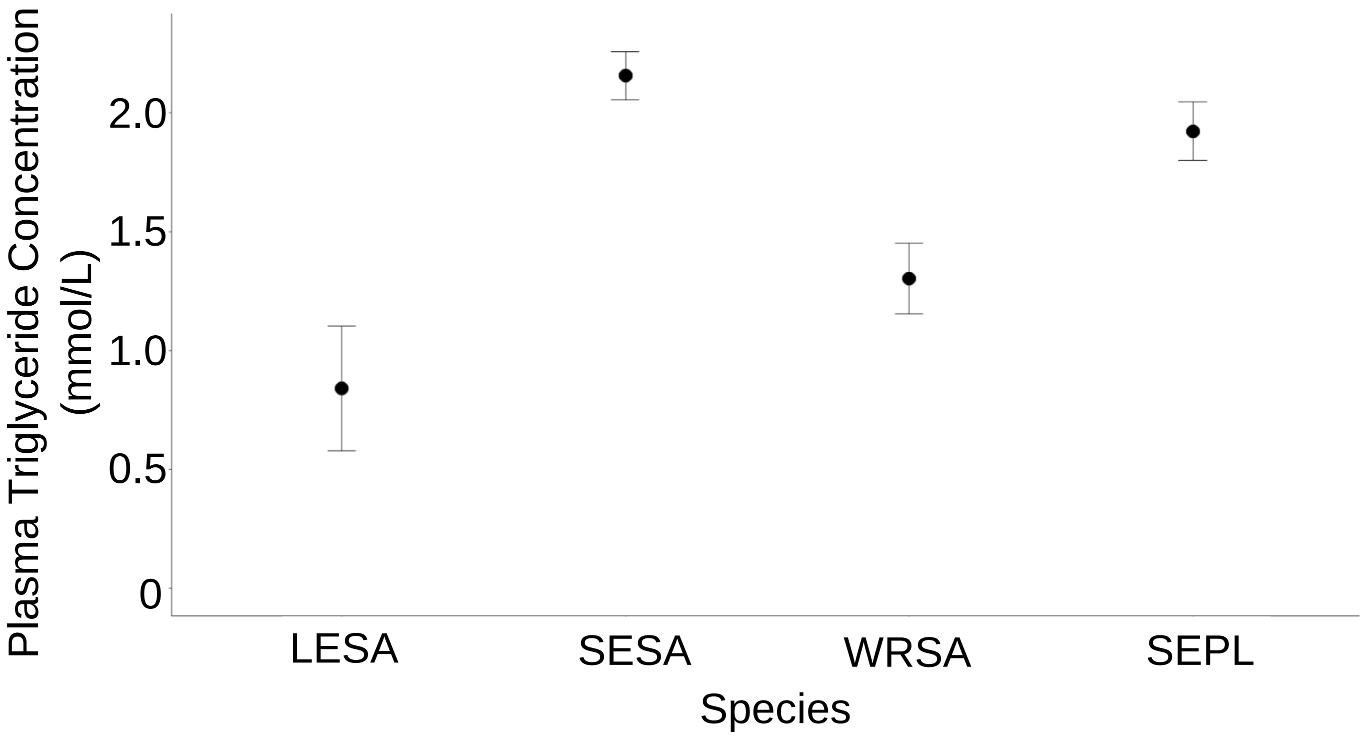

Figure 3.5. Mean transformed plasma triglyceride concentrations (mmol/L) of four different shorebird species caught at Petit-Cap, NB. Plasma triglyceride values are corrected to the mean standard size-adjusted mass of each species and back-transformed from square root data. Points represent means, while whiskers represent ± standard deviation. Results of statistical tests are provided in Table 3.3.

Table 3.3. Adjusted P-values from pairwise Tukey multiple comparisons of means between plasma triglyceride concentrations of shorebirds caught on the Northumberland Strait. Significant p-values marked with asterisk (*)

	LESA	SESA	WRSA
LESA			
SESA	< 0.001*		
WRSA	0.2764	< 0.001*	
SEPL	< 0.001*	0.367	0.006*

B-hydroxybutyrate analysis

B-hydroxybutyrate concentrations were higher in juvenile than adult Semipalmated Sandpipers (t_{26} = -2.189, p = 0.038; Figure 3.6), requiring that comparisons among species be completed separately for adults and juveniles because we did not have both ages for all species. Among adult birds, we found no differences in the levels of *B*-hydroxybutyrate among species ($F_{2,32}$ = 1.7, p = 0.199; Figure 3.7). However, for juveniles we did find differences among species in *B*-hydroxybutyrate concentrations (Table 3.4; Figure 3.8). Least Sandpipers had the highest concentration of *B*-hydroxybutyrate, suggesting that they may be fasting more than other species. However, we did not find a difference in *B*-hydroxybutyrate concentrations between juvenile Semipalmated Sandpipers and Semipalmated Plovers.

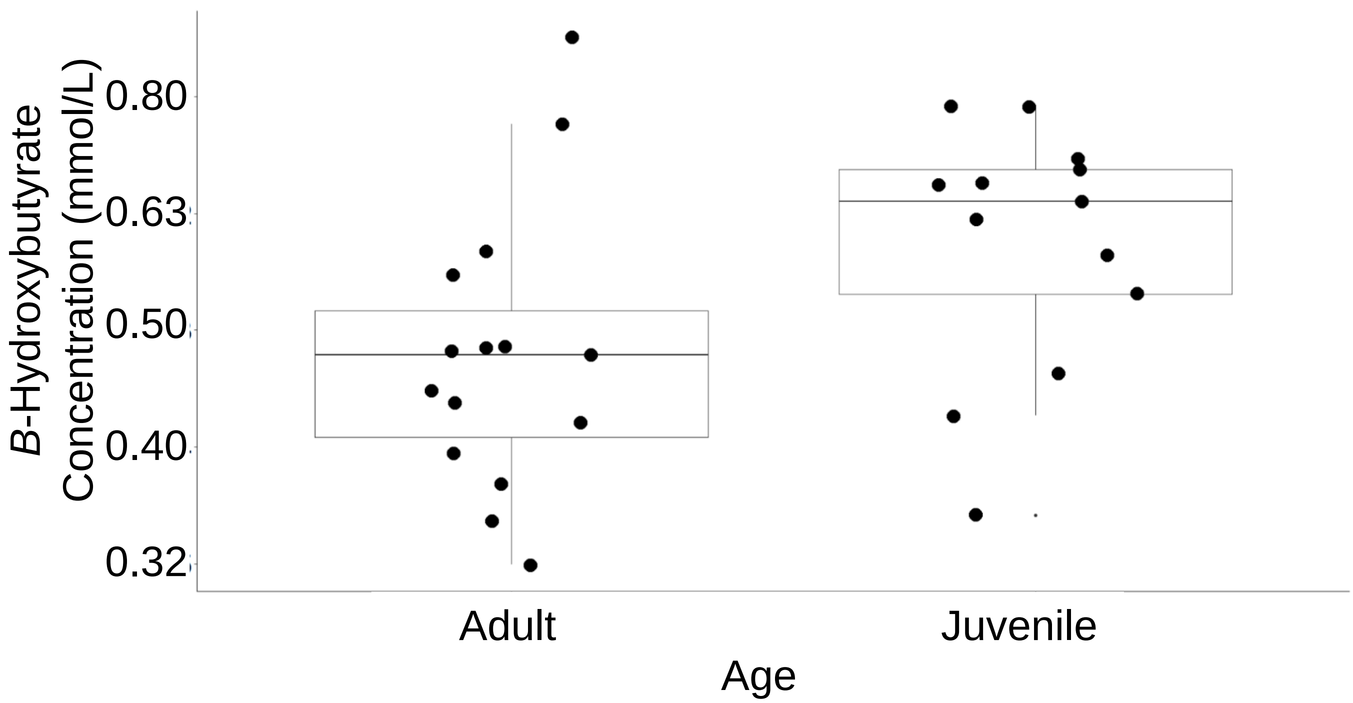

Figure 3.6. Mean *B*-hydroxybutyrate concentration (mmol/L) of adult and juvenile Semipalmated Sandpipers caught at Petit-Cap, NB. *B*-hydroxybutyrate concentrations are back-transformed from logged data. Boxes represent 1st and 3rd quartiles around the median line, and whiskers represent ± interquartile range. Statistic test result in text.

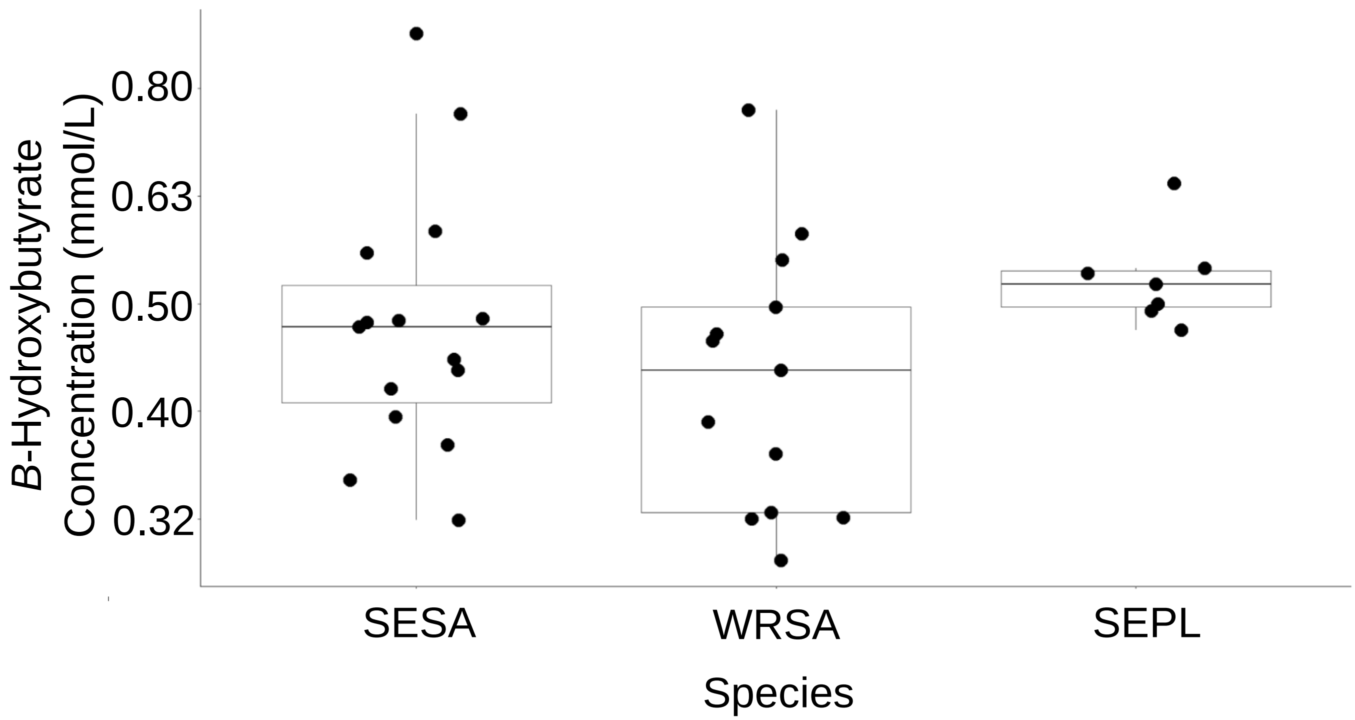

Figure 3.7. Mean logged *B*-hydroxybutyrate concentration (mmol/L) of adult shorebirds belonging to three species. *B*-hydroxybutyrate concentrations are back-transformed from logged data. Boxes represent 1st and 3rd quartiles around the median line, and whiskers represent ± interquartile range. Statistic test result in text.

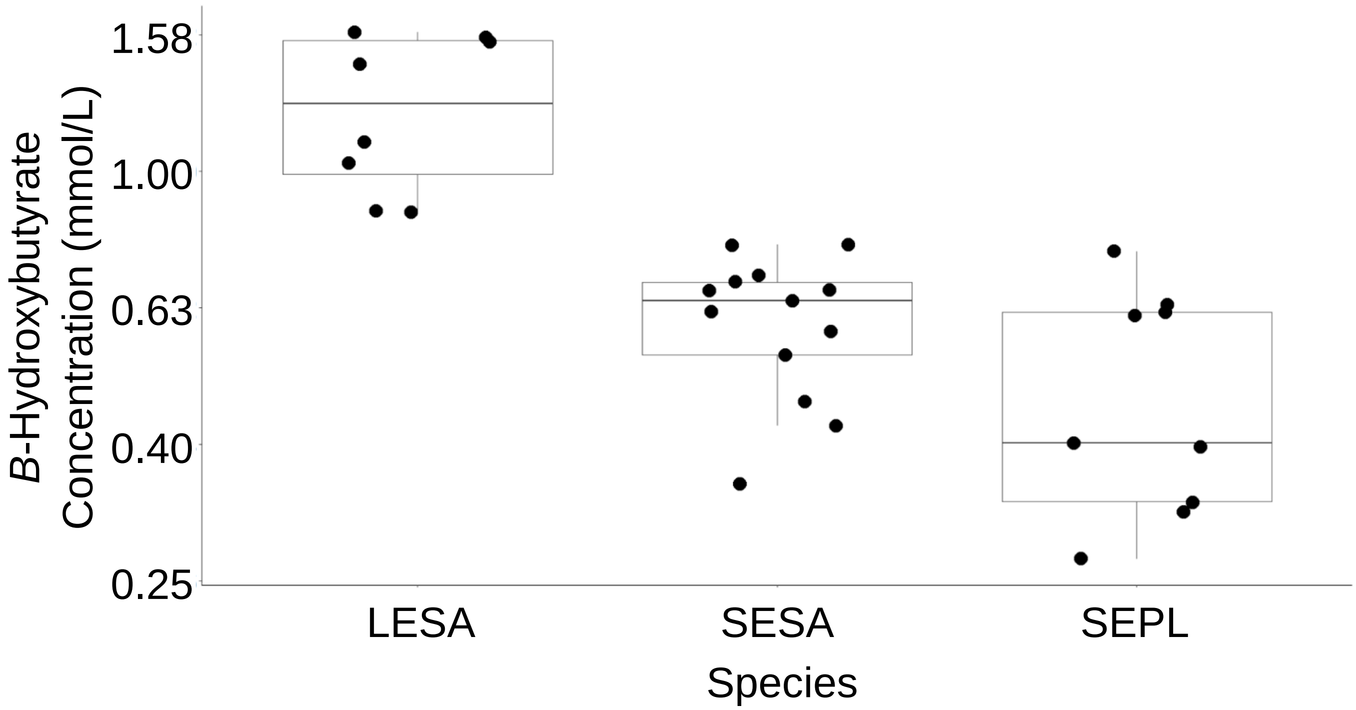

Figure 3.8. Mean logged *B*-hydroxybutyrate concentration (mmol/L) of juvenile shorebirds belonging to three species. *B*-hydroxybutyrate concentrations are back-transformed from logged data. Boxes represent 1st and 3rd quartiles around the median line, and whiskers represent ± interquartile range. Statistic test result in Table 3.4.

Table 3.4. Adjusted P-values from pairwise Tukey multiple comparisons of means *B*-hydroxybutyrate concentrations of juvenile shorebirds caught on the Northumberland Strait. Significant p-values marked with asterisk (*)

	LESA	SESA
LESA		
SESA	< 0.001*	
SEPL	< 0.001*	0.107

Chapter 4: Discussion

Overview

Many species of shorebirds migrate annually from Arctic breeding grounds to wintering locations ranging from the Caribbean to South America (Anderson et al. 2019). To make this journey, they require access to stopover sites that offer predictable, food-abundant habitat at which they can build fat stores to support migration (Bonter et al. 2009). These fat stores are burned during flight; therefore, migration success is closely tied to body condition (Duijns et al. 2017). Recently, Anderson et al. (2019) found that the stopover length, fuel loads upon departure, and use of multiple stopovers during migration by shorebirds at the James Bay, Ontario stopover site is dependent on the total migration distance of a species. Birds that migrate long distances, like Semipalmated Sandpipers and White-rumped Sandpipers, require higher fuel loads to fly their total migration route compare to short-distant migrants like Least Sandpipers and Semipalmated Plovers. Additionally, long-distance migrants need to travel farther while seasonally abundant resources are available, limiting the time birds have to build fat (Anderson et al. 2019). It is less clear how the different pressures of long- and short-distance migration influence bird behaviour while building fat stores at stopover sites. We addressed part of this uncertainty by characterizing the fattening rate and habitat use of long- and short-distance migratory shorebirds during their stopover along the Northumberland Strait (NB and NS) coast.

Semipalmated Sandpipers and White-rumped Sandpipers

Semipalmated Sandpipers are generalists and opportunistic predators that consume highly diverse assemblages of invertebrates and microphytobenthos (Skagen 1997, MacDonald et al. 2012, Quinn and Hamilton 2012, Gerwing et al. 2016). This can help birds ensure that they always have a food source even when the assemblages and densities of prey items vary from year to year (Gerwing et al. 2015). There is limited information on invertebrate abundance and diversity at habitats used by shorebirds on the Northumberland Strait. Therefore, it is difficult to estimate the extent to which prey communities change year to year. However, significant weather events such as hurricane Dorian in 2019, coupled with shoreline hardening (Gittman et al. 2016), sea level rise (Robinson et al. 2009), and activity levels of humans and dogs (Burger et al. 2007; Dekker et al. 2011) probably lead to changes in the properties of these habitats over time. Despite this, we found that Semipalmated Sandpipers had length of stay, plasma triglyceride levels (and index of fattening rate), and *B*-hydroxybuterate levels (representing the use of fat stores) equal to those observed at Petit-Cap in 2018 and 2019 (R. Linhart, unpublished data; Arseneault 2020). Therefore, Semipalmated Sandpipers have shown the ability to use a habitat in a consistent manner through time. We found that these birds had the highest fattening rate among the sandpipers included in this study. This was unexpected, as White-rumped Sandpipers migrate farther than Semipalmated Sandpipers and therefore should theoretically have a higher fattening rate. Indeed, Arseneault (2020) found that White-rumped Sandpipers captured at Petit-Cap in 2019 had higher plasma triglyceride levels than Semipalmated Sandpipers. However, our results show that White-rumped Sandpipers had lower plasma triglyceride levels during their 2020 stopover.

In addition to having lower plasma triglyceride concentrations than in the previous year, White-rumped Sandpipers had an average length of stay 1.5 days longer than that reported in 2019 (Arseneault 2020). *B*-hydroxybutyrate concentrations for White-rumped Sandpipers were not reported in 2019, but, compared to the other species in this study they were among the lower concentrations. If we take those low concentrations to mean White-rumped Sandpipers are not fasting and thus not mobilizing lipids, then we can assume that these birds are still gaining weight while they are in the region, albeit at a slower rate than in 2019.

The ability for an organism to alter its diet in response to unpredictable or changing environments is considered advantageous compared to specialist that rely on one or a few resources (Overington et al. 2008). This can be observed during spring migration in Delaware Bay where there is a mixture of shorebirds with both highly specialized and generalist dietary niches. Red Knots are specialist foragers, relying heavily on horseshoe crab (*Limulus polyphemus* L.) eggs to build fat stores during their stopover in Delaware Bay (Tsipura and Burger 1999). Harvesting of horseshoe crab eggs greatly reduced the available eggs for shorebirds (Niles et al. 2009). In years following intense harvesting, Red Knot populations dramatically declined in the region, as many birds were unable to build enough fat fast enough to complete their migration (Mizrahi and Peters 2009; Niles et al. 2009). Semipalmated Sandpipers and Semipalmated Plovers are both generalist foragers that use Delaware Bay. They too were negatively affected by a reduction of the available horseshoe crab eggs, but were able to supplement their diet with prey items collected from salt marshes when egg numbers were low and, in the process, avoid a population crash (Tsipura and Burger 1999; Mizrahi and Peters

2009). White-rumped Sandpipers have a relatively narrow dietary niche consisting of 75% gastropods (Bellefontaine 2020). Therefore, if disturbances in mudflat structure, such as those caused by hurricane Dorian in 2019, altered gastropods densities or assemblages, then the reduced plasma triglyceride concentration of White-rumped Sandpipers may reflect a decrease in quality of Northumberland Strait habitat for this species. Additionally, the generalist nature of Semipalmated Sandpipers, which provides them with a wider dietary niche (Bellefontaine 2020), may make it easier for them to adapt to changing prey and habitat conditions without adjusting rates of weight gain or stopover duration. If the White-rumped Sandpiper's plasma metabolite concentrations and length of stay are changing in response to coastal habitat changes, it may suggest that this species is more sensitive than Semipalmated Sandpipers to habitat disturbances.

Although both adult and juvenile Semipalmated Sandpipers had lower concentrations of *B*-hydroxybutyrate concentrations than White-rumped Sandpipers, we found that these concentrations were not the same between Semipalmated Sandpipers age classes. Adults had lower *B*-hydroxybutyrate concentrations suggesting that they were gaining weight more efficiently than juveniles. In many shorebird species, juveniles are often less competent foragers, having longer handling time of prey and sometimes less foraging success (Groves 1978; Hand et al. 2010). Additionally, we found that juvenile Semipalmated Sandpipers move between sites more than adults. Therefore, it is possible that juvenile Semipalmated Sandpipers are building fat at a slower rate than their adult counterparts due to inexperience in foraging, as well as their increased expenditure of energy moving between sites along the Northumberland Strait.

Least Sandpipers

We found that among the shorebirds included in this study, Least Sandpipers had the highest *B*-hydroxybutyrate concentrations and was one of the two species with low plasma triglyceride concentrations. This suggests that among the species we investigated, Least Sandpipers are gaining weight at the slowest rate. Even so, Least Sandpipers stay for roughly the same number of days as both Semipalmated Sandpipers and White-rumped Sandpipers.

Many shorebird species undergo reduced function and atrophy of the gut, kidneys, and liver during prolonged flights between stopover sites (Piersma 1998). In species that migrate over usable habitat and short distances, we see reduction in function and some atrophy of digestive organs, but this is to a lesser degree than birds that perform trans-oceanic flights

(Piersma 1998). Although the functional reduction and atrophy of organs in Least Sandpipers is yet unknown, it has been observed in other *Calidris* species, including Semipalmated Sandpipers (Risely et al. 2017). This creates a lag period upon arrival where shorebirds rebuild and return function to their digestive organs (Piersma 1998). Additionally, it is thought the time it takes for changes in plasma triglyceride and *B*-hydroxybutyrate concentrations to begin reflecting fattening and fasting are size dependent, with small songbirds transitioning in 90 min of fasting, while Red Knots transition sometime after 5 hours of fasting (Jenni-Eiermann and Jenni 1991; Jenni-Eiermann et al. 2002b). Assuming there is a lag phase between when birds arrive at stopover sites and when plasma metabolite concentrations are reflective of foraging behaviour at that stopover site, it is possible that the plasma metabolite data we collected on Least Sandpipers are reflective of when they arrive at the Northumberland Strait and not when they are building fat. Least Sandpipers had significantly higher mean *B*-hydroxybutyrate concentration than the other species and all of our sampled birds had little fat, which may suggest that we caught these birds very early upon arrival. There is also one individual that was originally assumed to be an outlier as it had a plasma triglyceride concentration 2.5x greater than the mean triglyceride concentration for Least Sandpipers. Without more data points in this range or samples of heavier Least Sandpipers, we are unable to confirm if this is a real value representative of fattening rate after recovering from migration or an outlier. Future capture efforts targeting Least Sandpipers should aim to collect the metabolites of birds at a much wider range of weights then those seen in this study. Thus, plasma metabolites could be compared between birds that may have just arrived and those that have been foraging for an extended period. With this it would be possible to test if Least Sandpipers build fat very slowly or if the metabolites analyzed in this study are reflective of recent prolonged flight.

Semipalmated Plovers

We found that Semipalmated Plovers had among the higher plasma triglyceride concentrations, similar to Semipalmated Sandpipers. Coupled with a low mean *B*-hydroxybutyrate concentration, this suggests that Semipalmated Plovers are gaining weight quickly. However, Semipalmated Plovers are a short-distance migrant, sometimes only migrating as far as the Southern United States (Nol and Blanken 2014). Therefore, the results of Anderson et al. (2019) suggest that these plovers should have a shorter length of stay. Instead, we found that Semipalmated Plovers have the longest length of stay among the species we tested. The relationships of plasma triglyceride concentrations and length of stay between Semipalmated Plovers and Semipalmated Sandpipers that we found differ from those of recent studies at stopover sites on the Acadian Peninsula in northeastern New Brunswick (MacKeller 2018; Geldart 2018). There, it was found Semipalmated Plovers and Sandpipers did not differ in their length of stay, and that Semipalmated Plovers had significantly lower concentrations of triglyceride in their blood compared to Semipalmated Sandpipers (MacKeller 2018; Geldart 2018). These opposing results suggest that stopover strategies vary both within and between species among stopover sites in Atlantic Canada. Given the distance between the Acadian Peninsula and the Northumberland Strait, it is possible that variables other than weight gain, such as environmental factors, may contribute to the differences in length of stay of Semipalmated Plovers at these sites.

It is not uncommon for shorebirds to remain at a site after they have built up fat stores necessary for their next migratory flight (Dunn et al. 1988). Pfister et al. (1998) found that 32-43% of Semipalmated Sandpipers at stopovers in Plymouth and Duxbury Bay, Massachusetts stayed for longer than they need to refuel. Other studies in the Bay of Fundy found that Semipalmated Sandpipers that arrive early stay longer than those that arrive late in the season (Mann et al. 2017; Neima 2017). Additionally, it was found that many Semipalmated Sandpipers in the Bay of Fundy also remained longer than necessary to rebuild fat stores (Neima 2017). Shorebirds may increase their length of stay to match their departure timing with the occurrence of tailwinds, which make flying more efficient (Neima 2017, Åkesson and Hedenström 2000) and shorten the time it takes to complete a migration bout (Liechti and Bruderer 1998).

Wing loading is a measurement of how much weight a wing is lifting relative to its surface area (Wegener 1986). Therefore, wing loading increases as a bird’s weight increases, and if left uncheck would theoretically reach a maximum where the bird is unable to fly. Tailwinds are an important determinant of stopover departure of small birds, such as shorebirds. This is due to their slower flight speeds than larger birds, which makes them unable to fly forward in strong headwinds (Åkesson and Hedenström 2007). Saino et al. (2010) found that higher fat stores and wing loadings are correlated with stronger tailwinds on departure, suggesting that these factors lead to greater wind selectivity in migratory birds. All of the species we examined in this study are known to be wind selective when departing stopover sites (Anderson et al. 2019). However, the extra time Semipalmated Plovers stayed in the region relative to the other species suggests that they may be especially particular about departure conditions. Although untagged, we did capture 7 Semipalmated Plovers that were over 60 g, demonstrating that there are at least some in the area that are building very large fat stores. If our tagged plovers reached similarly large fat stores, these birds may have been approaching their maximum wing loading, therefore increasing their need of tailwinds to complete their migration. Neima (2017) observed that in the Bay of Fundy, favourable tailwinds are more common in the later seasons of migration. Due to its close proximity to the Northumberland Strait, and birds' tendency to aggregate at the tip of Southern Nova Scotia for departure, it is safe to assume our birds are subjected to the same timing of favourable winds. That is to say, the long length of stay and substantial weight gain by Semipalmated Plovers found in this study may be related to increased specificity in departure tailwinds preferences compared to other species. It should also be noted that these plovers were the only species of Charadriidae that we studied, while the three other species belong to the genus *Calidris* (family Scolopacidae). Therefore, we cannot rule out that the length of stay along the Northumberland Strait is rooted in phylogeny.

Daily Habitat Use

Habitat use in various shorebird species has been found to differ between age classes (Warnock and Takekawa 1995; van den Hout et al. 2013). In Red Knots, aggression from adults forces juveniles to forage in lower quality and more dangerous areas (van den Hout et al. 2013). While differences in habitat use by Western Sandpiper (*Calidris mauri* Cabanis) is driven by the selectivity of habitat by each age class, with juveniles being less selective for high quality habitat (Warnock and Takekawa 1995). Our comparison between adult and juvenile habitat use by Semipalmated Sandpipers, found that juveniles used more sites than adults, which aligns with previously findings in the region (R. Linhart, unpublished data). This suggests that older and more experienced Semipalmated Sandpipers are more selective with their choice of habitat. Whether juveniles are less selective of their habitat or are being forced to forage at other sites due to aggression from adults is unknown.

Across all of the species, we found that Johnston Point was the most used site by the birds we tracked. Allison was the second most used site, having frequent visits from White-rumped Sandpipers and Semipalmated Plovers. Semipalmated Sandpipers showed preferential use for Johnston Point, but unlike the other species, they regularly used every site in the study with the exception of Allison. This suggests that Semipalmated Sandpipers are utilizing the Northumberland Strait to a fuller extent than the other species, especially compared to Least Sandpipers that only frequented Johnston Point.

Within the Bay of Fundy Semipalmated Sandpipers regularly move between mudflats and coastlines within each arm of the bay (Neima et al. 2020). However, only a small portion of these birds move between arms of the bay (Neima et al. 2020). A similar study by Geldart (2018) found that Semipalmated Sandpipers and Semipalmated Plovers rarely move between stopover sites in the Acadian Peninsula but do regularly move within the site. We assumed that the various shorebird species would move between sites along the Northumberland Strait, as the distance between sites adjacent to one another are well within the range frequently traveled by Semipalmated Sandpipers in the Bay of Fundy (Neima et al. 2020) and at the upper limits of daily movement of Semipalmated Plovers in the St. Lawrence River Estuary (Turcotte et al. 2013). However, our findings suggest that for all species except Semipalmated Sandpipers, movements between sites is infrequent. Instead, birds primarily used the two habitats, Johnston Point and Allison, which are nearest to our capture site, Petit-Cap. Therefore, our assumption that the Northumberland Strait was a single stopover site is an overestimation of the habitat use by 3 species in this study. Instead, it would be more appropriate to treat the Northumberland Strait as a collection of stopover sites, with Petit-Cap being the most used stopover site by certain populations of multiple species. However, drawing conclusions regarding species use of the Northumberland Strait as a whole may be partially biased, as the high number of tagged Semipalmated Sandpipers increases the chance that the towers they visited passed the minimum number of visits to be considered for analysis. Subsequently removing towers that may be extensively used by other species. Therefore, use of other sites may be present but undetectable in our analysis. With such a high diversity of stopover strategies and evidence that birds tagged at Petit-Cap do not represent the Northumberland Strait region as a whole, we recommend future studies aim to determine the structure of shorebird populations along the Northumberland Strait using radio telemetry tracking of tags deployed at numerous sites. The tracking performed in this study does not capture the extensive use of various sites by species seen in the ACSS (2017). As such, we would expect that birds caught at other locations would demonstrate different habitat use behaviour. Exemplifying the need to conserve multiple sites along the Northumberland Strait, as birds other than Semipalmated Sandpipers may not be moving between sites.

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