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Divergent habitat use and the influence of sea ice concentration on the movement behaviour of ringed seals *Pusa hispida* in Labrador, Canada

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ABSTRACT: Climate change and industrial activities are leading to significant ecological changes in the Eastern Canadian Arctic, with consequences for top predators, including ringed seals *Pusa hispida*. However, there remains a limited understanding of habitat use, constraining an understanding of the impacts of change on this culturally valued pinniped. A total of 20 ringed seals from 2 areas in Labrador with different geomorphic attributes (Saglek Fjord in the North, and Lake Melville, an estuarine 'fjard' in the South) were equipped with satellite-linked transmitters to characterize behaviour states, home ranges, core use areas and environmental variables. Lake Melville-tagged seals had a smaller home range than Saglek Fjord seals (84 968 vs. 196 886 km^2). There was little spatial overlap in the home ranges (10%) and core use areas (0%) between the 2 areas, which were separated by 572 km. Lake Melville seals spent more time in a transiting state during open water conditions (26%) than during ice-covered periods (9%), probably due to an influence of sea ice concentration; they also spent more time in the area in which they were tagged (72%) than did Saglek Fjord seals (36%), increasing the risk of exposure to local contaminants associated with hydroelectric developments. Our results suggest that ringed seals in Lake Melville have better feeding opportunities but may be more vulnerable to changing ice conditions and contaminants compared to seals in Saglek. These results will support the development of a planned culturally based Marine Protected Area in Nunatsiavut and can inform efforts to remediate contaminant sources in the region.

KEY WORDS: Satellite telemetry · Climate change · Sea ice · Contaminants · Methyl mercury · Polychlorinated biphenyls

1. INTRODUCTION

Understanding the movement behaviour of species is an important facet of characterizing the structure and function of populations and ecosystems (Nathan et al. 2008). Animal movements facilitate the transport of nutrients (Darimont et al. 2003, Doughty et al. 2016), as well as contaminants (Christensen et al. 2013, Brown et al. 2014b) within and across ecosystems. Documenting the relationship among movements, life history, and environmental conditions can reveal differences in habitat use and feeding ecology within species (Yurkowski et al. 2016a), which can better inform conservation and management.

The rapidly changing sea ice conditions in the Arctic create particularly poignant challenges for natural

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resource managers as they seek to understand the potential consequences of industrial development and maritime traffic on the biology and habitat of marine species. Ringed seals *Pusa hispida* are the most abundant upper-trophic-level endemic marine mammal in the circumpolar Arctic, with a life history that is strongly tied to sea ice (McLaren 1958, Smith & Hammill 1981). However, due to their ecology, subnivean life stages, and remote habitat, there are no precise abundance estimates or unique sub-population information (Reeves 1998, Pilfold et al. 2014). During the winter and spring, ringed seals maintain breathing holes through the ice by scraping it with their claws and excavate snow lairs over the ice, where females give birth to a single pup between February and May, depending on the geographical location (McLaren 1958). Their pupping and mating season is followed by an annual moult, which requires stable sea ice conditions (McLaren 1958). Ringed seals feed primarily on pelagic forage fish, such as Arctic cod *Boreogadus saida*, saffron cod *Eleginus gracilis*, sandlance *Ammodytes* sp., rainbow smelt *Osmerus mordax*, Pacific herring *Clupea pallasi* and capelin *Mallotus villosus* (Lowry et al. 1980, Labansen et al. 2007, Crawford et al. 2015), as well as invertebrates including *Eualus* sp., *Pandalus* sp., and *Themisto libellula* under the ice or in the open water (Brown et al. 2015, Crawford et al. 2015). Given their strong ties to sea ice, understanding how ringed seals use their environment and how environmental conditions influence their behaviour by season is important to determine the impacts of climate change and contaminant exposure.

Climate change in the Arctic has led to dramatically reduced summer sea ice extent, increased freshwater inputs, increased sea surface temperature, and altered winter snow cover and depth (IPCC 2014, Box et al. 2019). These changes appear to be driving a poleward shift in species distributions at low, mid, and upper trophic levels (Kortsch et al. 2015, Yurkowski et al. 2018), leading to changes in productivity, species diversity and abundance, feeding ecology, and increases in disease/pathogen transmission in some regions (Wassmann et al. 2011, Descamps et al. 2017). Increased temperatures have been associated with a shift in ringed seal feeding ecology to more pelagic prey (Young & Ferguson 2013, Yurkowski et al. 2018). In 2010, the Labrador coast had abnormally high sea surface temperatures, below normal sea ice extent, and earlier spring breakup (Colbourne et al. 2011, Stenson & Hammill 2014), which resulted in a more diverse diet in ringed seals as determined by an isotopic study (Anderson 2022). A longer open water period and higher chlorophyll concentrations also contributed to ringed seals feeding on more pelagic prey (Anderson 2022). Ringed seal mercury (Hg) concentrations were higher when sea surface temperatures were abnormally high and sea ice broke up early (Anderson 2022); therefore, a more pelagic prey diet may increase contaminant exposure over time and impact the overall health of ringed seals. Continued changes in these environmental factors, along with changes in the distribution and availability of fish and invertebrates (Bluhm & Gradinger 2008, Cooper et al. 2009), are expected to influence the foraging behaviour, body condition, pup survival, and productivity of ice-associated seals across the Arctic (Grebmeier et al. 2006, Moore & Huntington 2008, Cameron et al. 2010, Kelly et al. 2010, Kovacs et al. 2011). Such changes could have significant consequences for the ringed seal, a Species of Special Concern in Canada (COSEWIC 2019).

Tracking animal movements using satellite telemetry has proven to be a useful tool for inferring habitat use and foraging behaviour of marine mammals and, when combined with environmental data (e.g. sea ice concentration), can inform how animals are responding to changing environmental conditions. Satellite telemetry has also been used to better understand exposure to different contaminant sources for mobile predators, including ringed seals (Brown et al. 2014b).

Contaminant concerns in coastal Labrador include the potential increase in methyl mercury (MeHg) concentrations due to 2 hydroelectric projects on the largest river in Labrador, the Churchill River, which flows into Lake Melville. One project, located in the upper Churchill River, has been generating electricity since the early 1970s (Smallwood Reservoir), and the Lower Churchill River project, since 2020 (Muskrat Falls). Increased MeHg concentrations in aquatic food webs of recently impounded reservoirs have been attributed to an increase in mobilized Hg and organic matter from flooded lands, oxygen depletion in the sediments, and subsequent microbial methylation of inorganic Hg (Hall et al. 2005, Schartup et al. 2015). Calder et al. (2016) suggested that MeHg will increase downstream of the recently developed Muskrat Falls dam (10-fold increase in riverine waters; 2.6-fold increase in estuarine waters) during flooding events due to disturbance of reservoir sediments. Therefore, MeHg may increase in fish, birds, and seals in the area post flooding (Calder et al. 2016), which is a concern for local residents who consume wildlife from the area. Another contaminant concern includes 2 significant point sources of polychlorinated biphenyls (PCBs) associated with former military radar stations on the Labrador coast (Saglek Fjord and Hopedale Harbour). PCBs from these sources are known to have contaminated Indigenous marine foods in the area (Kuzyk et al. 2005, Brown et al. 2009, ESG 2009).

Here, we describe the movements of ringed seals tagged at 2 locations on the Labrador coast: Lake Melville, a sub-Arctic, semi-enclosed estuary, formally classified as a fjard in southern Labrador with a Hg point source; and Saglek Fjord, an Arctic fjord in northern Labrador with a PCB point source (Brown et al. 2009, 2014a, Calder et al. 2016, Kamula et al. 2020). The movements of the seals tagged in Saglek Fjord relative to exposure to the local PCB source were previously described by Brown et al. (2014b); however, the detailed movements and habitat use of Saglet Fjord ringed seals relative to seals tagged in Lake Melville, with environmental variables and other known sources of contamination, have not. Therefore, the objectives of this study were to (1) describe the movements of ringed seals tagged at 2 locations on the Labrador coast, (2) compare movements and habitat use by tagging location relative to environmental variables (i.e. sea ice concentration, bathymetry, and distance from shore), and (3) use the habitat ranges for the seals tagged in the 2 areas and the time spent (%) analysis in the estuary/fjord where each seal was tagged to characterize ringed seals exposure to local contaminant sources in the region.

2. MATERIALS AND METHODS

2.1. Study animals

A total of 20 ringed seals were captured and equipped with a satellite-linked Platform Transmitter Terminal (PTT) (Wildlife Computers SPLASH; dimensions: 5 × 6 cm, weight: 65 g in air; see Brown et al. 2014b for details on capture, measuring, and tagging procedures) at Lake Melville ($n = 7$) and Saglek Fjord ($n = 13$), Labrador, Canada. Captures were conducted from June to September 2008 to 2011 (see Table 1).

A minimum age estimate was obtained by counting annuli on the claws of the forelimbs (McLaren 1958), and morphometric measurements (i.e. length and weight) were taken. The estimated age class for each seal was validated by comparing their length and weight measurements to those of Labrador ringed seals aged previously by longitudinally thin-sectioning a lower canine tooth and counting the annual growth layers in the cementum using a compound microscope and transmitted light (Stewart et al. 1996). Ringed seals ≤5 yr of age were considered subadults based on age of sexual maturity (≥6 yr of age, McLaren 1958; see Table 1 for morphometric measurements and satellite telemetry information per individual). A general linear model with age class as the dependent variable and standard length as the independent variable showed that adults were larger than subadults ($p < 0.01$, $R^2 = 0.63$).

The Nunatsiavut Government, Nunatsiavut Health and Environment Review Committee and the Fisheries and Oceans Canada (Newfoundland Region, Canada) Animal Care Committee approved all animal handling and sampling procedures.

2.2. Study areas

Lake Melville (53° 45′ N, 59° 27′ W) is a subarctic estuary adjacent to the high boreal forest ecoregion of southern Labrador that is formally classified as a fjard (rather than a fjord) because of its irregular bathymetry, low relief, and gentle undulating topography (Embleton & King 1968, Carpenter et al. 2020; see Fig. 1). Lake Melville is connected to Groswater Bay and the Labrador Sea through a narrow (2.8 km) channel known as Rigolet Narrows (Figs. S1 & S2 in the Supplement at www.int-res.com/articles/suppl/m710p137_supp.pdf). A shallow sill (30 m), located within the narrow, restricts the exchange of seawater between Lake Melville and Groswater Bay and helps to support upwelling for the area (Bobbitt & Akenhead 1982, Lu et al. 2013).

The Lake Melville system extends 130 km inland to the mouth of Goose Bay, which has 4 major rivers that discharge freshwater into it: Churchill, Goose, North West, and Kenamu (Figs. S1 & S2). The Churchill River is the largest of the 4 rivers, with a mean discharge of 1700 $m^3 s^{-1}$ (Bobbitt & Akenhead 1982), drains approximately 120 000 km^2 (Anderson 2011), and is one of the world's most prominent sources of hydroelectric power. The flooding of the Smallwood Reservoir in the 1970s, located in the Upper Churchill, caused MeHg concentrations to increase in fish in the river system, including 300 km downstream in Lake Melville (Anderson 2011). The more recent hydroelectric project (Muskrat Falls), located in the Lower Churchill, only 40 km from the mouth of the river that feeds into Lake Melville, is expected to further increase MeHg concentrations in aquatic biota. The 4 rivers contribute sediment-enriched freshwater to the cold saltwater of the Atlantic Ocean, creating a highly productive and species-diverse coastal ecosystem that provides food for ringed seals as well as other marine mammals, such as harp seals *Pagophilus groenlandicus*, humpback whales *Megaptera novaeangliae*, and minke whales *Balaenoptera acutorostrata* (Durkalec et al. 2016). As a result, Lake Melville has been identified as an 'Ecologically and Biologically Significant Area' by the Department of Fisheries and Oceans Canada (Durkalec et al. 2016).

Known fish species that live within the area include freshwater species such as lake whitefish *Coregonus clupeaformis*, longnose sucker *Catostomus catostomus*, and white sucker *Catostomos commersonii* (Durkalec et al. 2016) as well as diadromous species, such as brook trout *Salvelinus fontinalis* and rainbow smelt *Osmerus mordax*. Further, there are numerous Atlantic salmon *Salmo salar* and sea-run brook trout *Salvelinus fontinalis* spawning and juvenile rearing areas in the estuary and tributaries.

Saglek Fjord (58° 28′ N, 63° 18′ W) is an Arctic fjord in northern Labrador that extends >40 km inland from the coast (Figs. S3 & S4). The fjord is narrow (1.5–3 km), with steep slopes and sidewalls and underwater basins nearly 300 m deep that are separated by shallower sills (45–96 m). Saglek Fjord is connected to the Labrador Sea through Saglek Bay, an area that was heavily contaminated by PCBs from a former military radar station (Brown et al. 2009).

A number of catchments deliver freshwater and sediment to Saglek Fjord, including Nakvak Brook, which is one of the largest catchments located approximately halfway between where the fjord formally begins, near Jens Haven Island, to the head of the North and South arms (Figs. S3 & S4). Saglek Fjord is a highly productive ecosystem (Simo-Matchim et al. 2016) and is home to many fish and invertebrate species (Greenland cod *Gadus ogac*, capelin *Mallotus villosus*, shorthorn sculpin *Myoxocephalus scorpius*, snake blenny *Lumpenus lampretaeformis*, daubed shanny *Leptoclinus maculatus*, dusky snailfish *Liparis gibbus*, amphipod *Themisto libellula*, and Greenland shrimp *Eualus macilentus*) that are commonly preyed upon by ringed seals (Brown et al. 2015).

2.3. Satellite telemetry

Telemetry data were obtained via the ARGOS satellite system (System Argos). Ringed seal locations were estimated based on uplinks when the PTT communicated with ARGOS satellites while the individual was at the surface (Fedak et al. 2002). PTTs were programmed to send up to 250 transmissions d^{-1}, providing dive data (depth, duration). The transmission interval was every 45 s when the seal was at the surface in the water and every 90 s when hauled out.

2.4. Movement behaviour analysis

To account for observation error and infer behavioural states (area-restricted movement vs. transiting), we fit the Bayesian 2-state 'switching' state-space model described by Jonsen et al. (2005) to the time series of each seal's ARGOS locations using 'bsam' v.044 (Jonsen et al. 2013) in R v.3.6.1 by running Markov chain Monte Carlo (MCMC) methods using Just Another Gibbs Sampler at a 12 h time step. Two MCMC chains were run for 30 000 iterations, with a burn-in of 20 000 and thinned every 10 samples for a total of 1000 estimates in the posterior distribution. Temporal autocorrelation was assessed visually using trace and autocorrelation plots, and chain convergence was estimated using Gelman and Rubin's scale reduction factor (<1.1 for all parameters). Transiting behaviour (a behavioural state value closer to 0) consists of fast, directed movements, whereas area-restricted behaviour (a behavioural state value closer to 1) is identified by slow, non-directed movements, thought to occur when resting or foraging (Kareiva & Odell 1987, Dragon et al. 2012).

Estimated ringed seal locations at 12 h time steps were used to assess spatial distribution by calculating utilization distribution maps (UDs). UDs were estimated using 2 methods: minimal convex polygons (MCPs) and Brownian bridge kernels (BBs; Horne et al. 2007), implemented in the R package 'adehabitatHR' v.0.4.18 (Calenge 2006). MCPs are commonly used, but they can produce biased home range estimates by overestimating home range size (Burgman & Fox 2003). The BB method of home range estimation requires the specification of 2 smoothing parameters: sig1 and sig2. Sig1 controls the width of the 'bridge' between successive relocations and is complexly related to the speed of the animal, with larger sig1 values resulting in a wider bridge (Calenge 2006). This value was chosen for each animal using the 'liker' function ('adehabitatHR'), which implements a maximum likelihood approach developed by Horne et al. (2007). Sig2 controls the width of the size of the area around each relocation and is thus related to relocation imprecision (Calenge 2006). Sig2 was estimated using the longitudinal error from the state-space model outputs (sample-size-weighted average from all runs) in decimal degrees (0.008225°), converted to meters at 56.457136° N (the mean latitude for all seals). This resulted in a sig2 value of 510 m. Before estimating the UDs, locations were projected to a Universal Transverse Mercator coordinate system, zone 21 (Snyder 1987).

We estimated home range (95%) and core area (70%) contour intervals as previously described in Brown et al. (2014b), removing areas on land by clipping range polygons with high-resolution coastlines from the 'rnaturalearth' package in R (South 2017). The selection of a 70% core area was in keeping with a core area needing to contain at least 50% of locations (Kenward et al. 2001, Di Pierro et al. 2008). UDs were calculated for each individual and for each group of seals (i.e. Lake Melville and Saglek).

Distance travelled away from the tagging location for each seal was calculated in R v.3.6.1 (R Core Team 2019) using the 'spDistsN1' function in the package 'sp' (Pebesma & Bivand 2005, Bivand et al. 2013).

2.5. Environmental variables

Bathymetry (depth in m), sea ice concentration (%), salinity (psu), sea surface temperature (°C), net primary productivity (mg C m^{-2} d^{-1}), chlorophyll *a* (mg m^{-3}), and distance from shore (km) were extracted at each seal location using ArcGIS 10.1 software (ESRI). However, only bathymetry, sea ice concentration, and distance from shore had sufficient data (>70%) at each location to be used in the analysis. Sea ice concentration data were obtained via Special Sensor Microwave/Imager (SSM/I) passive microwave data at a spatial resolution of 25 km in 8 d composite images (Cavalieri et al. 1996).

Resident behaviour variability relative to sea ice concentration within and among years between study locations was obtained from weekly sea ice concentration estimates from 2008 to 2012, including each study location, using the Canadian Ice Service's IceGraph 2.0 tool (https://open.canada.ca/en/apps/icegraph-20-tool, accessed September 2014; Yurkowski et al. 2016a). Following the methods of Stirling et al. (1999), ice-free and ice-covered conditions at each study location were defined by total sea ice concentration <50 and ≥50%, respectively. This cutoff was chosen because sea ice concentrations under 50% generally coincide with peak phytoplankton biomass and productivity (Rysgaard et al. 1999, Smith et al. 2000). Bathymetry (m) was extracted from GEBCO (IOC) at a resolution of 30 arc-seconds. Seal location estimates that were on the shoreline were given a bathymetric value of 1 m. Distance from shore was measured in R using the 'st_distance' function in the 'sf' package (Pebesma 2018), which calculated the minimum distance between each seal location and shore.

2.6. Statistical analysis

Variables were tested for normality and homoscedasticity using Shapiro-Wilk and Levene's tests, respectively. Either *t*-tests (when data were normal and homoscedastic) or Wilcoxon rank sum tests (when data were not normal and/or were heteroscedastic) were used to compare distances travelled, movement rates, and percentage of time spent conducting area-restricted movements between seals tagged at the 2 locations, using the location estimates from the state-space models.

Results are reported as mean ± SD of non-transformed data throughout. Analyses were performed using R v.3.6.1 (R Core Team 2019), and the level of statistical significance used was $\alpha \leq 0.05$. Linear mixed-effects models (GLMMs) were run using 'glmmPQL' from the R package 'MASS' (Venables & Ripley 2002) to examine the effects of sea ice, bathymetry, distance to shore, age class, and sex on ringed seal behavioural states (dependent variable) between a value of 0 (transiting) and 1 (area-restricted movement). Seal ID was included as a random effect, and sea ice concentration, bathymetry, distance to shore, age class, and sex were fixed effects.

Additional models were run with all above variables and with both locations grouped, with location included as a random effect in addition to seal ID, to examine patterns among subadult and adult age groups. An autocorrelation structure of order 1 was included in each model, and model fit was assessed using r^2 values calculated using the 'r.squaredGLMM' function in the 'MuMIn' package (Barton 2020). Models were run in a stepwise manner, removing non-significant variables until all predictors were significant following the procedure outlined in Zuur et al. (2009). Collinearity between variables was assessed with variance inflation factors using the 'vif' function in the 'car' package (Fox & Weisberg 2019), with all values ≤ 2.5.

3. RESULTS

PTTs were deployed from June–September on 13 ringed seals in Saglek Fjord (2 adult males, 5 subadult females, 6 subadult males) and 7 in Lake Melville (2 adult females, 3 subadult females, 2 subadult males; Table 1). Deployment duration for Saglek seals ranged from 114–274 d, with an average of 172 ± 58 d, and duration for Lake Melville seals ranged from 21–246 d, with an average of 185 ± 87 d (Table 1). The average number of ARGOS locations observed per individual was 1512 ± 832 and ranged from 104–2999 across all individuals.

3.1. Movement behaviour

The total distance travelled (km), maximum distance from their tagging location, movement rate (km d^{-1}), and time spent (%) in the estuary/fjord where each seal was tagged are reported in Table 2. No differences were found between locations for the total distance travelled (Welch 2-sample *t*-test: $t_{8.92}$ = 1.28, p = 0.23; Lake Melville: 1991 ± 1147 km, n = 7; Saglek Fjord: 1376 ± 759.5 km, n = 13), maximum distance travelled from tagging location (Wilcoxon rank sum test: *W* = 48, p = 0.88; Lake Melville: 252.3 ± 178.0 km, n = 7; Saglek Fjord: 278.8 ± 284.4 km, n = 13), distance travelled during the open water period (Welch 2-sample *t*-test: $t_{8.73}$ = 0.97, p = 0.36; Lake Melville: 1654 ± 394.1 km, n = 7; Saglek Fjord: 1232 ± 185.3 km, n = 13), distance travelled during the ice-covered period (Wilcoxon rank sum exact test: *W* = 14, p = 0.26; Lake Melville: 781.72 ± 391.07 km, n = 3; Saglek Fjord: 303.64 ± 110.47 km, n = 6), or movement rate (Wilcoxon rank sum test: *W* = 48, p = 0.88; Lake Melville: 10.35 ± 4.070 km d^{-1}; Saglek Fjord: 10.92 ± 5.695 km d^{-1}). Time spent in the tagging inlet was significantly different, with Lake Melville seals spending more time in the inlet (see Section 3.2 below).

3.1.1. Lake Melville

All movement tracks for the Lake Melville seals are depicted in Figs. 1A & S5. The 2 adult females (LM-10-02, LM-10-03) remained within Lake Melville, whereas the 5 subadults spent between 37 and 94% of their time in Lake Melville (Table 2). Three of the 5 subadults spent more than 50% of their time in Lake Melville (Table 2), with the remainder of their time spent travelling either offshore or to the south along the coast. One subadult male (LM-10-01) left Lake Melville on 18 June 2010, travelled 300 km offshore, then returned to the estuary on 3 August. The

Table 1. Morphometrics, tagging location, and tracking period for ringed seals tagged in Lake Melville (n = 7) and Saglek Fjord (n = 13), Labrador, Canada. Dates given as yyyy-mm-dd

Seal ID	Tagging location	Sex	Age category	Mass (kg)	Length (cm)	Axillary girth (cm)	Tagging date	Date of last transmission	Track end date	Days tagged (d)
LM-09-09	Lake Melville	Female	Subadult	24.5	82.5	80	2009-09-18	2010-05-22	2010-05-21	246
LM-09-10	Lake Melville	Female	Subadult	22.5	93	76	2009-09-18	2010-01-05	2010-01-04	109
LM-09-14	Lake Melville	Female	Subadult	35	103.5	87.5	2009-09-21	2010-05-22	2010-05-21	243
LM-09-19	Lake Melville	Male	Subadult	30	107.5	87	2009-09-25	2010-05-03	2010-05-03	220
LM-10-01	Lake Melville	Male	Subadult	21	85.5	75.5	2010-06-12	2011-01-25	2011-01-18	227
LM-10-02	Lake Melville	Female	Adult	38	114	90	2010-07-20	2010-08-10	2010-08-09	21
LM-10-03	Lake Melville	Female	Adult	53	132	107.5	2010-07-20	2011-03-03	2011-01-30	226
SB-08-01	Saglek Fjord	Male	Subadult	25	90	83	2008-08-11	2009-04-29	2008-12-31	261
SB-08-02	Saglek Fjord	Male	Adult	84	124	127	2008-08-14	2009-01-24	2008-12-20	163
SB-08-03	Saglek Fjord	Female	Subadult	37	96	87	2008-08-19	2008-12-24	2008-10-25	127
SB-09-04	Saglek Fjord	Male	Subadult	32	94	85	2009-09-01	2009-12-24	2009-10-21	114
SB-09-05	Saglek Fjord	Male	Subadult	23	91	72	2009-09-01	2009-12-31	2009-10-12	121
SB-09-08	Saglek Fjord	Male	Subadult	24	95	79	2009-09-01	2009-12-26	2009-12-01	116
SB-10-09	Saglek Fjord	Female	Subadult	26	83	76	2010-09-01	2011-04-21	2011-04-20	232
SB-10-10	Saglek Fjord	Male	Subadult	31	96	85	2010-09-01	2011-01-14	2010-12-28	135
SB-10-11	Saglek Fjord	Male	Subadult	27	91	83	2010-09-01	2011-03-06	2011-03-06	186
SB-10-12	Saglek Fjord	Female	Subadult	34	113	85	2010-09-02	2011-06-03	2011-06-03	274
SB-10-13	Saglek Fjord	Female	Subadult	29	95	84	2010-09-02	2011-04-06	2011-01-25	216
SB-11-14	Saglek Fjord	Male	Adult	73	128	84	2011-08-11	2012-01-27	2012-01-27	169
SB-11-15	Saglek Fjord	Female	Subadult	38	90	82	2011-08-11	2011-12-15	2011-12-14	126

Table 2. Distance travelled by each ringed seal, maximum distance travelled away from their tagging location, movement rate, and time spent in the estuary/fjord where they were tagged. Seals were tagged in Lake Melville (n = 7; 2009–2010) and Saglek Fjord (n = 13; 2008–2011), Labrador, Canada

Seal ID	Tagging location	Total distance travelled (km)	Max. distance from tagging location (km)	Movement rate (km d^{-1})	Time spent in the tagging estuary/fjord (%)
LM-09-09	Lake Melville	2164	209.5	8.830	36.66
LM-09-10	Lake Melville	1283	259.7	11.88	94.01
LM-09-14	Lake Melville	1996	185.2	8.250	43.01
LM-09-19	Lake Melville	3008	557.8	13.67	49.77
LM-10-01	Lake Melville	3615	406.5	16.51	79.09
LM-10-02	Lake Melville	80.26	39.5	4.010	100.0
LM-10-03	Lake Melville	1790	107.7	9.280	100.0
Average ± SD		1991 ± 1147	252 ± 178	10.35 ± 4.070	71.79 ± 27.95
SB-08-01	Saglek Fjord	1651	210.6	11.63	14.79
SB-08-02	Saglek Fjord	753.4	13.40	5.890	100.0
SB-08-03	Saglek Fjord	441.1	65.60	6.580	27.61
SB-09-04	Saglek Fjord	379.6	43.20	7.590	37.00
SB-09-05	Saglek Fjord	1013	436.5	24.72	2.440
SB-09-08	Saglek Fjord	1078	522.0	11.85	73.77
SB-10-09	Saglek Fjord	2177	755.2	9.420	12.93
SB-10-10	Saglek Fjord	1053	90.40	9.000	82.13
SB-10-11	Saglek Fjord	1947	186.4	10.47	34.95
SB-10-12	Saglek Fjord	1537	74.40	5.610	2.060
SB-10-13	Saglek Fjord	2920	887.5	20.14	5.140
SB-11-14	Saglek Fjord	2128	209.7	12.59	69.91
SB-11-15	Saglek Fjord	806.3	129.1	6.450	2.390
Average ± SD		1376 ± 759.5	278.8 ± 284.4	10.92 ± 5.695	35.78 ± 34.42

other subadult male (LM-09-19) left Lake Melville on 13 January 2010 and travelled the farthest (558 km) south to Springdale in Newfoundland until the track end date on 3 May 2010. A subadult female (LM-09-10) left Lake Melville on 29 December 2009, travelled south 260 km to Saint Lewis and did not return to the estuary before the track end date on 4 January 2010. The 2 juvenile subadult females (LM-09-09 and LM-09-14) spent 37 and 43% of their time in Lake Melville, respectively (Table 2). LM-09-09 travelled to Goose Bay, up the Lower Churchill River towards the Muskrat Falls site, and left the Lake Melville estuary on 28 November 2009, travelling 210 km south along the coast before returning on 3 May 2010. The other female (LM-09-14) spent time around Rigolet in the outer estuary, left the area on 31 December 2009, and travelled 185 km north along the coast to Hopedale until the track end date on 21 May 2010.

3.1.2. Saglek Fjord

All movement tracks for the Saglek Fjord ringed seals are depicted in Figs. 1B,C & S6. One adult male (SB-08-02) remained within Saglek Fjord during its entire tagged period, whereas the other adult male (SB-11-14) remained within Saglek Fjord for 70% of the time (Table 2) and then travelled 216 km south to South Aulatsivik Island, which is just north of the community of Nain, Labrador (56° 32′ 32″ N, 61° 41′ 34″ W). Two subadult males (SB-10-10 and SB-09-08) spent more than 70% of their time in Saglek Fjord (Table 2); for the remainder of the time, SB-10-10 travelled north (90 km) to the mouth of Nachvak Fjord (59° 02′ 09″ N, 63° 44′ 52″ W) until the track end date on 28 December 2010, and SB-09-08 travelled 522 km south, almost to Lake Melville until the track ended on 1 December 2009. One subadult male (SB-09-04) and 2 subadult females (SB-08-03 and SB-10-12) spent less time (2–37%) in Saglek Fjord (Table 2) and more time within 70 km of their tagging location in the neighbouring fjords and inlets. A subadult female (SB-11-15) and male (SB-10-11) also spent less time (2 and 35%, respectively) in Saglek Fjord (Table 2) and more time 120 km south in and around Okak Fjord (57° 26′ N, 62° 25′ W). The remaining subadults, 2 males (SB-09-05 and SB-08-01) and 2 females (SB-10-13 and SB-10-09), spent between 2 and 15% of their time in Saglek Fjord (Table 2); the rest was spent travelling great distances (range: 1013–2920 km) offshore, along the Labrador coast, across Ungava Bay, or up through Hudson Strait and along Baffin Island.

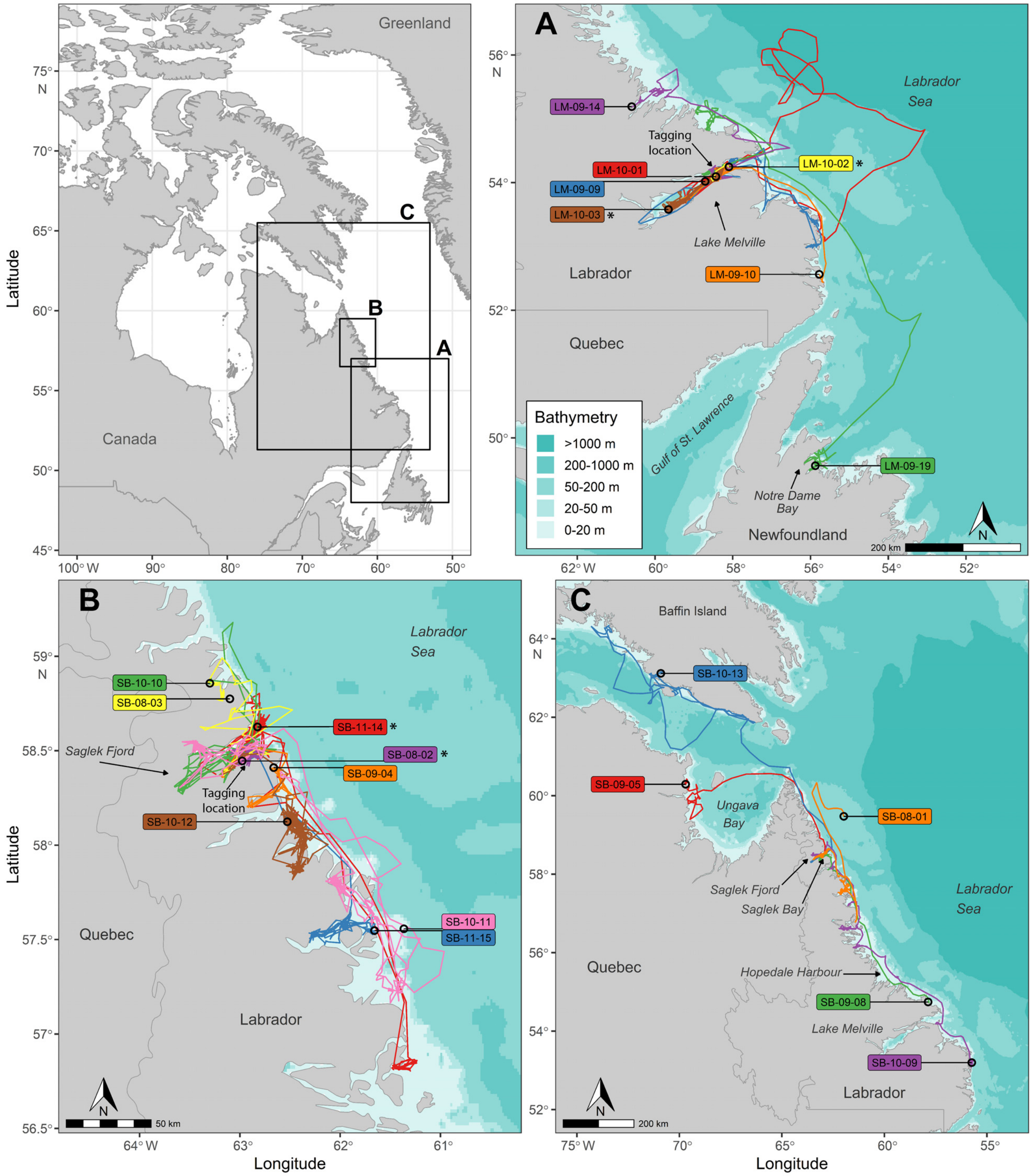

Fig. 1. Movements of ringed seals tagged in (A) Lake Melville (n = 7; 2009–2010) and (B,C) Saglek Fjord (n = 13; 2008–2011), Labrador, Canada. Each track line represents a different seal, identified in the text boxes. Adult seals are indicated by an asterisk next to the ID label. Placement of coloured seal ID boxes indicates the final recorded location for each individual

3.2. Local vs. non-local behaviour

Across both locations, 45% (9 of 20) of the seals spent ≥50% of their time in the local fjord or fjard where they were tagged (Table 2). There were no differences observed in the distance travelled and movement rate metrics ($p > 0.05$) between seals that remained local to the inlet in which they were tagged compared to those that spent <50% of their time in the inlet. These included the following metrics: total distance travelled (Welch 2-sample *t*-test: $t_{14.14} = 0.21$, p = 0.83; local: 1643.27 ± 1120.39 km, n = 9; non-local: 1548.36 ± 803.33 km, n =11), maximum distance travelled from tagging location (Wilcoxon rank sum test: *W* = 47, p = 0.88; local: 245.19 ± 206.38 km, n = 9; non-local: 289.38 ± 285.13 km, n = 9), distance travelled during open water conditions (Welch 2-sample *t*-test: $t_{9.55} = 1.59$, p = 0.14; local: 700.14 ± 419.19 km, n = 7; non-local: 413.19 ± 284.96 km, n = 11), distance travelled during ice-covered conditions (Wilcoxon rank sum exact test: *W* = 28, p = 1.00; local: 273.71 ± 209.23 km, n = 7; non-local: 304.71 ± 273.81 km, n = 8), and movement rate (Wilcoxon rank sum test: *W* = 58, p = 0.55; local: 10.52 ± 3.90 km d^{-1}, n = 9; non-local: 10.88 ± 6.07 km d^{-1}, n = 11).

Most Lake Melville ringed seals (71%, 5 of 7; Table 2) spent ≥50% of their time in Lake Melville, whereas relatively few ringed seals tagged in Saglek Fjord spent ≥50% of their time in Saglek Fjord (31%, 4 of 13; Table 2). On average, the Lake Melville ringed seals spent a greater percentage of their time (71.79 ± 27.95%, n = 7) in the estuary in which they were tagged relative to the Saglek Fjord ringed seals (35.78 ± 34.42%, n = 13; Wilcoxon rank sum test: *W* = 74, p = 0.03).

3.3. Utilization distributions

The combined home range (95% polygon) for Lake Melville ringed seals was 84 968 and 15 001 km^2, using the MCP and BB methods, respectively, compared to 196 886 and 29 149 km^2 for the Saglek Fjord seals. The combined core area (70% polygon) for Lake Melville ringed seals was 14 916 and 1748 km^2 using the MCP and BB methods, respectively, compared to 6665 and 5440 km^2 for the Saglek Fjord ringed seals (Fig. 2). Average BB home range size did not differ (Wilcoxon rank sum test: *W* = 48, p = 0.88) between the Lake Melville seals (2638 ± 2977 km^2) and Saglek Fjord seals (2765 ± 3716 km^2), nor was there a difference (Welch 2-sample *t*-test: $t_{13.00} = 0.04$,

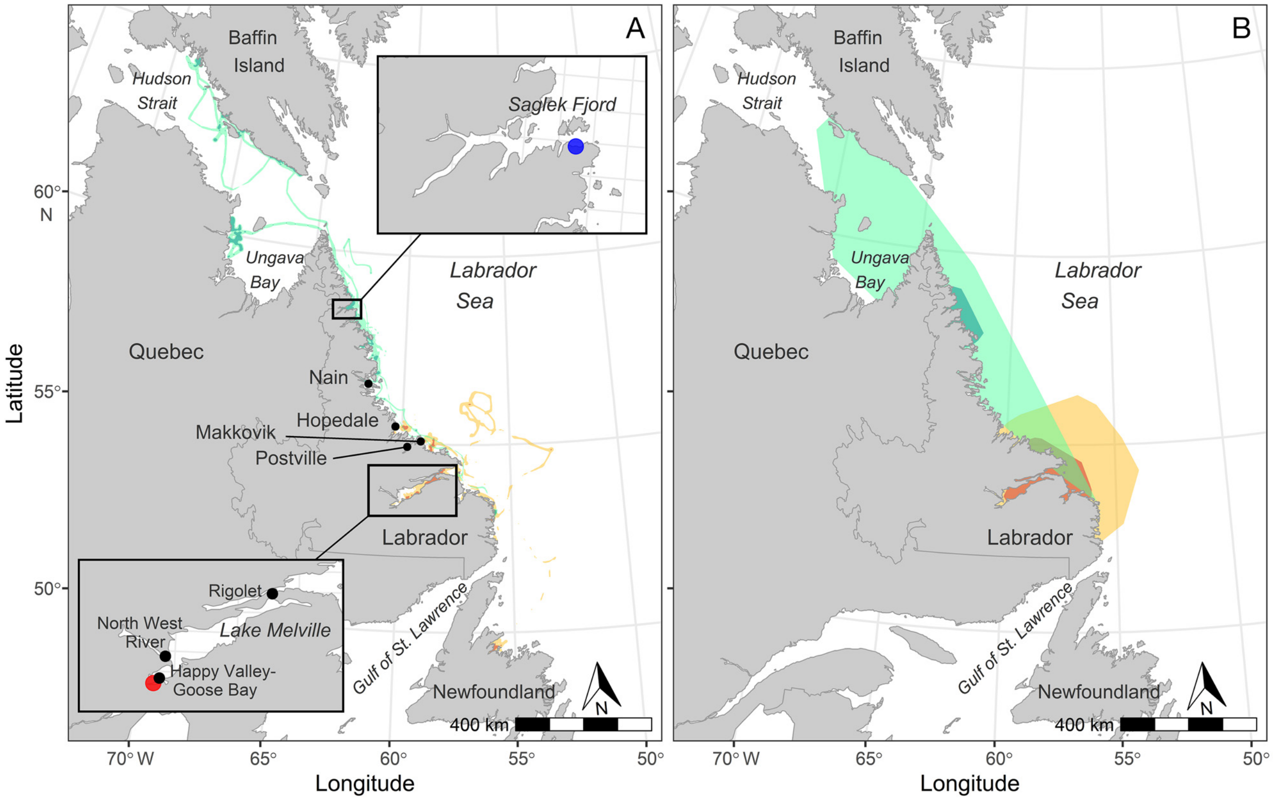

Fig. 2. Divergent space use of ringed seals tagged in Lake Melville (n = 7; 2009–2010; orange shading) and Saglek Fjord (n = 13; 2008–2011; green shading), Labrador, Canada, as determined by (A) Brownian bridge movement models and (B) Minimum convex polygons. Home ranges (95%) are represented with lighter shading; core areas (70%) are represented with darker shading. Red circle: location of the Muskrat Falls hydroelectric development; blue circle: location of PCB-contaminated area in Saglek Bay

p = 0.97) in the size of the average BB core areas between the Lake Melville seals (359 ± 269 km^2) and Saglek Fjord seals (479 ± 634 km^2). There was similarly no difference in MCP home range area (Lake Melville: 19 724 ± 28 263 km^2, Saglek Fjord: 16 857 ± 27 528 km^2; Wilcoxon rank sum test: $W = 52$, p = 0.64) or core area (Lake Melville: 3765 ± 4120 km^2; Saglek Fjord: 6954 ± 13 766 km^2; Wilcoxon rank sum test: $W = 50$, p = 0.77) between ringed seals from the 2 tagging locations. There was minimal overlap in the home range (MCP = 9.76 %; BB = 1.61 %) and 0 % overlap in the core area between the Saglek Fjord and Lake Melville ringed seals (Fig. 2). Home range overlap calculated using the MCP method was higher than using the BB method but overlap remained below 10 % in both cases.

3.4. Behavioural state (area-restricted vs. transiting) in relation to environment

Bathymetry and distance to shore data were available for all modelled locations (n = 3056), and sea ice data were available for 2116 locations (70 % of the total). Distance travelled during the open water period (Lake Melville: 1654.3 ± 1042.8 km, n = 7; Saglek Fjord: 1231.9 ± 668.0 km, n = 13) was greater than distance travelled during the ice-covered period for Saglek Fjord seals (303.6 ± 270.6 km, n = 6; Welch 2-sample *t*-test: $t_{16.92} = -4.30$, $p < 0.001$), but not for Lake Melville seals (781.7 ± 677.4 km, n = 3; Welch 2-sample *t*-test: $t_{6.05} = -1.57$, p = 0.17). Sea ice and distance to shore had a significant effect on the behavioural state of Lake Melville ringed seals in all stepwise GLMM runs ($p \leq 0.01$, theoretical $R^2_C = 0.15$; Table S1), with individuals transiting more during open water conditions (25.5 ± 10.5 %, n = 5) than during ice-covered conditions (9.2 ± 7.2 %, n = 6) and when farther from shore than near shore (Table S1). The behavioural state of Saglek Fjord ringed seals was not significantly predicted by sea ice, bathymetry, or distance to shore ($p > 0.05$, theoretical $R^2_C = 0.17$; Table S2). Summary statistics (mean ± SD) of sea ice concentration, bathymetry, and distance to shore at each ringed seal location are presented in Table S3.

3.5. Behavioural state (area-restricted vs. transiting) relative to sex and age

GLMMs of all seals, with ID and tagging location as random effects, revealed that sex had no effect (p = 0.84, theoretical $R^2_C = 0.26$; Table S4) on the behavioural state of Labrador ringed seals. However, age class had a significant effect (p = 0.04; Table S4), with subadults spending more time (9.7 ± 9.2 %, n = 16) transiting compared to adults (1.8 ± 2.4 %, n = 4; Wilcoxon rank sum test: $W = 9$, p = 0.03). This result was consistent during ice-covered (adult: 1.63 ± 2.82 %, n = 3; subadult: 13.49 ± 14.01 %, n = 12; Welch 2-sample *t*-test: $t_{12.98} = -2.72$, p = 0.02) and open water periods (adults: 3.53 ± 4.99 %, n = 2; subadults: 22.39 ± 21.76 %, n = 16; Welch 2-sample *t*-test: $t_{8.28} = -2.91$, p = 0.02). Conversely, adults spent more time (98.23 ± 2.37 %, n = 4) in an area-restricted state compared to subadults (90.32 ± 9.18 %, n = 16; Wilcoxon rank sum test: $W = 55$, p = 0.03) throughout their respective tracked periods. This result was also consistent during both ice-covered (adults: 98.37 ± 2.82 %, n = 3; subadults: 86.51 ± 14.01 %; n = 12; Welch 2-sample *t*-test: $t_{12.98} = 2.72$, p = 0.02) and open water (adults: 96.47 ± 4.99 %, n = 2; subadults: 77.61 ± 21.76 %; n = 16; Welch 2-sample *t*-test: $t_{8.28} = 2.91$, p = 0.02) periods. In the context of environmental variables, distance to shore influenced the behavioural state of the subadults, with more area-restricted movements observed closer to shore ($p < 0.001$, theoretical $R^2_C = 0.11$; Table S5). For adults, none of the investigated environmental variables significantly predicted their behavioural state ($p > 0.05$, theoretical $R^2_C = 0.06$; Table S6). These sex- and age-class differences should be interpreted with some caution, however, due to our relatively small sample sizes.

4. DISCUSSION

This study presents a detailed analysis of the different movement behaviour and habitat use of ringed seals tagged in Saglek Fjord and those tagged in Lake Melville. Less than 10 % overlap in home range and 0 % overlap in core area use may be explained by the use of different foraging strategies or prey availability in the 2 areas. For example, over 70 % of the seals tagged in Lake Melville spent more than 50 % of their time in the estuary, and their behavioural state was influenced by sea ice concentration in that seals tended to show more area-restricted behaviour during the ice-covered season than during the open water season, whereas the seals tagged in Saglek Fjord spent very little time in the fjord and their behavioural state was not dependent on sea ice concentration. In addition, the minimal home range overlap between the Lake Melville and Saglek Fjord ringed seals suggests the potential for distinct ringed seal stocks, which could have implications for conservation and management strategies along the coast. The behaviour of ringed seals tagged at both locations also differed by age class, with adults spending more time in an area-restricted state and subadults spending more time in a transiting state regardless of tagging location. Distance to shore also influenced the behavioural state of the subadults, whereby more area-restricted movement behaviour was observed closer to shore.

4.1. Habitat range and use

Ringed seals tagged in Lake Melville maintained a more southerly home range along the Labrador coast, from Hopedale to Mary's Harbour (Figs. 2, S1 & S2), compared to the seals tagged in Saglek Fjord, which generally displayed a much larger and more northerly home range from the southwest coast of Baffin Island in the Eastern Canadian Arctic to the small fishing community of Black Tickle, located in southern Labrador (Figs. S3 & S4). Movements of the Saglek ringed seals, particularly subadults, were variable, with some seals transiting to the west coast of Ungava Bay, across Hudson Strait, and along the southwestern coast of Baffin Island, while others remained along or just offshore of the Labrador coast. This is consistent with the movements of ringed seals reported in other areas of the Arctic, where some seals travelled over large distances (Ridoux et al. 1998, Teilmann et al. 1999, Freitas et al. 2008, Crawford et al. 2012, Harwood et al. 2012, Von Duyke et al. 2020), whereas others stayed within a much smaller area (Smith & Hammill 1981, Kapel et al. 1988, Freitas et al. 2008, Harkonen et al. 2008, Lydersen et al. 2014).

The core areas for Lake Melville ringed seals were concentrated largely within Lake Melville, along the southern shore, in and around Rigolet Narrows, and in Groswater Bay (Figs. S1 & S2). In addition, one seal swam up Goose Bay Narrows and the Goose River. The core areas of Saglek ringed seals to the north were largely within coastal inlets along the northern Labrador coast, west coast of Ungava Bay, and southwestern coast of Baffin Island (Figs. S3 & S4).

The core areas of Lake Melville ringed seals suggest a greater preference for the area in which they were tagged compared to the Saglek Fjord ringed seals. For example, 60% of the Lake Melville subadult ringed seals remained in the estuary for more than 50% of their time, whereas only 18% of the Saglek subadults spent more than 50% of their time in Saglek Fjord. While both inlets are known to be productive (Durkalec et al. 2016, Simo-Matchim et al. 2016), Lake Melville's productivity may be higher, with greater prey diversity than Saglek Fjord, as lower latitudes generally have increased species diversity (Bluhm et al. 2011). Ringed seals tagged in Lake Melville may also have greater access to fish with lower dispersal behaviours and greater predictability in their distribution due to the longer ice-free period (Yurkowski et al. 2016a). In contrast, ringed seals tagged in Saglek Fjord may be feeding more on Arctic cod, which have been declining in abundance at low- and mid-Arctic latitudes since the 1990s and have high dispersal behaviour and more patchy distributions (McNicholl et al. 2016). Arctic cod have been identified as an important prey for ringed seals harvested from 4 northern Labrador inlets, including Saglek Fjord. This finding has been reported using stable isotope mixing models (Yurkowski et al. 2016b), fatty acid profiles (Brown et al. 2015), and stomach content data (B. Sjare & T. M. Brown unpubl. data). Further, the overall preference for Lake Melville by seals tagged in that area may also reflect an area less frequented by predators, such as polar bears *Ursus maritimus*, Greenland sharks *Somniosus microcephalus*, and killer whales *Orcinus orca*.

Although sample sizes are small, adult ringed seals appeared to display greater preference for their tagging areas than subadults across both sites. The 2 adult females from Lake Melville (LM-10-02 and LM-10-03) and 1 adult male from Saglek Fjord (SB-08-02) remained in their respective tagging areas for the entire tracking period, and the other adult male from Saglek (SB-11-14) spent 70% of his time in that fjord. Further, 1 adult female from Lake Melville (LM-10-02; Fig. S5) and 1 adult male from Saglek Fjord (SB-08-02; Fig. S6) displayed extreme preferences for specific regions near their tagging areas. The female occupied only the Rigolet Narrows and Groswater Bay area near the entrance of Lake Melville, and the male mainly occupied the southwestern part of Saglek Fjord. Similar habitat preferences have been previously observed in adult ringed seals. For example, large adult ringed seals in Svalbard displayed high preference for tidewater glacier front habitat while subadults were highly mobile (Lydersen et al. 2014); in winter, adult ringed seals preferred heavy ice habitat in the Chukchi Sea while subadults preferred the looser ice at the ice edge in the Bering Sea (Crawford et al. 2012); and strong site preference was observed in adult ringed seals from 3 areas of the Baltic Sea (Harkonen et al. 2008). A strong preference for specific areas or site fidelity to known breeding areas are also more commonly observed among adults compared to subadults in other marine mammal species, including harbour seals *Phoca vitulina*, northern fur seals *Callorhinus ursinus*, and Weddell seals *Leptonychotes weddellii* (Harkonen & Harding 2001, Cameron et al. 2007, Hoffman & Forcada 2012, Dietz et al. 2013).

Age-class is often a defining variable for movement behaviour in ringed seals (Kelly et al. 2010, Crawford et al. 2012, Yurkowski et al. 2016a), with adults tending to spend more time in an area-restricted state relative to subadults, which lack reproductive pressure to maintain territories under shore-fast ice (Smith & Stirling 1975, Smith et al. 1991, Kelly et al. 2010). These observations are consistent with our results, despite our relatively low adult sample size; adults more often exhibited area-restricted movement behaviours than subadults, which were generally in a more transiting state. Furthermore, the fact that the adult females remained within Lake Melville for the entire tracking period supports the recognition of Lake Melville as an important ringed seal overwintering and breeding area and is consistent with the findings of other studies noted below (Durkalec et al. 2016). Previous studies have reported overlapping use of territories by more than one adult female during the breeding season, and that the above- and under-ice ranges of adult females tend to be larger than those of males (Kelly et al. 2010). Further, it has been suggested that adult males have been found to guard their mate by positioning themselves near the main breathing hole of a post-parturient female (Kelly et al. 2010). In contrast, subadults tend to be displaced to less-stable peripheral areas (McLaren 1958, Smith 1973). This spatial segregation is most common during the winter and spring breeding period, when adult ringed seals establish their territories, but can be observed as early as ice formation in the fall (Smith & Hammill 1981, Crawford et al. 2012). In the present study, however, no age-related spatial segregation was observed during the open water or ice-covered period. Subadults in the present study may be selecting to travel long distances to marginal sea ice, where they have a productive prey base, no need to maintain a breathing hole, and low polar bear predation risk, as suggested by Crawford et al. (2012).

Distance to shore also influenced the behavioural state of the subadult seals from both tagged areas, where more area-restricted movement behaviour was observed closer to shore. This could be due to preferred prey being more abundant and/or accessible in coastal areas relative to farther offshore. The northern fjords of Labrador and the Lake Melville area have been characterized as highly productive and biodiverse (Brown et al. 2012, Durkalec et al. 2016, Simo-Matchim et al. 2016). In addition, coastal areas along the northern Labrador coast are also generally characterized by having shore-fast ice during the winter months, which can provide adequate snow cover to minimise risk of predation by polar bears to ringed seals hauled out in lairs, creating a safer area for foraging (Smith & Hammill 1981, Pilfold et al. 2014).

4.2. Movement behaviour relative to sea ice concentration

Ringed seals tagged at Saglek Fjord were more mobile during the open water period and travelled greater distances compared to the ice-covered period. These results are consistent with previous studies, which have shown that ringed seals travel more during the open water period, when constraints imposed by sea ice are negligible or absent (Crawford et al. 2012, Harwood et al. 2012, Luque et al. 2014). Sea ice concentration influenced the behavioural state (area-restricted vs. transiting) of the ringed seals tagged in Lake Melville, with these seals exhibiting more area-restricted behaviour during ≥50% ice-covered conditions. One explanation may be that the Lake Melville seals are feeding more under the ice and, therefore, do not need to transit to other areas to find prey compared to seals tagged in Saglek Fjord. During the ice-covered period, ringed seals maintain holes through the ice that they use for access to air and the sea ice surface, which they use as a platform for resting (McLaren 1958). The need to maintain breathing holes throughout the ice-covered period restricts ringed seal movements to limited areas around or between breathing holes (McLaren 1958, Kelly & Quakenbush 1990, Kelly et al. 2010). Both sexes also excavate subnivean lairs above some of their breathing holes; however, in the spring, adult females use lairs to also give birth and nurse their young (Smith & Hammill 1981). These interactions with the sea ice, especially for the adult females in Lake Melville, likely explain, at least in part, the reduced ringed seal movement observed during ice-covered conditions in the present study.

Declining sea ice conditions associated with climate change could have stronger implications for Lake Melville seals, as their behavioural states appeared to be more influenced by the presence of sea ice than were Saglek Fjord seals. Yurkowski et al. (2016a) found that ringed seals inhabiting lower latitudes tend to be less adjusted to sea ice unpredictability between years and to a longer ice-free duration, which resulted in lower latitude seals spending more time in an area-restricted state and having lower movement rates relative to higher latitude individuals. The loss of sea ice over time in the Arctic, however, would be expected to impact ringed seals if prey quality is reduced, prey become less available, or if ice as a substrate for pupping and nursing is not adequate (Kovacs & Lydersen 2008, Laidre et al. 2008, 2015, Moore & Huntington 2008, Kovacs et al. 2011). Further, sea ice plays a significant role in the distribution and abundance of key ringed seal prey species, with a northward expansion of species from the south (Kortsch et al. 2015) potentially having significant implications for ringed seal condition and health. Despite ringed seals exhibiting adaptive foraging strategies that reflect the variety of sea ice conditions across the Arctic (Yurkowski et al. 2016a), negative impacts on their demography, feeding ecology, and body condition have been associated with climate change in Canada (Ferguson et al. 2005, 2017, Harwood et al. 2015, Brown & Noël 2018).

4.3. Exposure to local contaminant sources

The habitat use of ringed seals in our 2 study areas has strong potential to affect exposure to contaminants. The habitat ranges for seals tagged in the 2 areas and the time spent (%) in the estuary/fjord where each seal was tagged, along with associated proximity to the known point sources of PCBs (Saglek Bay and Hopedale Harbour) and Hg (associated with the Muskrat Falls Reservoir), illustrate a ready pathway for heightened contaminant exposure in certain ringed seals.

Saglek Bay has been the site of a military radar station since the late 1950s; however, it was not until 1996 that PCB contamination was discovered at the site, along with evidence that PCBs had entered the marine environment (Kuzyk et al. 2005). Approximately 260 kg of PCBs were released into the marine environment (ESG 2000), contaminating adjacent marine sediments, benthic invertebrates, bottom-feeding fish, diving seabirds (Kuzyk et al. 2005, Brown et al. 2009), and up to 60 % of the ringed seals sampled in the central and northern Labrador coast (Brown et al. 2014a). The abandoned military radar station in Hopedale, located approximately 1 km from the community (approximate population: 625), was built in the 1950s and decommissioned in 1985. At that time, some site remediation was conducted, although investigations in 2011 revealed that sediment concentrations of PCBs in Hopedale Harbour exceeded the Canadian Council of Ministers of the Environment (CCME) Interim Sediment Quality Guideline (ISQG) and CCME Probable Effects Level (PEL). A study using the Saglek Fjord telemetry data presented in this paper, as well as contaminant and dietary tracer data, revealed that small home range and core area sizes, as well as increased time in coastal inlets, contributed to increased PCB exposure in ringed seals from northern Labrador (Brown et al. 2014b). Results from the current study build on this earlier assessment and provide evidence that the Lake Melville seals are not likely to be exposed to the residual PCB contamination at Saglek Bay given their more southerly habitat range. However, the Lake Melville ringed seals as well as the Saglek seals may be exposed to the PCB contamination in Hopedale Harbour, given that this area was within their habitat ranges.

The lower Churchill River provides >60 % of freshwater inputs to Lake Melville (Schartup et al. 2015). In September 2019, 41 km^2 of land was flooded to create a hydro-reservoir of 101 km^2, known as the Muskrat Falls Reservoir (Durkalec et al. 2016). Flooding of land for reservoir creation is well known to result in both altered food web structure and increased MeHg levels in food webs within the reservoir and downstream waterbodies (Calder et al. 2016, Brown et al. 2018). The Muskrat Falls Reservoir may also re-mobilize other contaminants, such as emerging polyfluoroalkyl substances (PFASs) (e.g. perfluorooctanoic acid, PFOA), which were used in Teflon production, and perfluorooctane sulfonate (PFOS), which was used in firefighting foams, surface treatment products, and many other applications (Moody & Field 2000). Along with PCBs from the area, these 'forever chemicals' have been reported in the area due to local contamination from the Goose Bay military base (Scott et al. 2007). Our results suggest that while Saglek ringed seals may be exposed to lower concentrations of contaminants (i.e. PCBs) as a result of the successful remediation of the site as well as less time spent in this contaminated fjord, Lake Melville seals may be exposed to increasing concentrations of multiple contaminants (e.g. MeHg, PCBs, and PFAS) as a consequence of the recent Muskrat Falls Reservoir development and more time spent in this latter inlet.

5. CONCLUSIONS AND RECOMMENDATIONS

This study provides new insights into the movements and habitat use of ringed seals from a changing Labrador coast. Seals were captured in 2 areas with different geomorphic attributes and with known local contaminant sources. There was little spatial overlap in home ranges and core use areas between the 2 areas, indicating the potential for distinct ringed seal stocks, which could have significant implications for conservation and management strategies. Seals tagged in Lake Melville tended to stay relatively localized within the estuary compared to seals tagged in Saglek Fjord, which occupied a diversity of habitats, from very localized within the fjord, to nearby inlets, and to far offshore and wide-ranging locations north and south. Ringed seals tagged in Lake Melville were influenced by sea ice concentration, with individuals spending more time in a transiting state during open water conditions than during ice-covered periods. Together, these findings suggest that ringed seals in Lake Melville have better feeding opportunities but may be more vulnerable to changing ice conditions and contaminants compared to seals in Saglek Fjord.

Additional studies of tagged adult ringed seals as well as the inclusion of prey availability data would further improve our understanding of ringed seal movement ecology, sensitivity to changing conditions, and exposure risk to contaminants. Further, additional environmental data would help to better characterize the behaviour patterns of Saglek Fjord seals. Monitoring changing habitat use of ringed seals and other culturally valued species will be important for Indigenous communities as the climate continues to change. Our results may help identify important marine habitat features in support of the development of a planned culturally based Marine Protected Areas in Nunatsiavut, as well as advance efforts to pinpoint and remediate local sources of contamination in the region.

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