# Impact of vessel traffic on the home ranges and movement of Shorthorn Sculpin (Myoxocephalus scorpius) in the nearshore environment of the high Arctic

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Impact of vessel traffic on the home ranges and movement of Shorthorn Sculpin

(Myoxocephalus scorpius) in the nearshore environment of the high Arctic

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Abstract:

Sea ice reduction in the Arctic is allowing for increased vessel traffic and activity. Vessel noise is a known anthropogenic disturbance but its effects on Arctic fish are largely unknown. Using acoustic telemetry – Vemco® Positioning System (VPS) – we quantified home ranges and fine-scale movement types (MT) of Shorthorn Sculpin (*Myoxocephalus scorpius*), a common benthic Arctic fish, in response to vessels and environmental drivers during open water over three years (2012-2014). Low overlap of core home ranges (50%) for all years and a change of overall MT proportions (significant in 2012 only) were observed when vessels were present compared to absent. However, changes in MTs associated with vessel presence were not consistent between years. Photoperiod was the only environmental driver that influenced ($R^2$=0.32) MTs of sculpin. This is the first study of vessel impacts on arctic fish using acoustic telemetry and demonstrates that individuals alter their behavior and home ranges when vessels are present. Given increasing vessel traffic in the Arctic, additional study on the impact of vessels on these ecosystems is warranted.

Keywords: Shorthorn Sculpin, acoustic telemetry, Arctic, benthic fish, movement ecology, anthropogenic disturbance.
Introduction

Ships and boats, hereafter vessels, produce noises that fall within the same frequency range as fish hearing and communication (Slabbekoorn et al. 2010), and have been documented to impact fish behavior, movements and distributions (Holles et al. 2013; Vabø et al. 2002), and are known to cause stress and mortality by predation (Wysocki et al. 2006; Simpson et al. 2016) in temperate and tropical ecosystems. Vessels can also increase water turbidity, which can alter vegetation and substrate that are critical habitat to fish for refuge and spawning (Eriksson et al. 2004; Sandström et al. 2005).

Anthropogenic disturbance due to vessel activity is a relatively new issue in the Arctic region, and while attention has been focused on its impact on marine mammals (Nowacek et al. 2007) such studies on fish are lacking. This has been partly due to the difficulty of accessing the Arctic but also due to lack of suitable technologies.

Recent technological advancements are allowing for novel *in-situ* scientific observations of individual fish in a wide range of environments through the application of acoustic telemetry (Hussey et al. 2015), providing an excellent tool to assess the impacts of vessels on arctic fish behavior. Acoustic telemetry utilizes either manual tracking or fixed stations, and the latter has the advantage of tracking animals remotely over long periods of time to provide high resolution movement data (Cooke et al. 2013; Hussey et al. 2015; Kessel et al. 2015). Organisms are usually tagged internally and released, with the tag emitting a unique signal every few minutes, which, when in range, is logged by fixed listening stations, called receivers. When receiver arrays are arranged strategically to allow tag signals to be detected simultaneously on three or more receivers, continuous locations of individual fish can be quantified. Such high-resolution positional data has
allowed quantification of fine scale movement behaviors of fish (McLean et al. 2014; Landry et al. see this issue), and extraction of home ranges and spatial use patterns of different species (Hussey et al. 2015). In addition, telemetry can be used to study the effects of anthropogenic disturbance on fish in-situ. For example, Vaudo and Lowe (2006) showed that coastal development influenced the movements of stingrays and Russell et al. (1998) demonstrated that salmonids change their movement patterns when estuarine barrages are present.

Receding of sea ice in the Arctic (Richardson et al. 2016; Comiso et al. 2008) has opened up the Northwest Passage to exploration, ship traffic and increased development and exploitation of natural resources (US Energy Information Administration 2012; Cressey 2011). In addition to the greater vessel traffic in the Arctic related to growing fisheries, oil and mining industries, the Northwest Passage is also a preferred route between North America, Europe and Asia for shipping companies (Standing Senate Committee on Fisheries and Oceans 2009), and of increasing interest to tourists and cruise-liners (Dawson et al. 2014). Thus, anthropogenic disturbance due to vessel traffic in the Arctic is growing, providing an excellent opportunity to understand the impact of vessel activity on fish behavior in a relatively non-impacted region, but also requiring study to guide management and conservation of this sensitive ecosystem.

The Arctic Ocean is a low species richness ecosystem (Kortsch et al. 2015) that is experiencing multiple stressors driven directly and indirectly by climate change, including decreasing ice cover, expansion of temperate fish species into the Arctic (Kortsch et al. 2015), and increasing vessel activity (Cressey 2011). Thus, due to its lower functional redundancy in species, the Arctic would be impacted more by these
stressors than temperate and tropical ecosystems. Given this, information on fish movement behavior and spatial/habitat utilization is necessary for conservation initiatives and management, especially with new evidence of the large scale movement of arctic organisms (Heide-Jørgensen et al. 2003; Hauser et al. 2014), including forage fish (Kessel et al. 2017). Without an understanding of how vessel activity in the Arctic affects the movement and behavior of aquatic species, it will be difficult to manage this ecosystem in a sustainable manner.

Shorthorn Sculpin (*Myoxocephalus scorpius*) is a benthic fish found in high abundance throughout the Arctic (Seth et al. 2013), with a relatively wide range of temperature tolerance (Seth et al. 2013; Grans et al. 2013). Seth et al. (2013) suggested these sculpin are a “sit-and-wait predator”, and use cover when under predation threat. Sculpin feed on invertebrates and fish, are known for cannibalism (Landry JJ, Fisk, AT, Yurkowski, DJ, Hussey, NE, Dick, T, Crawford, RE, and Kessel ST. In press), and although not considered a preferred prey item, have a wide range of predators, from seabirds, such as the Black Guillemot (*Cepphus grylle*) (Divoky & Tremblay 2013), to marine mammals, such as beluga whales (*Delphinapterus leucas*) (Breton-Honeyman et al. 2016) and seals (Lowry et al. 1980), to Greenland sharks (*Somniosus microcephalus*) (Fisk et al. 2002). Shorthorn Sculpin represent an indicator species for Arctic marine ecosystems in part due to their limited long-distance movements (Dick et al. 2009) and as such, a baseline understanding of their ecology in the Arctic is important to predict anthropogenic effects in the future.

In this study, we used fixed station acoustic telemetry, specifically VPS, to track and record high-resolution Shorthorn Sculpin movements over a period of three years.
(2012 – 2015) in Resolute Bay, Nunavut, a small bay in the high Canadian Arctic. Data from the tagged individuals were used to examine the spatial use and fine-scale movements of these benthic fish in relation to vessel activity and the environment during the open water ice-free period of summer and early autumn. We hypothesized that sculpin would exhibit a change in behavior and movement when vessels were moving and present compared to periods when absent, and specifically predicted that: individuals will exhibit lower rates of movement during vessel movement and presence, and, in periods when vessels are present sculpin will reduce their spatial use (home ranges) in the bay.

**Methods**

**Study Site**

Resolute Bay, Nunavut (74.6773°N and 94.8297°W) is located on the north shore of the Northwest Passage and vessels are common in the bay during open water periods (approx. end of July till end of September), utilizing it as an anchorage area for supplies restocking and passenger exchange. The settlement is to the northeast of the bay, has 243 residents (Anon 2013), and contributes nutrients through the sewage outflow. The bay is generally < 20 m deep, with the head of the bay reaching a depth of 30 m and a shallow sill reaching 1 m depth at low tide located at the center of the mouth of the bay (Fig. 1). One small river on the west shore and two streams on the east contribute freshwater input.

**Fish telemetry**
Shorthorn Sculpin (*Myoxocephalus scorpius*) were caught in Resolute Bay in August 2012, 2013 and 2014 with a gill net (30 m length, 2 inch mesh size) set for 6 hrs, in three locations - northeastern, northwestern and southwestern part of the bay. The number of individuals tagged in 2012, 2013 and 2014 were 22, 12, and 26, respectively. Upon capture, total length (L) was measured to the nearest 1 mm and mass (M) to nearest 0.1 g prior to insertion of acoustic tags. Condition index (K) was calculated using the formula:

\[ K = \frac{M \times 10^3}{L^3} \quad (1) \]

Vemco® V9 (Halifax, Nova Scotia, Canada, years 2012 and 2013) and Vemco® V6 (year 2014) acoustic transmitters, i.e., tags, were used in this study with tag to body weight ratio of < 2% for all individuals. Following capture, fish were held in 120 L coolers, filled with bay water and water was agitated regularly to maintain oxygen levels prior to tag insertion surgery. An anaesthetic bath of MS222 (1:5 ratio with sea water) for 2-5 min was used for fish sedation. Individuals were placed in a sponge bed for surgery, with gills irrigated continuously with seawater. A ventral incision (~8 mm) anterior of the pelvic fins was made for tag insertion and closed with three independent sutures (coated Vicryl Ethicon® VCP423, 3-0 FS-2 cutting) each tied with a triple surgeon’s knot; procedure duration was 2 to 4 min. A 10% betadine solution was used for sterilizing all surgical equipment and the incision site. Fish were left to recover in a holding tank with seawater and aeration, and monitored until equilibrium was regained. Individuals were released at the capture location approximately 1 hr after completion of surgery.

In 2012 and 2013, a Vemco® VR2W 69 kHz acoustic receiver array, consisting of 44 units each year, was used to record movements of individual fish, while in 2014 the
array consisted of 28 Vemco® VR2W 180 kHz units (Fig. 2). Each year the array was deployed in the beginning of August and recovered at approximately the same time the following year. Due to considerations for winter ice cover, a minimum deployment depth of 15 m was used with spacing between individual units from 150 to 300 m. Each unit consisted of a ~40 kg rock anchor attached via ~2 m rope to an ORE Port ME acoustic release (manufactured by Edge Tech, USA), the receiver and a subsurface float to maintain the mooring in an upright position. Sync tags were attached to 19 receivers across the array and were used for receiver clock drift correction during the processing of positional data (Espinoza et al. 2011).

Presence and movement of ships in Resolute Bay

To determine vessel absence, presence and movement times, we used Satellite Automatic Identification System (AIS) archive data from 2012, 2013, and 2014. Data from August and September were used, as these are the months with ship activity in Resolute Bay. A total of 7, 10 and 7 vessels (>40 m length) visited Resolute Bay in 2012, 2013 and 2014, respectively. All vessels enter and exit the bay using two shipping lanes and the times for entry/exit were extracted from the AIS dataset. These times were cross-referenced with a time-lapse footage set at 10 s intervals in 2014 from a camera facing the bay (Canon EOS T4, 50mm lens, set in a weather-proof box with constant power supply). From this footage, we determined that passenger and cargo vessels took 10 and 30 min (±1 min), respectively, to enter the bay, and 15 and 30 min (±1 min) to exit. Passenger vessels typically use the western track and cargo vessels utilize the eastern track (see Fig. 1). An additional 5 min were added to the time of anchorage and time prior to departure for statistical analysis to include noise from anchor dropping or pulling,
respectively. Vessel states were defined as follows: vessels absent from the bay (VA); vessels were moving either entering or exiting the bay (VM); and vessels were anchored and thus present in the bay, but not moving (VP).

Acoustic telemetry data processing

Positional data was generated by processing all raw data through Vemco’s VPS analysis. The analysis uses the differences in detection times in milliseconds at three or more time-synchronized receivers to triangulate the position of the signal/individual (Smith 2013). Positional data for n=22, 14 (includes 2 IDs from 2012 tagging) and 26 individuals in 2012, 2013 and 2014, respectively, was filtered for HPE (horizontal position error, a unitless estimate of the sensitivity of the calculated position (Smith 2013)), and any HPE values larger than 37 were removed from further analysis. This value for HPE was chosen based on the average relative to the HPE for the sentinel tags in our VPS as suggested by Smith (2013), resulting in a distance error of > 10 m. In 2014, the total IDs used for further analysis dropped to 12 individuals due to lack of sufficient detections. A total of 20,847, 16,882, and 3,478 detections for 2012, 2013 and 2014, respectively, were included in the final analysis.

To generate home ranges and estimate movement behaviors of sculpin adeHabitatHR and adeHabitatLT packages (Calenge 2006) in R (version 0.98.1103 running on Mac OS X 10.9.5), respectively, were used. These metrics were grouped into three vessel variables: 1) vessels absent from the bay (VA), 2) vessels present/anchored in the bay (VP), and 3) vessels moving, either entering or exiting the bay (VM). During VP, vessel generators were running to produce and supply power, and small boats transported passengers and/or goods to the shore and back, adding more noise to the
background. During VM additional noise stems mainly from the vessel’s propellers, the vessel moving through the water, and anchor dropping or pulling. Small boat noises, such as those produced by local fisherman’s boats and recreational yachts < 40 m in length occurred during VA, VP and VM, but were not considered in the analysis because the duration of these boats’ activities within the bay was fairly short (2-3 minutes) and occurred sporadically during each vessel state. In comparison, boats/servicing tenders of ships during VP moved consistently from the vessel to the shore.

Sculpin’s core and general home ranges were established using Kernel utilization distributions (KUD) at 50% and 95%, while Minimum Convex Polygon (MCP) was used to determine the extended home range area. The data were separated by vessel variable (VA, VP and VM) and home range analysis was performed for all individuals that had ≥5 detections (Table 2). Home ranges for each individual and variable were mapped separately and sizes calculated in hectares. Using CalcHR.R and Indices.txt (Fieberg & Kochanny 2005) we performed an overlap estimation for 50% and 95% KUD for VP, VA and VM by calculating the Hurlbert Index of overlap. To examine the differences in individual MCP area sizes between VA and VP, a Kruskal-Wallis rank sum test was undertaken.

Sculpin movement behaviors were quantified using trajectory bursts – discrete segments of successive VPS positions (Turchin 1998). Bursts were extracted from each individual’s trajectory (a collection of VPS positions forming a continuous curve of that individual’s movements (Calenge et al. 2009)) based on time and date of detection with cut off between bursts of > 30 min between consecutive positions, i.e., no detections of the individual. Only bursts with a minimum of 5 consecutive VPS positions were
considered. This allowed for the elimination of prolonged/excessive periods between detections/positions of individual fish, providing continuous high-resolution data to identify distinct movement behaviors. We clustered the bursts using a diagonal, varying volume and shape (VVI) model with 3 components as suggested by the Mclust function (Fraley & Raftery 1999) in R. Descriptive parameters with correlations greater than 0.45 were removed. We used the following descriptive parameters to define the bursts’ movement types (MT): 1) distance between successive relocations; (2) rate of movement (ROM; m s$^{-1}$); (3) turning angle, which measures the change in direction between relocations; (4) a linearity ratio, where 1 denotes a straight path and 0 a less linear path (Heupel et al. 2012); (5) total distance travelled in a burst; (6) bearing; (7) depth; and (8) acceleration (7 and 8 were only available in 2012 and 2013).

Based on the time and date of their occurrence, identified burst MTs were assigned to the three vessel variables (VA, VP and VM), and individual and mean proportions of each were calculated (Table 3). A chi-squared test was performed for the mean proportions of VP and VM using VA as the expected value to determine overall differences in MT proportions between vessel variables. To determine the actual differences between identified MTs for VA, VP and VM, we compared individual proportion values using Kruskal-Wallis rank sum test and T-test as appropriate based on our results from a Shapiro-Wilk normality test.

Environmental variables processing

Hourly-averaged salinity (PSU), water temperature ($^\circ$C), and dissolved oxygen saturation (%) were collected using a Satlantic STOR-X submersible data logger with a Seabird 37-SIP microCAT C-T recorder, sampling for 30 s every hour at resolutions of 1,
1, and 5 s, respectively. The instruments were deployed and retrieved in August of each year, and were located approximately 0.5 m above the seafloor, in 33 m of water in the depression at the head of the bay (74.68549° N 94.86194° W). Daily average wind speeds and air temperatures were obtained from the Environment and Climate Change Canada online archives (Weather Canada 2015). Photoperiod (h) was downloaded from the time and date online archives (Steffen Thorsen 2014). A general linear mixed model was used to assess the influence of environmental variables on MTs. Variables with correlation >30 were removed from analysis for all years. We used vessel activity, photoperiod, dissolved oxygen and wind speed as fixed effects in 2012. Similarly, for 2013 plus salinity; however, in 2014 only vessel activity, photoperiod and dissolved oxygen were used. Fish ID was added as a random effect for all years. Based on the model, variables that showed significance were examined individually to establish the strength of the relationships using linear regression.

Results

Sculpin body sizes

There was no significant difference in total length of tagged sculpin between 2012 and 2013 (p = 0.57; t-test with equal variances), however, 2014 fish were significantly smaller than both 2012 and 2013 (both p < 0.01; t-test with equal variances) (Table 1). Condition index calculations showed no significant differences in individual condition among years (all p > 0.05, t-test).

Movement types
For 2012, MTs were explained by mean rate of movement (ROM), linearity, mean depth, and standard deviation (SD) of turn angle and acceleration (Kruskal-Wallis rank sum test; Fig. 3). Higher ROM, acceleration and depth, and more linear trajectory with lower turning angles characterized MT 2 and distinguished it from MTs 1 and 3. MT 1 had the lowest rate of movement and acceleration, and somewhat lower linearity than MT 3. Medium ROM, linearity and acceleration defined MT 3. In 2013, descriptive parameters that significantly influenced MTs were mean ROM, sum of distance, SD of turn angle and acceleration (Kruskal-Wallis rank sum test; Fig. 3). Similarly to 2012, highest ROM, sum of distance and acceleration distinguished MT 2 from the rest. MT 1 had the lowest acceleration and sum of distance values, while MT 3 had medium values. For 2014, mean ROM, linearity, sum of distance and SD of turn angle were significant (p < 0.001 for all, Kruskal-Wallis rank sum test; Fig. 3). Here too, MT 2 had the highest ROM and sum of distance, and MT 1 had the lowest of these values, although both had very similar linearity. MT 3 had medium values for ROM and sum of distance, but the lowest linearity.

Based on these variables for all three years, MT 1 was identified as behavior typical of fish that are feeding/hiding, MT 2 as typical of in-transit movement, and MT 3 as typical of foraging behavior (Fig. 4).

**Influence of vessels on movement types**

In 2012 and 2014, there were no significant differences in overall MT proportions between vessel variables (chi-squared, p > 0.05, Fig. 5). However, in 2013 a change in overall MT proportions was observed for VA compared to VP (chi-squared = 7.46, p = 0.024), but not for VA and VM (chi-squared = 0.745, p = 0.69). Examining each MT
separately between vessel variables in 2012 and 2013, we found MT 1, associated with feeding/hiding, decreased significantly when vessels were moving in the bay in 2012 compared to periods when vessels were absent (p=0.034, Kruskal-Wallis rank sum test; Fig. 5), while in-transit movement (MT 2) in 2013 decreased significantly when vessels were present (VP) in comparison to when vessels were absent (p=0.012, Kruskal-Wallis rank sum test; Fig. 5).

Vessel movements occur over 10 to 30 minute periods and identified MTs often spanned vessels movement, presence and/ or absence periods. This confounded our ability to tease apart any influence of VM on MTs. Thus, significant differences in MTs during VM periods are reported above but excluded from further analysis and discussion.

Influence of environment on fish behavior

A general linear mixed model analysis for environmental variables revealed photoperiod and vessel activity in 2012 (p < 0.001 for both) significantly influenced the proportions of MTs. However, linear regressions of photoperiod with individual MTs had low R-squared values (R-squared < 0.1 for all). In 2013, vessels, photoperiod and wind speed were significant for the model (p < 0.01 for all), however only photoperiod influenced MT 2 in the linear regression (R-squared = 0.32; Fig. 6). MT 2 (in-transit movement) increased in frequency with decreasing daylight, while MT 1 and MT 3 (feeding/hiding & foraging movement, respectively) showed a slight decrease. In 2014, vessels, photoperiod and hourly dissolved oxygen significantly influenced sculpin’s MTs in the model (p < 0.05 for all); however, linear regression R-squared values were low (R-squared < 0.03 for all variables).

Home Ranges
Home ranges during vessel movement (VM) periods are reported for each year but excluded from further analysis and discussion due to bias resulting from shorter periods of time over which detections during VM were collected.

In 2012, MCP area for VP and VM were lower when compared to VA periods (VA; p-value = 0.002, and < 0.001, respectively; Kruskal-Wallis rank sum test; Fig. 7 and 8). Hurlbert overlap test had a mean index of 0.073 and 0.375 for 50% and 95% KUD, respectively, between VA and VP.

In 2013, MCP decreased significantly during VP and VM (p = 0.028 and 0.01, respectively; Kruskal-Wallis rank sum test; Fig. 7 and 8). Area for 50% and 95% KUD also decreased significantly for VM as compared to VA (p < 0.02 for both). The mean overlap was 0.114 and 0.325 for 50% and 95% KUD, respectively, for VA vs VP.

In 2014, no significant differences were found in any of the area sizes (all p > 0.15, Fig. 8); however, it should be noted that sample size was low (VA n=4, VP n=4, and VM n=2). The overlaps between VA and VP for 50% and 95% KUD were 0.248 and 0.149, respectively (Kruskal-Wallis rank sum test). For VA vs VM test was not performed due to the low sample size. The Hurlbert overlap test (n=4) between VA and VP revealed a low overlap with mean index of 0.013 and 0.063 for 50% and 95% KUD, respectively.

Discussion

In all three years of this study, we identified three general movement types for Shorthorn Sculpin in Resolute Bay, Nunavut using VPS acoustic telemetry – feeding/hiding (MT 1), in-transit (MT 2) and foraging (MT 3). In-transit behaviour
decreased with vessel presence in 2013, but not in other years. In all three years – 2012, 2013 and 2014 – the extent of spatial use by sculpin was smaller for all individuals when vessels were present, and core home ranges had low overlap between times of vessel absence and presence. This study demonstrates that the presence of large vessels can impact benthic fish habitat use in nearshore Arctic environments, with implications for management and conservation in the light of expanding vessel traffic in these sensitive ecosystems.

During 2012 and 2013, in periods with no vessels, feeding/hiding behavior (MT1) was the most frequent movement behavior for Shorthorn Sculpin, followed by foraging (MT3) and in-transit movement (MT2). Kasumyan (1999) looked at five different species of sturgeon and identified each to have a slow and twisting movement trajectory in response to prey odors in holding tanks, similar to MT 1 in this study. Sturgeon are also benthic fish, although they are not considered a sit-and-wait predator, and instead search for benthic food using barbels. McLean et al. (2014), using VPS, attributed to feeding similar behavior adopted by Atlantic Sturgeon (*Acipenser oxyrinchus*) when in prey patches. Similar movement trajectories have been observed for terrestrial species, such as the Baltimore Checkerspot butterfly (*Euphydras phaeton*), which had shortest movement lengths and large turning angles in habitats where food was abundant (Brown et al. 2017). As Shorthorn Sculpin is thought to be a sit-and-wait predator, the very low rate of movement for MT 1 indicates feeding associated behavior. However, it could indicate anti-predator behavior for sculpin, which take cover when under predator threat and sit motionless under shelter (Shi et al. 2017). Both of these behaviors are supported by the low distance travelled by sculpin when exhibiting this movement type. Thus, MT 1 could
be associated with feeding and/or hiding, and further finer scale studies are required to
distinguish between the two for Shorthorn Sculpin.

We identified MT 2 as directional in-transit behavior, which is believed to be
associated with general dispersal, movement through inhospitable areas, movement
between prey patches and/or extra-home-range exploration due to the relatively large
ROM and distance travelled. McLean et al. (2014) identified a similar pattern of
movement for Atlantic Sturgeon (*Acipenser oxyrinchus*), which the authors described as
straight-line rapid movement with large mean distance between relocations, and
attributed to dispersal and movement between patches. This type of movement has been
observed for terrestrial species as well. Zollner & Lima (1999) described it in their
simulation based on small forest mammals as related to extensive search of food patches,
where straight-line travel is utilized to minimize effort, but also, as a movement related to
greater risk, such as moving through areas with higher risk of mortality. Additionally,
Frafjord & Prestrud (1992) linked this type of movement to extra home-range exploration
and roaming in Arctic Foxes (*Alopex lagopus*) in Svalbard, Norway.

Movement type 3 was identified as foraging, characteristic of movement between
food patches within the home range, due to its medium tortuosity and irregular movement
trajectory, resembling food search behavior. Coughlin et al. (1992) found swimming
paths for clownfish larvae (*Amphiprion perideraion*) were intermediate in complexity
when individuals were looking for food. McLean et al. (2014) attributed erratic
movements of Atlantic sturgeon to be associated with searching for food between
patches. A similar movement type has been observed for terrestrial species by Brown et
al. (2017), who reported intermediate length of movements and turning angles when butterflies were in low food quality habitats.

In 2013, in-transit movements by Shorthorn Sculpin decreased significantly when vessels were present/anchored in the bay (VP) compared to when vessels were absent (VA). Extra home range exploration, i.e. in-transit movement, is important for individuals for updating the cognitive map of their home range as that information increases fitness and survival, through, for example, mapping of food resources (Spencer 2012). This indicates that sculpin were likely affected by the presence of vessels in the bay and reduced their extra home-range exploration in response. However, interpretation here needs to be made with caution, because in 2012 in-transit movement types showed no statistical difference between VA and VP. Additionally, we saw a negative correlation of in-transit movements for 2013 with photoperiod, but this correlation again was not observed for any other years. Moore & Moore (1974) found that Shorthorn Sculpin had restricted visual capacity during ice cover and, thus, changed their food search behavior. This suggests that at 24 h photoperiod sculpin have good visibility reducing the pressure to search for food. However, with diminishing light conditions sculpin may spend more time travelling between patches. A decrease in in-transit movements in 2013 may therefore be linked to increased prey availability; unfortunately prey abundance data are not available to test this idea, and any influences by vessels’ presence cannot be completely excluded as a cause at this point (see discussion in paragraphs below). Therefore, our results regarding vessel presence influences on sculpin in-transit movements are somewhat inconclusive, and we recommend further study.
We also suggest that sculpin were aware of the presence of anchored vessels in the bay, likely perceive it as a threat, and thus decrease exploratory behavior and the use of their extended home range. Minimum convex polygon (MCP) represents the extent of the area utilized by species in a habitat, which in our study was interpreted as extended home range, or areas that an individual explores outside of its immediate home range. The observed decrease of MCP in all years when vessels were present but not moving implies reduced extra-home-range exploration when vessels are present in the bay. The significant decrease of in-transit movements in 2013 and the overall movement type proportions changing between VA and VP provide further evidence to support this. These results are in agreement with disturbance studies on other species. For example, dolphins (Tursiops aduncus) changed their overall behavioral patterns in response to boats (Pérez-Jorge et al. 2017), while herring (Clupea harengus) exhibited vessel avoidance behavior (Vabø et al. 2002). Similarly for terrestrial species, leopards (Panthera pardus) reduced their overall activity, and rhinoceros (Diceros bicornis) and spider monkeys (Ateles spp.) relocated and/ or reduced their home ranges to avoid human settlements and anthropogenically disturbed areas, respectively (Ngoprasert et al. 2017; Odendaal-Holmes et al. 2014; Asensio et al. 2017).

While Sculpin VP core home ranges (50%) were still located within VA’s larger (95%) home range boundaries, there was low overlap of VP with VA core home ranges (50%). We suggest that there is a shift of the core’s locations during VP. Similar results were observed for spider monkeys, which minimize the use of a particular part of their home range based on the degree of habitat disparity due to disturbance (Asensio et al. 2017). Anchored vessels run generators to supply electricity for everyday use and thus,
produce noise. This noise along with the associated particle pressure are likely perceived as predator threat, and cause habitat disparity in our study; when under threat sculpin are known to utilize shelter (Moring 2001). The seabed of Resolute Bay has patchily distributed vegetation cover, and a shift in the core when vessels were present likely indicates relocation of the individual to an area within their home range with more vegetation cover, where shelter is easily accessible. Similar behavior has been observed for Brown Trout (Salmo trutta) which had increased preference for territories with cover after simulated predator attack (Johnsson et al. 2004), and for Three-Spined Stickleback (Gasterosteus aculeatus), which prefer to build their nests near vegetation as shelter from predators (Huntingford & Coyle 2007). The observed shift in the location of the core home ranges provides further evidence of vessel presence influences on sculpin.

There were fewer detections in 2014 than 2012 and 2013, and quantified MTs are likely compromised, with only four bursts observed for VP. There are two likely explanations for the observed low number of detections in 2014: 1) less coverage of bay due to fewer receivers used in array (28 receivers in 2014 versus 44 in 2012 and 2013; detections range varied between 10 to 130 m (Kessel et al. 2015)), and 2) smaller tagged sculpin in 2014 left the area due to size segregation associated with cannibalism by larger and older conspecifics (Pfister 2003; Petty & Rossman 2007). Sculpin are territorial (Petty & Rossman 2007) and as such are very individualistic, i.e. they do not form schools or occur in groups. They are also known for cannibalism (Pfister 2003; Landry JJ, Fisk, AT, Yurkowski, DJ, Hussey, NE, Dick, T, Crawford, RE, and Kessel ST. In press) and size-dependent intraspecific competitive interaction, thus smaller sculpin avoid close encounters with larger individuals (Petty & Rossman 2007). Since sculpin
tagged in 2014 were significantly smaller, they may have avoided larger conspecifics and may have moved out of the array’s effective range. Due to this, movement types for 2014 were not considered in the results and conclusions. Home range data were included in the spatial analysis because there were sufficient detections per individual to extract these and calculate overlaps. Important to note here is that there were fewer individuals included in the analysis of 2014 home ranges compared to other years (see Table 2).

The observed inconsistencies between years for the quantified MTs may be due to: 1) an overall small sampling size for sculpin, and 2) environmental variation between years. In 2012, 22 individuals were tagged, but only 17 individuals were used for analysis for VA and VP (Table 2), while in 2013 we tagged 14 fish but were able to use 11 for VA and VP. Although all tagged individuals for both years were detected, some individuals appear to have left the system for the period of our study, resulting in insufficient number of detections for the statistical analysis. Environmental factors also showed variation in the months of August and September between 2012 and 2013. For example, average monthly air temperature for the two months of interest was 0.9° C in 2012 and -2.25° C in 2013; and total precipitation also varied between years, 28.9 mm in 2012 compared to 9.05 mm in 2013 (Environment and Climate Change Canada 2017). Also, differences between 2012 and 2013 were seen in salinity means (32 and 29, respectively), water temperature (-0.33° C and -1.1° C) and dissolved oxygen (81.7 and 72.8). Thus, environmental variation along with small sampling size may partly explain the inter-annual variation observed in our results for MTs between years.

Taken together, the results of this study suggest Shorthorn Sculpin are influenced by vessel activity in Resolute Bay. We observed a change in the proportions of different
movement types and behavior and in the spatial area use by individual fish during vessel presence. While changes in movement types associated with vessel activity did not show consistency throughout years, spatial area use changes were consistent and the overall results clearly support further study on the impact of increasing vessel traffic and associated activity on fish in the arctic and other regions. It is likely that the observed inter annual variation in MTs was a result of a combination of changes in study design among years and environmental differences. In addition, more research is required to establish the mechanisms by which vessels affect sculpin, and the noise and particle pressure tolerance levels of this species. The implications these may have for sculpin are at this point unclear and additional examination is required pertaining to prey, and any effects vessels may have on sculpin’s feeding and foraging behaviors under varying prey availability. Shorthorn Sculpin are an integral part of the Arctic food web, and are believed to be a good indicator of changes in the Arctic marine ecosystem (Dick et al. 2009). Our study provides the first assessment of vessel influences on the fine scale movements and home ranges for this species in the Arctic. As such, it provides a baseline to which future studies on general vessel activity influences in the high Arctic, sculpin, and sculpin behavior and home ranges can be compared.

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Table 1: Total length, mass and condition index (mean ± 1 standard error) for all tagged Shorthorn Sculpin in Resolute Bay, Nunavut. Letters indicate significant differences between years (t-test, p < 0.05).

<table>
<thead>
<tr>
<th>Year</th>
<th>n</th>
<th>Total length (cm)</th>
<th>Mass (g)</th>
<th>Condition index</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>22</td>
<td>28.1 ± 0.6</td>
<td>319.4 ± 20.3</td>
<td>14.1 ± 0.4</td>
</tr>
<tr>
<td>2013</td>
<td>12</td>
<td>28.9 ± 1.3</td>
<td>359.4 ± 55.2</td>
<td>13.9 ± 0.4</td>
</tr>
<tr>
<td>2014</td>
<td>26</td>
<td>23.2 ± 0.5</td>
<td>174.8 ± 13.8</td>
<td>13.5 ± 0.2</td>
</tr>
</tbody>
</table>
Table 2: Number of unique Shorthorn Sculpin individuals (detected and used for further analysis), and number of total and used detections in spatial analysis from acoustic telemetry study in Resolute Bay, Nunavut.

<table>
<thead>
<tr>
<th>Year</th>
<th>Vessel State</th>
<th># of unique IDs detected (# of IDs used in analysis)</th>
<th>Total # of detections (Total used in analysis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>Vessels Absent (VA)</td>
<td>22 (17)</td>
<td>12,803 (12,642)</td>
</tr>
<tr>
<td></td>
<td>Vessels Present (VP)</td>
<td>18 (17)</td>
<td>3,716 (3,679)</td>
</tr>
<tr>
<td></td>
<td>Vessels Moving in bay (VM)</td>
<td>13 (7)</td>
<td>54 (48)</td>
</tr>
<tr>
<td>2013</td>
<td>Vessels Absent (VA)</td>
<td>14 (11)</td>
<td>14,282 (13,759)</td>
</tr>
<tr>
<td></td>
<td>Vessels Present (VP)</td>
<td>13 (11)</td>
<td>2,558 (2,553)</td>
</tr>
<tr>
<td></td>
<td>Vessels Moving in bay (VM)</td>
<td>9 (3)</td>
<td>36 (22)</td>
</tr>
<tr>
<td>2014</td>
<td>Vessels Absent (VA)</td>
<td>14 (4)</td>
<td>3,040 (681)</td>
</tr>
<tr>
<td></td>
<td>Vessels Present (VP)</td>
<td>8 (4)</td>
<td>447 (419)</td>
</tr>
<tr>
<td></td>
<td>Vessels Moving in bay (VM)</td>
<td>2 (2)</td>
<td>21</td>
</tr>
</tbody>
</table>
Table 3: Frequencies of movement types (MT) of Shorthorn Sculpin in Resolute Bay, Nunavut, used to calculate for each year MT proportions per vessel variable. Vessel variables are as follows: VA - vessels absent from the bay; VP - vessels present in the bay; and VM - vessels moving (entering or exiting the bay).

<table>
<thead>
<tr>
<th>Year</th>
<th>MT frequencies (bursts)</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MT 1</td>
<td>MT 2</td>
<td>MT 3</td>
<td>MT 1</td>
</tr>
<tr>
<td>Vessel variable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VA</td>
<td>214</td>
<td>60</td>
<td>164</td>
<td>59</td>
</tr>
<tr>
<td>VM</td>
<td>7</td>
<td>3</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>VP</td>
<td>72</td>
<td>22</td>
<td>64</td>
<td>9</td>
</tr>
</tbody>
</table>
**Fig. 1:** Location of Resolute Bay, Nunavut, Canada. The inset depicts the bathymetry of the bay (depth is shown in meters) and the features surrounding it. Thin black lines denote the eastern and western shipping lanes and the anchoring locations are denoted with a red “X”. *(Map source: Natural Earth. Inset map source: Google Imagery ©2017 TerraMetrics)*

**Fig. 2:** Locations of acoustic telemetry receivers in Resolute Bay, Nunavut by year. Numbers of receivers in each array are 44 for 2012 and 2013, and 28 for 2014.

**Fig. 3:** Examples of Shorthorn Sculpin movement descriptive parameters versus movement type with respective significance values (Kruskall-Wallis rank sum test) from acoustic telemetry study in Resolute Bay, Nunavut. Significant p-values are denoted with star symbols. Only significant descriptive parameters were used to define the movement types (ROM = rate of movement, SD = standard deviation).

**Fig. 4:** Samples of Shorthorn Sculpin movement types from Resolute Bay, Nunavut (note differences in scales). Circles denote detection locations with green identifying the starting point of the movement and black line denotes the movement path. An example of MT 1 associated with feeding/hiding is shown for individual 6008. This particular burst had a mean rate of movement (ROM) of 0.003 m/s, mean acceleration of 0.06, and 0.016 linearity ratio (shown are all 246 positions detected over a period of 30 hours). Example of MT 2 associated with in-transit movement is shown for individual with tag number 6018. Mean ROM for this behavior was 0.165 m/s, with mean acceleration of 1.16, and 0.88 linearity ratio (shown are all 20 positions detected over a period of 3 hours). Example of MT 3 associated with foraging is from individual 6018 and had mean ROM
of 0.021 m/s, 0.25 mean acceleration, and 0.48 linearity ratio (shown are all 158 positions detected over a period of 21.5 hours).

Fig. 5: Mean proportions of movement types for Shorthorn Sculpin per vessel variable in Resolute Bay, Nunavut. VA denotes periods with vessels absent from the bay, VP is for periods with vessels present and VM for periods with vessels moving in the bay.

Fig. 6: Linear regression relationships of each movement type (MT) versus photoperiod for 2013 for Shorthorn Sculpin, Resolute Bay, Nunavut.

Fig. 7: Mapped Shorthorn Sculpin home ranges for three individuals from Resolute Bay, Nunavut. Dark and light pink denote 50% and 95% KUD for VA, respectively, dark and light blue denote these for VP, and yellow and light green denote these for VM home ranges.

Fig. 8: Mean minimum convex polygon (MCP), 50 and 95% home range area sizes for Shorthorn Sculpin individuals from Resolute Bay, Nunavut, are plotted against vessel variables. In 2012, MCP area sizes for vessel presence (VP) and movement (VM) decreased when compared to periods with no vessels (VA; p-value = 0.002, and <0.001, respectively; Kruskal-Wallis rank sum test). In 2013, MCP decreased significantly during VP and VM (p = 0.028 and 0.01, respectively; Kruskal-Wallis rank sum test). Area sizes for 50% and 95% home ranges also decreased significantly for VM as compared to VA (p = 0.016 for both). In 2014, no significant differences were found in any of the area sizes. Numbers of individuals used for the analysis were as follows: VA n=4, VP n=4, and VM n=2.
Figure 1
Figure 2
Figure 3
Figure 4
Figure 5
Figure 6
Figure 7
2012

**Figure 8**

- Mean MCP area size (in hectares)
- Mean 50% KDE area size (in hectares)
- Mean 95% KDE area size (in hectares)