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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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Manuscripts

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

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

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23　**Abstract:**

24　Sea ice reduction in the Arctic is allowing for increased vessel traffic and activity. Vessel

25　noise is a known anthropogenic disturbance but its effects on Arctic fish are largely

26　unknown. Using acoustic telemetry – Vemco[®] Positioning System (VPS) – we quantified

27　home ranges and fine-scale movement types (MT) of Shorthorn Sculpin (*Myoxocephalus*

28　*scorpius*), a common benthic Arctic fish, in response to vessels and environmental drivers

29　during open water over three years (2012-2014). Low overlap of core home ranges (50%)

30　for all years and a change of overall MT proportions (significant in 2012 only) were

31　observed when vessels were present compared to absent. However, changes in MTs

32　associated with vessel presence were not consistent between years. Photoperiod was the

33　only environmental driver that influenced (R^2=0.32) MTs of sculpin. This is the first

34　study of vessel impacts on arctic fish using acoustic telemetry and demonstrates that

35　individuals alter their behavior and home ranges when vessels are present. Given

36　increasing vessel traffic in the Arctic, additional study on the impact of vessels on these

37　ecosystems is warranted.

38

39　**Keywords:** Shorthorn Sculpin, acoustic telemetry, Arctic, benthic fish, movement

40　ecology, anthropogenic disturbance.

Introduction

41

42   Ships and boats, hereafter vessels, produce noises that fall within the same

43 frequency range as fish hearing and communication (Slabbekoorn et al. 2010), and have

44 been documented to impact fish behavior, movements and distributions (Holles et al.

45 2013; Vabø et al. 2002), and are known to cause stress and mortality by predation

46 (Wysocki et al. 2006; Simpson et al. 2016) in temperate and tropical ecosystems. Vessels

47 can also increase water turbidity, which can alter vegetation and substrate that are critical

48 habitat to fish for refuge and spawning (Eriksson et al. 2004; Sandström et al. 2005).

49 Anthropogenic disturbance due to vessel activity is a relatively new issue in the Arctic

50 region, and while attention has been focused on its impact on marine mammals (Nowacek

51 et al. 2007) such studies on fish are lacking. This has been partly due to the difficulty of

52 accessing the Arctic but also due to lack of suitable technologies.

53   Recent technological advancements are allowing for novel *in-situ* scientific

54 observations of individual fish in a wide range of environments through the application of

55 acoustic telemetry (Hussey et al. 2015), providing an excellent tool to assess the impacts

56 of vessels on arctic fish behavior. Acoustic telemetry utilizes either manual tracking or

57 fixed stations, and the latter has the advantage of tracking animals remotely over long

58 periods of time to provide high resolution movement data (Cooke et al. 2013; Hussey et

59 al. 2015; Kessel et al. 2015). Organisms are usually tagged internally and released, with

60 the tag emitting a unique signal every few minutes, which, when in range, is logged by

61 fixed listening stations, called receivers. When receiver arrays are arranged strategically

62 to allow tag signals to be detected simultaneously on three or more receivers, continuous

63 locations of individual fish can be quantified. Such high-resolution positional data has

64   allowed quantification of fine scale movement behaviors of fish (McLean et al. 2014;

65   Landry et al. see this issue), and extraction of home ranges and spatial use patterns of

66   different species (Hussey et al. 2015). In addition, telemetry can be used to study the

67   effects of anthropogenic disturbance on fish *in-situ*. For example, Vaudo and Lowe

68   (2006) showed that coastal development influenced the movements of stingrays and

69   Russell et al. (1998) demonstrated that salmonids change their movement patterns when

70   estuarine barrages are present.

71   Receding of sea ice in the Arctic (Richardson et al. 2016; Comiso et al. 2008) has

72   opened up the Northwest Passage to exploration, ship traffic and increased development

73   and exploitation of natural resources (US Energy Information Administration 2012;

74   Cressey 2011). In addition to the greater vessel traffic in the Arctic related to growing

75   fisheries, oil and mining industries, the Northwest Passage is also a preferred route

76   between North America, Europe and Asia for shipping companies (Standing Senate

77   Committee on Fisheries and Oceans 2009), and of increasing interest to tourists and

78   cruise-liners (Dawson et al. 2014). Thus, anthropogenic disturbance due to vessel traffic

79   in the Arctic is growing, providing an excellent opportunity to understand the impact of

80   vessel activity on fish behavior in a relatively non-impacted region, but also requiring

81   study to guide management and conservation of this sensitive ecosystem.

82   The Arctic Ocean is a low species richness ecosystem (Kortsch et al. 2015) that is

83   experiencing multiple stressors driven directly and indirectly by climate change,

84   including decreasing ice cover, expansion of temperate fish species into the Arctic

85   (Kortsch et al. 2015), and increasing vessel activity (Cressey 2011). Thus, due to its

86   lower functional redundancy in species, the Arctic would be impacted more by these

87   stressors than temperate and tropical ecosystems. Given this, information on fish

88   movement behavior and spatial/habitat utilization is necessary for conservation initiatives

89   and management, especially with new evidence of the large scale movement of arctic

90   organisms (Heide-Jørgensen et al. 2003; Hauser et al. 2014), including forage fish

91   (Kessel et al. 2017). Without an understanding of how vessel activity in the Arctic affects

92   the movement and behavior of aquatic species, it will be difficult to manage this

93   ecosystem in a sustainable manner.

94   Shorthorn Sculpin (*Myoxocephalus scorpius*) is a benthic fish found in high

95   abundance throughout the Arctic (Seth et al. 2013), with a relatively wide range of

96   temperature tolerance (Seth et al. 2013; Grans et al. 2013). Seth et al. (2013) suggested

97   these sculpin are a "sit-and-wait predator", and use cover when under predation threat.

98   Sculpin feed on invertebrates and fish, are known for cannibalism (Landry JJ, Fisk, AT,

99   Yurkowski, DJ, Hussey, NE, Dick, T, Crawford, RE, and Kessel ST. *In press*), and

100   although not considered a preferred prey item, have a wide range of predators, from

101   seabirds, such as the Black Guillemot (*Cepphus grylle*) (Divoky & Tremblay 2013), to

102   marine mammals, such as beluga whales (*Delphinapterus leucas*) (Breton-Honeyman et

103   al. 2016) and seals (Lowry et al. 1980), to Greenland sharks (*Somniosus microcephalus*)

104   (Fisk et al. 2002). Shorthorn Sculpin represent an indicator species for Arctic marine

105   ecosystems in part due to their limited long-distance movements (Dick et al. 2009) and as

106   such, a baseline understanding of their ecology in the Arctic is important to predict

107   anthropogenic effects in the future.

108   In this study, we used fixed station acoustic telemetry, specifically VPS, to track

109   and record high-resolution Shorthorn Sculpin movements over a period of three years

110   (2012 – 2015) in Resolute Bay, Nunavut, a small bay in the high Canadian Arctic. Data

111   from the tagged individuals were used to examine the spatial use and fine-scale

112   movements of these benthic fish in relation to vessel activity and the environment during

113   the open water ice-free period of summer and early autumn. We hypothesized that

114   sculpin would exhibit a change in behavior and movement when vessels were moving

115   and present compared to periods when absent, and specifically predicted that: individuals

116   will exhibit lower rates of movement during vessel movement and presence, and, in

117   periods when vessels are present sculpin will reduce their spatial use (home ranges) in the

118   bay.

119

120   **Methods**

121   *Study Site*

122   Resolute Bay, Nunavut (74.6773°N and 94.8297°W) is located on the north shore

123   of the Northwest Passage and vessels are common in the bay during open water periods

124   (approx. end of July till end of September), utilizing it as an anchorage area for supplies

125   restocking and passenger exchange. The settlement is to the northeast of the bay, has 243

126   residents (Anon 2013), and contributes nutrients through the sewage outflow. The bay is

127   generally < 20 m deep, with the head of the bay reaching a depth of 30 m and a shallow

128   sill reaching 1 m depth at low tide located at the center of the mouth of the bay (Fig. 1).

129   One small river on the west shore and two streams on the east contribute freshwater

130   input.

131   *Fish telemetry*

132   Shorthorn Sculpin (*Myoxocephalus scorpius*) were caught in Resolute Bay in

133 August 2012, 2013 and 2014 with a gill net (30 m length, 2 inch mesh size) set for 6 hrs,

134 in three locations - northeastern, northwestern and southwestern part of the bay. The

135 number of individuals tagged in 2012, 2013 and 2014 were 22, 12, and 26, respectively.

136 Upon capture, total length (L) was measured to the nearest 1 mm and mass (M) to nearest

137 0.1 g prior to insertion of acoustic tags. Condition index (K) was calculated using the

138 formula:

139     $$K=(M \times 10^3)/L^3 \qquad (1).$$

140   Vemco[®] V9 (Halifax, Nova Scotia, Canada, years 2012 and 2013) and Vemco[®]

141 V6 (year 2014) acoustic transmitters, i.e., tags, were used in this study with tag to body

142 weight ratio of < 2% for all individuals. Following capture, fish were held in 120 L

143 coolers, filled with bay water and water was agitated regularly to maintain oxygen levels

144 prior to tag insertion surgery. An anaesthetic bath of MS222 (1:5 ratio with sea water) for

145 2-5 min was used for fish sedation. Individuals were placed in a sponge bed for surgery,

146 with gills irrigated continuously with seawater. A ventral incision (~8 mm) anterior of the

147 pelvic fins was made for tag insertion and closed with three independent sutures (coated

148 Vicryl Ethicon[®] VCP423, 3-0 FS-2 cutting) each tied with a triple surgeon's knot;

149 procedure duration was 2 to 4 min. A 10% betadine solution was used for sterilizing all

150 surgical equipment and the incision site. Fish were left to recover in a holding tank with

151 seawater and aeration, and monitored until equilibrium was regained. Individuals were

152 released at the capture location approximately 1 hr after completion of surgery.

153   In 2012 and 2013, a Vemco[®] VR2W 69 kHz acoustic receiver array, consisting of

154 44 units each year, was used to record movements of individual fish, while in 2014 the

155   array consisted of 28 Vemco® VR2W 180 kHz units (Fig. 2). Each year the array was

156   deployed in the beginning of August and recovered at approximately the same time the

157   following year. Due to considerations for winter ice cover, a minimum deployment depth

158   of 15 m was used with spacing between individual units from 150 to 300 m. Each unit

159   consisted of a ~40 kg rock anchor attached via ~2 m rope to an ORE Port ME acoustic

160   release (manufactured by Edge Tech, USA), the receiver and a subsurface float to

161   maintain the mooring in an upright position. Sync tags were attached to 19 receivers

162   across the array and were used for receiver clock drift correction during the processing of

163   positional data (Espinoza et al. 2011).

164   *Presence and movement of ships in Resolute Bay*

165   To determine vessel absence, presence and movement times, we used Satellite

166   Automatic Identification System (AIS) archive data from 2012, 2013, and 2014. Data

167   from August and September were used, as these are the months with ship activity in

168   Resolute Bay. A total of 7, 10 and 7 vessels (>40 m length) visited Resolute Bay in 2012,

169   2013 and 2014, respectively. All vessels enter and exit the bay using two shipping lanes

170   and the times for entry/exit were extracted from the AIS dataset. These times were cross-

171   referenced with a time-lapse footage set at 10 s intervals in 2014 from a camera facing

172   the bay (Canon EOS T4, 50mm lens, set in a weather-proof box with constant power

173   supply). From this footage, we determined that passenger and cargo vessels took 10 and

174   30 min (±1 min), respectively, to enter the bay, and 15 and 30 min (±1 min) to exit.

175   Passenger vessels typically use the western track and cargo vessels utilize the eastern

176   track (see Fig. 1). An additional 5 min were added to the time of anchorage and time

177   prior to departure for statistical analysis to include noise from anchor dropping or pulling,

178   respectively. Vessel states were defined as follows: vessels absent from the bay (VA);

179   vessels were moving either entering or exiting the bay (VM); and vessels were anchored

180   and thus present in the bay, but not moving (VP).

181   *Acoustic telemetry data processing*

182   Positional data was generated by processing all raw data through Vemco's VPS

183   analysis. The analysis uses the differences in detection times in milliseconds at three or

184   more time-synchronized receivers to triangulate the position of the signal/individual

185   (Smith 2013). Positional data for n=22, 14 (includes 2 IDs from 2012 tagging) and 26

186   individuals in 2012, 2013 and 2014, respectively, was filtered for HPE (horizontal

187   position error, a unitless estimate of the sensitivity of the calculated position (Smith

188   2013)), and any HPE values larger than 37 were removed from further analysis. This

189   value for HPE was chosen based on the average relative to the HPE for the sentinel tags

190   in our VPS as suggested by Smith (2013), resulting in a distance error of > 10 m. In 2014,

191   the total IDs used for further analysis dropped to 12 individuals due to lack of sufficient

192   detections. A total of 20,847, 16,882, and 3,478 detections for 2012, 2013 and 2014,

193   respectively, were included in the final analysis.

194   To generate home ranges and estimate movement behaviors of sculpin

195   adeHabitatHR and adeHabitatLT packages (Calenge 2006) in R (version 0.98.1103

196   running on Mac OS X 10.9.5), respectively, were used. These metrics were grouped into

197   three vessel variables: 1) vessels absent from the bay (VA), 2) vessels present/anchored

198   in the bay (VP), and 3) vessels moving, either entering or exiting the bay (VM). During

199   VP, vessel generators were running to produce and supply power, and small boats

200   transported passengers and/or goods to the shore and back, adding more noise to the

201   background. During VM additional noise stems mainly from the vessel's propellers, the

202   vessel moving through the water, and anchor dropping or pulling. Small boat noises, such

203   as these produced by local fisherman's boats and recreational yachts < 40 m in length

204   occurred during VA, VP and VM, but were not considered in the analysis because the

205   duration of these boats' activities within the bay was fairly short (2-3 minutes) and

206   occurred sporadically during each vessel state. In comparison, boats/servicing tenders of

207   ships during VP moved consistently from the vessel to the shore.

208   Sculpin's core and general home ranges were established using Kernel utilization

209   distributions (KUD) at 50% and 95%, while Minimum Convex Polygon (MCP) was used

210   to determine the extended home range area. The data were separated by vessel variable

211   (VA, VP and VM) and home range analysis was performed for all individuals that had ≥5

212   detections (Table 2). Home ranges for each individual and variable were mapped

213   separately and sizes calculated in hectares. Using CalcHR.R and Indices.txt (Fieberg &

214   Kochanny 2005) we performed an overlap estimation for 50% and 95% KUD for VP, VA

215   and VM by calculating the Hurlbert Index of overlap. To examine the differences in

216   individual MCP area sizes between VA and VP, a Kruskal-Wallis rank sum test was

217   undertaken.

218   Sculpin movement behaviors were quantified using trajectory *bursts* – discrete

219   segments of successive VPS positions (Turchin 1998). Bursts were extracted from each

220   individual's trajectory (a collection of VPS positions forming a continuous curve of that

221   individual's movements (Calenge et al. 2009)) based on time and date of detection with

222   cut off between bursts of > 30 min between consecutive positions, i.e., no detections of

223   the individual. Only bursts with a minimum of 5 consecutive VPS positions were

224   considered. This allowed for the elimination of prolonged/excessive periods between

225   detections/positions of individual fish, providing continuous high-resolution data to

226   identify distinct movement behaviors. We clustered the bursts using a diagonal, varying

227   volume and shape (VVI) model with 3 components as suggested by the Mclust function

228   (Fraley & Raftery 1999) in R. Descriptive parameters with correlations greater than 0.45

229   were removed. We used the following descriptive parameters to define the bursts'

230   movement types (MT): 1) distance between successive relocations; (2) rate of movement

231   (ROM; m s^{-1}); (3) turning angle, which measures the change in direction between

232   relocations; (4) a linearity ratio, where 1 denotes a straight path and 0 a less linear path

233   (Heupel et al. 2012); (5) total distance travelled in a burst; (6) bearing; (7) depth; and (8)

234   acceleration (7 and 8 were only available in 2012 and 2013).

235   Based on the time and date of their occurrence, identified burst MTs were

236   assigned to the three vessel variables (VA, VP and VM), and individual and mean

237   proportions of each were calculated (Table 3). A chi-squared test was performed for the

238   mean proportions of VP and VM using VA as the expected value to determine overall

239   differences in MT proportions between vessel variables. To determine the actual

240   differences between identified MTs for VA, VP and VM, we compared individual

241   proportion values using Kruskal-Wallis rank sum test and T-test as appropriate based on

242   our results from a Shapiro-Wilk normality test.

243   *Environmental variables processing*

244   Hourly-averaged salinity (PSU), water temperature (°C), and dissolved oxygen

245   saturation (%) were collected using a Satlantic STOR-X submersible data logger with a

246   Seabird 37-SIP microCAT C-T recorder, sampling for 30 s every hour at resolutions of 1,

247   1, and 5 s, respectively. The instruments were deployed and retrieved in August of each

248   year, and were located approximately 0.5 m above the seafloor, in 33 m of water in the

249   depression at the head of the bay (74.68549° N 94.86194° W). Daily average wind speeds

250   and air temperatures were obtained from the Environment and Climate Change Canada

251   online archives (Weather Canada 2015). Photoperiod (h) was downloaded from the time

252   and date online archives (Steffen Thorsen 2014). A general linear mixed model was used

253   to assess the influence of environmental variables on MTs. Variables with correlation

254   >30 were removed from analysis for all years. We used vessel activity, photoperiod,

255   dissolved oxygen and wind speed as fixed effects in 2012. Similarly, for 2013 plus

256   salinity; however, in 2014 only vessel activity, photoperiod and dissolved oxygen were

257   used. Fish ID was added as a random effect for all years. Based on the model, variables

258   that showed significance were examined individually to establish the strength of the

259   relationships using linear regression.

260

261   **Results**

262   *Sculpin body sizes*

263   There was no significant difference in total length of tagged sculpin between 2012

264   and 2013 (p = 0.57; t-test with equal variances), however, 2014 fish were significantly

265   smaller than both 2012 and 2013 (both p < 0.01; t-test with equal variances) (Table 1).

266   Condition index calculations showed no significant differences in individual condition

267   among years (all p > 0.05, t-test).

268   *Movement types*

269   For 2012, MTs were explained by mean rate of movement (ROM), linearity,

270 mean depth, and standard deviation (SD) of turn angle and acceleration (Kruskal-Wallis

271 rank sum test; Fig. 3). Higher ROM, acceleration and depth, and more linear trajectory

272 with lower turning angles characterized MT 2 and distinguished it from MTs 1 and 3. MT

273 1 had the lowest rate of movement and acceleration, and somewhat lower linearity than

274 MT 3. Medium ROM, linearity and acceleration defined MT 3. In 2013, descriptive

275 parameters that significantly influenced MTs were mean ROM, sum of distance, SD of

276 turn angle and acceleration (Kruskal-Wallis rank sum test; Fig. 3). Similarly to 2012,

277 highest ROM, sum of distance and acceleration distinguished MT 2 from the rest. MT 1

278 had the lowest acceleration and sum of distance values, while MT 3 had medium values.

279 For 2014, mean ROM, linearity, sum of distance and SD of turn angle were significant (p

280 < 0.001 for all, Kruskal-Wallis rank sum test; Fig. 3). Here too, MT 2 had the highest

281 ROM and sum of distance, and MT 1 had the lowest of these values, although both had

282 very similar linearity. MT 3 had medium values for ROM and sum of distance, but the

283 lowest linearity.

284   Based on these variables for all three years, MT 1 was identified as behavior

285 typical of fish that are feeding/hiding, MT 2 as typical of in-transit movement, and MT 3

286 as typical of foraging behavior (Fig. 4).

287 *Influence of vessels on movement types*

288   In 2012 and 2014, there were no significant differences in overall MT proportions

289 between vessel variables (chi-squared, $p > 0.05$, Fig. 5). However, in 2013 a change in

290 overall MT proportions was observed for VA compared to VP (chi-squared = 7.46, p =

291 0.024), but not for VA and VM (chi-squared = 0.745, p = 0.69). Examining each MT

292   separately between vessel variables in 2012 and 2013, we found MT 1, associated with

293   feeding/hiding, decreased significantly when vessels were moving in the bay in 2012

294   compared to periods when vessels were absent (p=0.034, Kruskal-Wallis rank sum test;

295   Fig. 5), while in-transit movement (MT 2) in 2013 decreased significantly when vessels

296   were present (VP) in comparison to when vessels were absent (p=0.012, Kruskal-Wallis

297   rank sum test; Fig. 5).

298   Vessel movements occur over 10 to 30 minute periods and identified MTs often

299   spanned vessels movement, presence and/ or absence periods. This confounded our

300   ability to tease apart any influence of VM on MTs. Thus, significant differences in MTs

301   during VM periods are reported above but excluded from further analysis and discussion.

302   *Influence of environment on fish behavior*

303   A general linear mixed model analysis for environmental variables revealed

304   photoperiod and vessel activity in 2012 ($p < 0.001$ for both) significantly influenced the

305   proportions of MTs. However, linear regressions of photoperiod with individual MTs had

306   low R-squared values (R-squared < 0.1 for all). In 2013, vessels, photoperiod and wind

307   speed were significant for the model ($p < 0.01$ for all), however only photoperiod

308   influenced MT 2 in the linear regression (R-squared = 0.32; Fig. 6). MT 2 (in-transit

309   movement) increased in frequency with decreasing daylight, while MT 1 and MT 3

310   (feeding/hiding & foraging movement, respectively) showed a slight decrease. In 2014,

311   vessels, photoperiod and hourly dissolved oxygen significantly influenced sculpin's MTs

312   in the model ($p < 0.05$ for all); however, linear regression R-squared values were low (R-

313   squared < 0.03 for all variables).

314   *Home Ranges*

315   Home ranges during vessel movement (VM) periods are reported for each year

316   but excluded from further analysis and discussion due to bias resulting from shorter

317   periods of time over which detections during VM were collected.

318   In 2012, MCP area for VP and VM were lower when compared to VA periods

319   (VA; p-value = 0.002, and < 0.001, respectively; Kruskal-Wallis rank sum test; Fig. 7 and

320   8). Hurlbert overlap test had a mean index of 0.073 and 0.375 for 50% and 95% KUD,

321   respectively, between VA and VP.

322   In 2013, MCP decreased significantly during VP and VM (p = 0.028 and 0.01,

323   respectively; Kruskal-Wallis rank sum test; Fig. 7 and 8). Area for 50% and 95% KUD

324   also decreased significantly for VM as compared to VA (p < 0.02 for both). The mean

325   overlap was 0.114 and 0.325 for 50% and 95% KUD, respectively, for VA vs VP.

326   In 2014, no significant differences were found in any of the area sizes (all p >

327   0.15, Fig. 8); however, it should be noted that sample size was low (VA n=4, VP n=4,

328   and VM n=2). The overlaps between VA and VP for 50% and 95% KUD were 0.248 and

329   0.149, respectively (Kruskal-Wallis rank sum test). For VA vs VM test was not

330   performed due to the low sample size. The Hurlbert overlap test (n=4) between VA and

331   VP revealed a low overlap with mean index of 0.013 and 0.063 for 50% and 95% KUD,

332   respectively.

333

334   **Discussion**

335   In all three years of this study, we identified three general movement types for

336   Shorthorn Sculpin in Resolute Bay, Nunavut using VPS acoustic telemetry –

337   feeding/hiding (MT 1), in-transit (MT 2) and foraging (MT 3). In-transit behaviour

338 decreased with vessel presence in 2013, but not in other years. In all three years – 2012,

339 2013 and 2014 – the extent of spatial use by sculpin was smaller for all individuals when

340 vessels were present, and core home ranges had low overlap between times of vessel

341 absence and presence. This study demonstrates that the presence of large vessels can

342 impact benthic fish habitat use in nearshore Arctic environments, with implications for

343 management and conservation in the light of expanding vessel traffic in these sensitive

344 ecosystems.

345 During 2012 and 2013, in periods with no vessels, feeding/hiding behavior (MT1)

346 was the most frequent movement behavior for Shorthorn Sculpin, followed by foraging

347 (MT3) and in-transit movement (MT2). Kasumyan (1999) looked at five different species

348 of sturgeon and identified each to have a slow and twisting movement trajectory in

349 response to prey odors in holding tanks, similar to MT 1 in this study. Sturgeon are also

350 benthic fish, although they are not considered a sit-and-wait predator, and instead search

351 for benthic food using barbels. McLean et al. (2014), using VPS, attributed to feeding

352 similar behavior adopted by Atlantic Sturgeon (*Acipenser oxyrinchus*) when in prey

353 patches. Similar movement trajectories have been observed for terrestrial species, such as

354 the Baltimore Checkerspot butterfly (*Euphydras phaeton*), which had shortest movement

355 lengths and large turning angles in habitats where food was abundant (Brown et al. 2017).

356 As Shorthorn Sculpin is thought to be a sit-and-wait predator, the very low rate of

357 movement for MT 1 indicates feeding associated behavior. However, it could indicate

358 anti-predator behavior for sculpin, which take cover when under predator threat and sit

359 motionless under shelter (Shi et al. 2017). Both of these behaviors are supported by the

360 low distance travelled by sculpin when exhibiting this movement type. Thus, MT 1 could

361   be associated with feeding and/or hiding, and further finer scale studies are required to

362   distinguish between the two for Shorthorn Sculpin.

363   We identified MT 2 as directional in-transit behavior, which is believed to be

364   associated with general dispersal, movement through inhospitable areas, movement

365   between prey patches and/or extra-home-range exploration due to the relatively large

366   ROM and distance travelled. McLean et al. (2014) identified a similar pattern of

367   movement for Atlantic Sturgeon (*Acipenser oxyrinchus*), which the authors described as

368   straight-line rapid movement with large mean distance between relocations, and

369   attributed to dispersal and movement between patches. This type of movement has been

370   observed for terrestrial species as well. Zollner & Lima (1999) described it in their

371   simulation based on small forest mammals as related to extensive search of food patches,

372   where straight-line travel is utilized to minimize effort, but also, as a movement related to

373   greater risk, such as moving through areas with higher risk of mortality. Additionally,

374   Frafjord & Prestrud (1992) linked this type of movement to extra home-range exploration

375   and roaming in Arctic Foxes (*Alopex lagopus*) in Svalbard, Norway.

376   Movement type 3 was identified as foraging, characteristic of movement between

377   food patches within the home range, due to its medium tortuosity and irregular movement

378   trajectory, resembling food search behavior. Coughlin et al. (1992) found swimming

379   paths for clownfish larvae (*Amphiprion perideraion*) were intermediate in complexity

380   when individuals were looking for food. McLean et al. (2014) attributed erratic

381   movements of Atlantic sturgeon to be associated with searching for food between

382   patches. A similar movement type has been observed for terrestrial species by Brown et

383   al. (2017), who reported intermediate length of movements and turning angles when

384   butterflies were in low food quality habitats.

385   In 2013, in-transit movements by Shorthorn Sculpin decreased significantly when

386   vessels were present/anchored in the bay (VP) compared to when vessels were absent

387   (VA). Extra home range exploration, i.e. in-transit movement, is important for individuals

388   for updating the cognitive map of their home range as that information increases fitness

389   and survival, through, for example, mapping of food resources (Spencer 2012). This

390   indicates that sculpin were likely affected by the presence of vessels in the bay and

391   reduced their extra home-range exploration in response. However, interpretation here

392   needs to be made with caution, because in 2012 in-transit movement types showed no

393   statistical difference between VA and VP. Additionally, we saw a negative correlation of

394   in-transit movements for 2013 with photoperiod, but this correlation again was not

395   observed for any other years. Moore & Moore (1974) found that Shorthorn Sculpin had

396   restricted visual capacity during ice cover and, thus, changed their food search behavior.

397   This suggests that at 24 h photoperiod sculpin have good visibility reducing the pressure

398   to search for food. However, with diminishing light conditions sculpin may spend more

399   time travelling between patches. A decrease in in-transit movements in 2013 may

400   therefore be linked to increased prey availability; unfortunately prey abundance data are

401   not available to test this idea, and any influences by vessels' presence cannot be

402   completely excluded as a cause at this point (see discussion in paragraphs below).

403   Therefore, our results regarding vessel presence influences on sculpin in-transit

404   movements are somewhat inconclusive, and we recommend further study.

405   We also suggest that sculpin were aware of the presence of anchored vessels in

406   the bay, likely perceive it as a threat, and thus decrease exploratory behavior and the use

407   of their extended home range. Minimum convex polygon (MCP) represents the extent of

408   the area utilized by species in a habitat, which in our study was interpreted as extended

409   home range, or areas that an individual explores outside of its immediate home range.

410   The observed decrease of MCP in all years when vessels were present but not moving

411   implies reduced extra-home-range exploration when vessels are present in the bay. The

412   significant decrease of in-transit movements in 2013 and the overall movement type

413   proportions changing between VA and VP provide further evidence to support this. These

414   results are in agreement with disturbance studies on other species. For example, dolphins

415   (*Tursiops aduncus*) changed their overall behavioral patterns in response to boats (Pérez-

416   Jorge et al. 2017), while herring (*Clupea harengus*) exhibited vessel avoidance behavior

417   (Vabø et al. 2002). Similarly for terrestrial species, leopards (*Panthera pardus*) reduced

418   their overall activity, and rhinoceros (*Diceros bicornis*) and spider monkeys (*Ateles* spp.)

419   relocated and/ or reduced their home ranges to avoid human settlements and

420   anthropogenically disturbed areas, respectively (Ngoprasert et al. 2017; Odendaal-

421   Holmes et al. 2014; Asensio et al. 2017).

422   While Sculpin VP core home ranges (50%) were still located within VA's larger

423   (95%) home range boundaries, there was low overlap of VP with VA core home ranges

424   (50%). We suggest that there is a shift of the core's locations during VP. Similar results

425   were observed for spider monkeys, which minimize the use of a particular part of their

426   home range based on the degree of habitat disparity due to disturbance (Asensio et al.

427   2017). Anchored vessels run generators to supply electricity for everyday use and thus,

428   produce noise. This noise along with the associated particle pressure are likely perceived

429   as predator threat, and cause habitat disparity in our study; when under threat sculpin are

430   known to utilize shelter (Moring 2001). The seabed of Resolute Bay has patchily

431   distributed vegetation cover, and a shift in the core when vessels were present likely

432   indicates relocation of the individual to an area within their home range with more

433   vegetation cover, where shelter is easily accessible. Similar behavior has been observed

434   for Brown Trout (*Salmo trutta*) which had increased preference for territories with cover

435   after simulated predator attack (Johnsson et al. 2004), and for Three-Spined Stickleback

436   (*Gasterosteus aculeatus*), which prefer to build their nests near vegetation as shelter from

437   predators (Huntingford & Coyle 2007). The observed shift in the location of the core

438   home ranges provides further evidence of vessel presence influences on sculpin.

439   There were fewer detections in 2014 than 2012 and 2013, and quantified MTs are

440   likely compromised, with only four bursts observed for VP. There are two likely

441   explanations for the observed low number of detections in 2014: 1) less coverage of bay

442   due to fewer receivers used in array (28 receivers in 2014 versus 44 in 2012 and 2013;

443   detections range varied between 10 to 130 m (Kessel et al. 2015)), and 2) smaller tagged

444   sculpin in 2014 left the area due to size segregation associated with cannibalism by larger

445   and older conspecifics (Pfister 2003; Petty & Rossman 2007). Sculpin are territorial

446   (Petty & Rossman 2007) and as such are very individualistic, i.e. they do not form

447   schools or occur in groups. They are also known for cannibalism (Pfister 2003; Landry

448   JJ, Fisk, AT, Yurkowski, DJ, Hussey, NE, Dick, T, Crawford, RE, and Kessel ST. *In*

449   *press*) and size-dependent intraspecific competitive interaction, thus smaller sculpin

450   avoid close encounters with larger individuals (Petty & Rossman 2007). Since sculpin

451   tagged in 2014 were significantly smaller, they may have avoided larger conspecifics and

452   may have moved out of the array's effective range. Due to this, movement types for 2014

453   were not considered in the results and conclusions. Home range data were included in the

454   spatial analysis because there were sufficient detections per individual to extract these

455   and calculate overlaps. Important to note here is that there were fewer individuals

456   included in the analysis of 2014 home ranges compared to other years (see Table 2).

457   The observed inconsistencies between years for the quantified MTs may be due

458   to: 1) an overall small sampling size for sculpin, and 2) environmental variation between

459   years. In 2012, 22 individuals were tagged, but only 17 individuals were used for analysis

460   for VA and VP (Table 2), while in 2013 we tagged 14 fish but were able to use 11 for VA

461   and VP. Although all tagged individuals for both years were detected, some individuals

462   appear to have left the system for the period of our study, resulting in insufficient number

463   of detections for the statistical analysis. Environmental factors also showed variation in

464   the months of August and September between 2012 and 2013. For example, average

465   monthly air temperature for the two months of interest was 0.9° C in 2012 and -2.25° C

466   in 2013; and total precipitation also varied between years, 28.9 mm in 2012 compared to

467   9.05 mm in 2013 (Environment and Climate Change Canada 2017). Also, differences

468   between 2012 and 2013 were seen in salinity means (32 and 29, respectively), water

469   temperature (-0.33° C and -1.1° C) and dissolved oxygen (81.7 and 72.8). Thus,

470   environmental variation along with small sampling size may partly explain the inter-

471   annual variation observed in our results for MTs between years.

472   Taken together, the results of this study suggest Shorthorn Sculpin are influenced

473   by vessel activity in Resolute Bay. We observed a change in the proportions of different

474   movement types and behavior and in the spatial area use by individual fish during vessel

475   presence. While changes in movement types associated with vessel activity did not show

476   consistency throughout years, spatial area use changes were consistent and the overall

477   results clearly support further study on the impact of increasing vessel traffic and

478   associated activity on fish in the arctic and other regions. It is likely that the observed

479   inter annual variation in MTs was a result of a combination of changes in study design

480   among years and environmental differences. In addition, more research is required to

481   establish the mechanisms by which vessels affect sculpin, and the noise and particle

482   pressure tolerance levels of this species. The implications these may have for sculpin are

483   at this point unclear and additional examination is required pertaining to prey, and any

484   effects vessels may have on sculpin's feeding and foraging behaviors under varying prey

485   availability. Shorthorn Sculpin are an integral part of the Arctic food web, and are

486   believed to be a good indicator of changes in the Arctic marine ecosystem (Dick et al.

487   2009). Our study provides the first assessment of vessel influences on the fine scale

488   movements and home ranges for this species in the Arctic. As such, it provides a baseline

489   to which future studies on general vessel activity influences in the high Arctic, sculpin,

490   and sculpin behavior and home ranges can be compared.

491

23

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498   fieldwork.

499 **References**

500 Anon, 2013. Resolute Bay. *Government of Nunavut*.

501 Asensio, N. et al., 2017. The effect of roads on spider monkeys' home range and mobility

502   in a heterogeneous regenerating forest. *Biotropica*, 49(4), pp.546–554.

503 Breton-Honeyman, K. et al., 2016. Inuit Knowledge of beluga whale (Delphinapterus

504   leucas) foraging ecology in Nunavik (Arctic Quebec), Canada. *Canadian Journal of*

505   *Zoology*, 94, pp.713–726.

506 Brown, L.M. et al., 2017. Using animal movement behavior to categorize land cover and

507   predict consequences for connectivity and patch residence times. *Landscape*

508   *Ecology*, 32(8), pp.1657–1670.

509 Calenge, C., 2006. The package adehabitat for the R software: a tool for the analysis of

510   space and habitat use by animals. *Ecological Modeling*, 197, pp.516–519.

511 Calenge, C., Dray, S. & Royer-Carenzi, M., 2009. The concept of animals' trajectories

512   from a data analysis perspective. *Ecological Informatics*, 4, pp.34–41.

513 Comiso, J.C. et al., 2008. Accelerated decline in the Arctic Sea ice cover. *Geophysical*

514   *Research Letters*, 35(1), p.

515 Cooke, S.J. et al., 2013. Tracking animals in freshwater with electronic tags: past, present

516   and future. *Animal Biotelemetry*, 1(5), pp.1–19.

517 Coughlin, D.J., Strickler, J.R. & Sanderson, B., 1992. Swimming and search behaviour in

518   clownfish, Amphiprion perideraion, larvae. *Animal Behaviour*, 44(PART 3),

519   pp.427–440.

520 Cressey, D., 2011. Open water: As the ice melts, fresh obstacles confront Arctic

521   researchers. *Nature*, 478, pp.174–177.

522   Dawson, J., Johnston, M.E. & Stewart, E.J., 2014. Governance of Arctic expedition

523   cruise ships in a time of rapid environmental and economic change. *Ocean and*

524   *Coastal Management*, 89, pp.88–99.

525   Dick, T., Chambers, C. & Gallagher, C.P., 2009. Parasites, diet and stable isotopes of

526   shorthorn sculpin (Myoxocephalus scorpius) from Frobisher Bay, Canada. *Parasite*,

527   16, pp.297–304.

528   Divoky, G. & Tremblay, Y., 2013. *Shifting Prey in a Melting Ocean: Seabirds Reveal*

529   *Annual and Seasonal Changes in Arctic Nearshore Fish*, Available at:

530   https://seagrant.uaf.edu/conferences/2013/wakefield-arctic-

531   ecosystems/presentations/divoky-seabirds-fish.pdf.

532   Environment and Climate Change Canada, 2017. Monthly Data Report-Climate-

533   Environment and Climate Change Canada. *Government of Canada*. Available at:

534   climate.weather.gc.ca [Accessed January 17, 2017].

535   Eriksson, B.K. et al., 2004. Effects of boating activities on aquatic vegetation in the

536   Stockholm archipelago , Baltic Sea. *Estuarine, Coastal and Shelf Science*, 61,

537   pp.339–349.

538   Espinoza, M. et al., 2011. Testing a new acoustic telemetry technique to quantify long-

539   term, fine-scale movements of aquatic animals. *Fisheries Research*, 108(2–3),

540   pp.364–371.

541   Fieberg, J. & Kochanny, C.O., 2005. Quanitfying home-range overlap: the importance of

542   the utilization distribution. *Journal of Wildlife Management*, 69(4), p.1346.

543   Fisk, A.T. et al., 2002. Using anthropogenic contaminants and stable isotopes to assess

544   the feeding ecology of greenland sharks. *Ecology*, (83), pp.2162–2172.

545   Frafjord, K. & Prestrud, P., 1992. Home range and movements of Arctic foxes (Alopex

546   lagopus) in Svalbard. *Polar Biology*, 12, pp.519–526.

547   Fraley, C. & Raftery, A.E., 1999. MCLUST: Software for Model-Based Cluster Analysis.

548   *Journal of Classification*, 16, pp.297–306.

549   Grans, A. et al., 2013. Effects of acute temperature changes on gut physiology in two

550   species of sculpin from the west coast of Greenland. *Polar Biology*, (36), pp.775–

551   785.

552   Hauser, S. et al., 2014. Population-specific home ranges and migration timing of Pacific

553   Arctic beluga whales (Delphinapterus leucas). *Polar Biology*, 37, pp.1171–1183.

554   Heide-Jørgensen, M.P. et al., 2003. The migratory behaviour of narwhals (Monodon

555   monoceros). *Canadian Journal of Zoology*, 81, pp.1298–1305.

556   Heupel, M.R. et al., 2012. Consistent movement traits indicative of innate behavior in

557   neonate sharks. *Journal of Experimental Marine Biology and Ecology*, 432–433,

558   pp.131–137. Available at: http://dx.doi.org/10.1016/j.jembe.2012.07.013.

559   Holles, S.H. et al., 2013. Boat noise disrupts orientation behaviour n a coral reef fish.

560   *Marine Ecology Progress Series*, 485, pp.295–300.

561   Huntingford, F.A. & Coyle, S., 2007. Antipredator Defences in Sticklebacks: Trade-Offs,

562   Risk Sensitivity and Behavioural Syndromes. In S. Ostlund-Nilsson, I. Mayer, & F.

563   A. Huntingford, eds. *Biology of the Three-Spined Stickleback*. Boca Raton, FL: CRC

564   Press, pp. 127–156.

565   Hussey, N.E. et al., 2015. Aquatic animal telemetry: A panoramic window into the

566   underwater world. *Science (New York, N.Y.)*, 348(6240), p.1255642-. Available at:

567   http://www.sciencemag.org/content/348/6240/1255642.full?utm_campaign=email-

568   sci-toc&utm_src=email.

569   Johnsson, J.I., Rydeborg, A. & Sundstrom, L.F., 2004. Predation risk and the territory

570   value of cover: an experimental study. *Behavioral Ecology and Sociobiology*, 56(4),

571   pp.388–392.

572   Kasumyan, A.O., 1999. Olfaction and taste senses in sturgeon behaviour. *Journal of*

573   *Applied Ichthyology-Zeitschrift Fur Angewandte Ichthyologie*, 15(4–5), pp.228–232.

574   Kessel, S.T. et al., 2015. Distinct patterns of Arctic cod (Boreogadus saida) presence and

575   absence in a shallow high Arctic embayment, revealed across open-water and ice-

576   covered periods through acoustic telemetry. *Polar Biology*, pp.1–12. Available at:

577   http://link.springer.com/10.1007/s00300-015-1723-y.

578   Kessel, S.T. et al., 2017. First documented large-scale horizontal movements of

579   individual Arctic cod (Boreogadus saida). *Canadian Journal of Fisheries and*

580   *Aquatic Sciences*, 296(January), pp.292–296.

581   Kortsch, S. et al., 2015. Climate change alters the structure of arctic marine food webs

582   due to poleward shifts of boreal generalists. *Proceedings of the Royal Society B of*

583   *the Royal Society B*, (282).

584   Lowry, L.F., Frost, K.J. & Burns, J.J., 1980. Variability in the diet of Ringed seals, Phoca

585   hispida, in Alaska. *Canadian Journal of Fisheries and Aquatic Sciences*, 37,

586   pp.2254–2261.

587   McLean, M.F. et al., 2014. Diversity of behavioural patterns displayed by a summer

588   feeding aggregation of Atlantic sturgeon in the intertidal region of Minas Basin, Bay

589   of Fundy, Canada. *Marine Ecology Progress Series*, 496, pp.59–69.

590   Moore, I.A. & Moore, J.W., 1974. Food of Shorthorn Sculpin, Myoxocephalus scorpius,

591   ln the Cumberland Sound Area of Baffin Island. *Journal Fisheries Research Board*

592   *of Canada*, 31(3), pp.355–359.

593   Moring, J.R., 2001. Appearance and possible homing of two species of sculpins in Maine

594   tidepools. *Northeastern Naturalist*, 8(2), pp.207–218.

595   Ngoprasert, D., Lynam, A.J. & Gale, G.A., 2017. Effects of temporary closure of a

596   national park on leopard movement and behaviour in tropical Asia. *Mammalian*

597   *Biology*, 82, pp.65–73. Available at:

598   http://dx.doi.org/10.1016/j.mambio.2016.11.004.

599   Nowacek, D.P. et al., 2007. Responses of cetaceans to anthropogenic noise. *Mammal*

600   *Review*, 37(2), pp.81–115.

601   Odendaal-Holmes, K., Marshal, J.P. & Parrini, F., 2014. Disturbance and habitat factors

602   in a small reserve: space use by establishing black rhinoceros (Diceros bicornis).

603   *South African Journal of Wildlife Research*, 44, pp.148–160.

604   Pérez-Jorge, S. et al., 2017. Deep-Sea Research II Estimating the cumulative effects of

605   the nature-based tourism in a coastal dolphin population from southern Kenya.

606   *Deep-Sea Research II*, 140, pp.278–289. Available at:

607   http://dx.doi.org/10.1016/j.dsr2.2016.08.011.

608   Petty, J.T. & Rossman, G.D., 2007. Size-Dependent Territoriality of Mottled Sculpin in a

609   Southern Appalachian Stream. *Transactions of the American Fisheries Society*,

610   (136), pp.1750–1761.

611   Pfister, C.A., 2003. Some consequences of size variability in juvenile prickly sculpin,

612   Cottus asper. *Environmental Biology of Fishes*, pp.383–390.

613   Richardson, M. et al., 2016. Reconciled climate response estimates from climate models

614   and the energy budget of Earth. *Nature Climate Change*, pp.1–22. Available at:

615   http://www.nature.com/doifinder/10.1038/nclimate3066.

616   Russell, I.C. et al., 1998. The migratory behaviour of juvenile and adult salmonids in

617   relation to an estuarine barrage. *Hydrobiologia*, (165555), pp.321–333.

618   Sandström, A. et al., 2005. Boating and navigation activities influence the recruitment of

619   fish in a Baltic Sea archipelago area. *The Journal of the Human Environment*, 34(2),

620   pp.125–130.

621   Seth, H. et al., 2013. Metabolic Scope and Interspecific Competition in Sculpins of

622   Greenland Are Influenced by Increased Temperatures Due to Climate Change. *PLoS*

623   *ONE*, 8(5).

624   Shi, X. et al., 2017. The angular position of a refuge affects escape responses in staghorn

625   sculpin Leptocottus armatus. *Journal of Fish Biology*, pp.2434–2442.

626   Simpson, S.D. et al., 2016. Anthropogenic noise increases fish mortality by predation.

627   *Nature communications*, 7, p.10544. Available at:

628   http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4748250&tool=pmcentr

629   ez&rendertype=abstract.

630   Slabbekoorn, H. et al., 2010. A noisy spring: The impact of globally rising underwater

631   sound levels on fish. *Trends in Ecology and Evolution*, 25(7), pp.419–427.

632   Smith, F., 2013. Understanding HPE in the VEMCO Positioning System (VPS). *Vemco*,

633   pp.1–31. Available at: http://vemco.com/wp-

634   content/uploads/2013/09/understanding-hpe-vps.pdf.

635   Spencer, W.D., 2012. Home ranges and the value of spatial information. *Journal of*

636   *Mammalogy*, 93(4), pp.929–947.

637   Standing Senate Committee on Fisheries and Oceans, 2009. *Controlling Canada's Arctic*

638   *Waters: Role of the Canadian Coast Guard*,

639   Steffen Thorsen, 2014. Sunrise and sunset times in Resolute Bay. *timeanddate.com*.

640   Available at: https://www.timeanddate.com/sun/canada/resolute [Accessed January

641   22, 2017].

642   Turchin, P., 1998. *Quantitative Analysis of Movement: measuring and modeling*

643   *population redistribution in plants and animals*, Sunderland, MA: Sinauer

644   Associates.

645   US Energy Information Administration, 2012. Arctic oil and natural gas resources. *US*

646   *Energy Information Administration*. Available at:

647   https://www.eia.gov/todayinenergy/detail.php?id=4650 [Accessed July 2, 2016].

648   Vabø, R., Olsen, K. & Huse, I., 2002. The effect of vessel avoidance of wintering

649   Norwegian spring spawning herring. *Fisheries Research*, 58(1), pp.59–77.

650   Vaudo, J.J. & Lowe, C.G., 2006. Movement patterns of the round stingray Urobatis

651   halleri (Cooper) near a thermal outfall. *Journal of Fish Biology*, 68(6), pp.1756–

652   1766.

653   Weather Canada, 2015. Hourly Data Report [data set]. *Environment and Climate Change*

654   *Canada*. Available at:

655   http://climate.weather.gc.ca/historical_data/search_historic_data_e.html [Accessed

656   November 1, 2015].

657   Wysocki, L.E., Dittami, J.P. & Ladich, F., 2006. Ship noise and cortisol secretion in

658   European freshwater fishes. *Biological Conservation*, 128(4), pp.501–508.

659   Zollner, P.A. & Lima, S.L., 1999. Search strategies for landscape-level interpatch

660   movements. *Ecology*, 80(3), pp.1019–1030.

661

662   **Table 1:** Total length, mass and condition index (mean ± 1 standard error) for all tagged

663   Shorthorn Sculpin in Resolute Bay, Nunavut. Letters indicate significant differences

664   between years (t-test, $p < 0.05$).

Year	*n*	Total length (cm)	Mass (g)	Condition index
2012	22	28.1 ± 0.6^{A}	319.4 ± 20.3^{A}	14.1 ± 0.4
2013	12	28.9 ± 1.3^{A}	359.4 ± 55.2^{A}	13.9 ± 0.4
2014	26	23.2 ± 0.5^{B}	174.8 ± 13.8^{B}	13.5 ± 0.2

665

666 **Table 2:** Number of unique Shorthorn Sculpin individuals (detected and used for further

667 analysis), and number of total and used detections in spatial analysis from acoustic

668 telemetry study in Resolute Bay, Nunavut.

	Vessel State	# of unique IDs detected (# of IDs used in analysis)	Total # of detections (Total used in analysis)
2012	Vessels Absent (VA)	22 (17)	12,803 (12,642)
	Vessels Present (VP)	18 (17)	3,716 (3,679)
	Vessels Moving in bay (VM)	13 (7)	54 (48)
2013	Vessels Absent (VA)	14 (11)	14,282 (13,759)
	Vessels Present (VP)	13 (11)	2,558 (2,553)
	Vessels Moving in bay (VM)	9 (3)	36 (22)
2014	Vessels Absent (VA)	14 (4)	3,040 (681)
	Vessels Present (VP)	8 (4)	447 (419)
	Vessels Moving in bay (VM)	2 (2)	21

669

670   **Table 3:** Frequencies of movement types (MT) of Shorthorn Sculpin in Resolute Bay,

671   Nunavut, used to calculate for each year MT proportions per vessel variable. Vessel

672   variables are as follows: VA - vessels absent from the bay; VP - vessels present in the

673   bay; and VM - vessels moving (entering or exiting the bay).

		Movement type frequencies (*bursts*)								
Year		*2012*			*2013*			*2014*		
MT		*MT 1*	*MT 2*	*MT 3*	*MT 1*	*MT 2*	*MT 3*	*MT 1*	*MT 2*	*MT 3*
Vessel variable	*VA*	214	60	164	59	189	121	26	18	23
	VM	7	3	9	2	5	5	1	0	1
	VP	72	22	64	9	55	47	5	4	6

674

675

676   **Fig. 1:** Location of Resolute Bay, Nunavut, Canada. The inset depicts the bathymetry of

677   the bay (depth is shown in meters) and the features surrounding it. Thin black lines

678   denote the eastern and western shipping lanes and the anchoring locations are denoted

679   with a red "X". (**Map source:** Natural Earth. **Inset map source:** Google Imagery ©2017

680   TerraMetrics)

681   **Fig. 2:** Locations of acoustic telemetry receivers in Resolute Bay, Nunavut by year.

682   Numbers of receivers in each array are 44 for 2012 and 2013, and 28 for 2014.

683   **Fig. 3:** Examples of Shorthorn Sculpin movement descriptive parameters versus

684   movement type with respective significance values (Kruskall-Wallis rank sum test) from

685   acoustic telemetry study in Resolute Bay, Nunavut. Significant p-values are denoted with

686   star symbols. Only significant descriptive parameters were used to define the movement

687   types (ROM = rate of movement, SD = standard deviation).

688   **Fig. 4:** Samples of Shorthorn Sculpin movement types from Resolute Bay, Nunavut (note

689   differences in scales). Circles denote detection locations with green identifying the

690   starting point of the movement and black line denotes the movement path. An example of

691   MT 1 associated with feeding/hiding is shown for individual 6008. This particular burst

692   had a mean rate of movement (ROM) of 0.003 m/s, mean acceleration of 0.06, and 0.016

693   linearity ratio (shown are all 246 positions detected over a period of 30 hours). Example

694   of MT 2 associated with in-transit movement is shown for individual with tag number

695   6018. Mean ROM for this behavior was 0.165 m/s, with mean acceleration of 1.16, and

696   0.88 linearity ratio (shown are all 20 positions detected over a period of 3 hours).

697   Example of MT 3 associated with foraging is from individual 6018 and had mean ROM

698   of 0.021 m/s, 0.25 mean acceleration, and 0.48 linearity ratio (shown are all 158 positions

699   detected over a period of 21.5 hours).

700   **Fig. 5:** Mean proportions of movement types for Shorthorn Sculpin per vessel variable in

701   Resolute Bay, Nunavut. VA denotes periods with vessels absent from the bay, VP is for

702   periods with vessels present and VM for periods with vessels moving in the bay.

703   **Fig. 6:** Linear regression relationships of each movement type (MT) versus photoperiod

704   for 2013 for Shorthorn Sculpin, Resolute Bay, Nunavut.

705   **Fig. 7:** Mapped Shorthorn Sculpin home ranges for three individuals from Resolute Bay,

706   Nunavut. Dark and light pink denote 50% and 95% KUD for VA, respectively, dark and

707   light blue denote these for VP, and yellow and light green denote these for VM home

708   ranges.

709   **Fig. 8:** Mean minimum convex polygon (MCP), 50 and 95% home range area sizes for

710   Shorthorn Sculpin individuals from Resolute Bay, Nunavut, are plotted against vessel

711   variables. **In 2012**, MCP area sizes for vessel presence (VP) and movement (VM)

712   decreased when compared to periods with no vessels (VA; p-value = 0.002, and <0.001,

713   respectively; Kruskal-Wallis rank sum test). **In 2013**, MCP decreased significantly during

714   VP and VM (p = 0.028 and 0.01, respectively; Kruskal-Wallis rank sum test). Area sizes

715   for 50% and 95% home ranges also decreased significantly for VM as compared to VA

716   (p = 0.016 for both). **In 2014**, no significant differences were found in any of the area

717   sizes. Numbers of individuals used for the analysis were as follows: VA n=4, VP n=4,
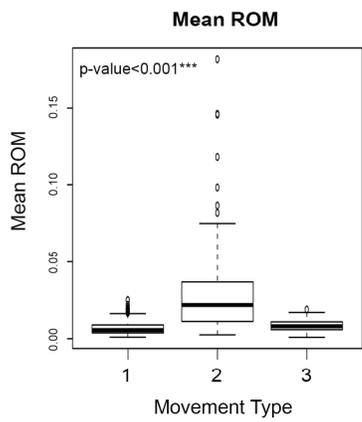
718   and VM n=2.
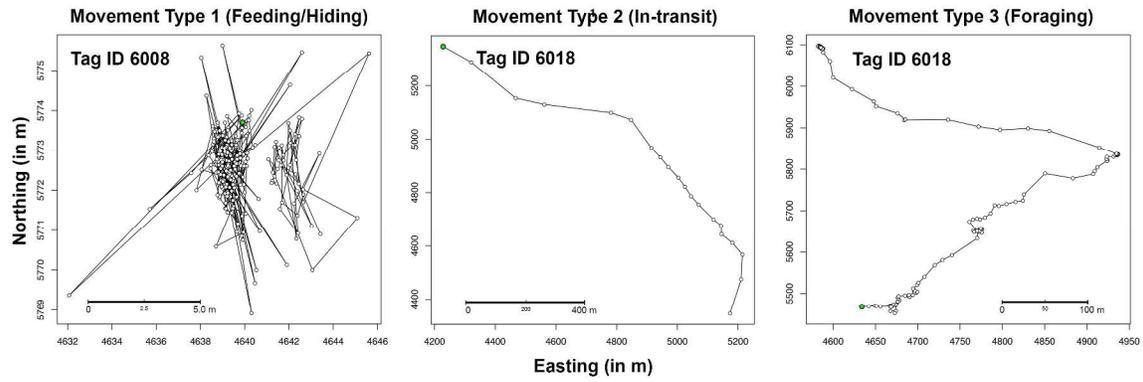
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720 **Figure 1**

721
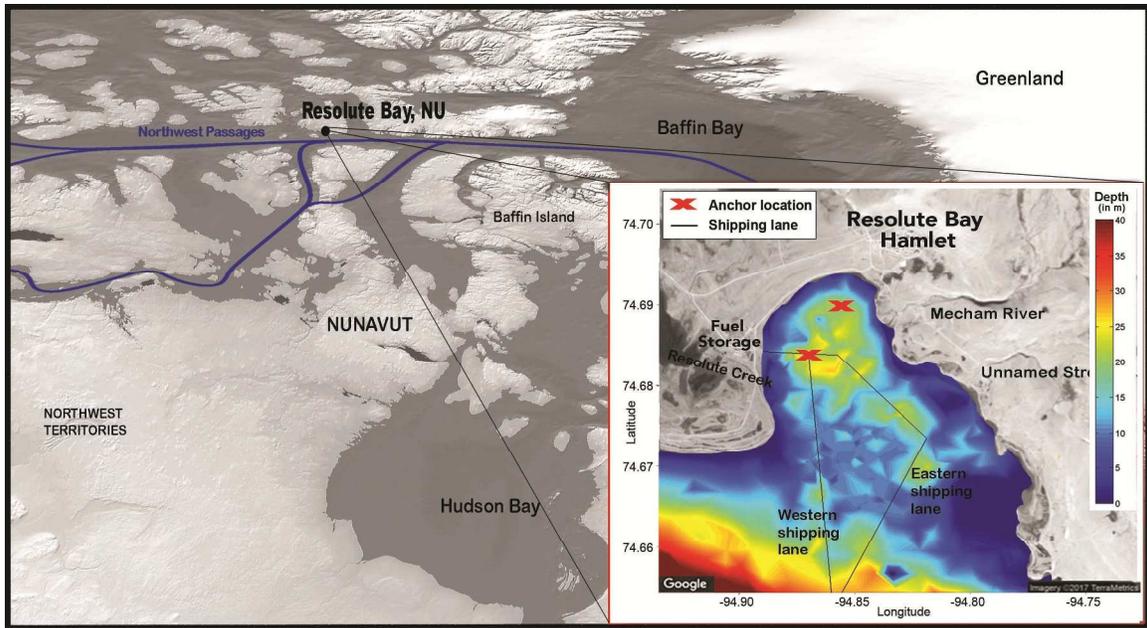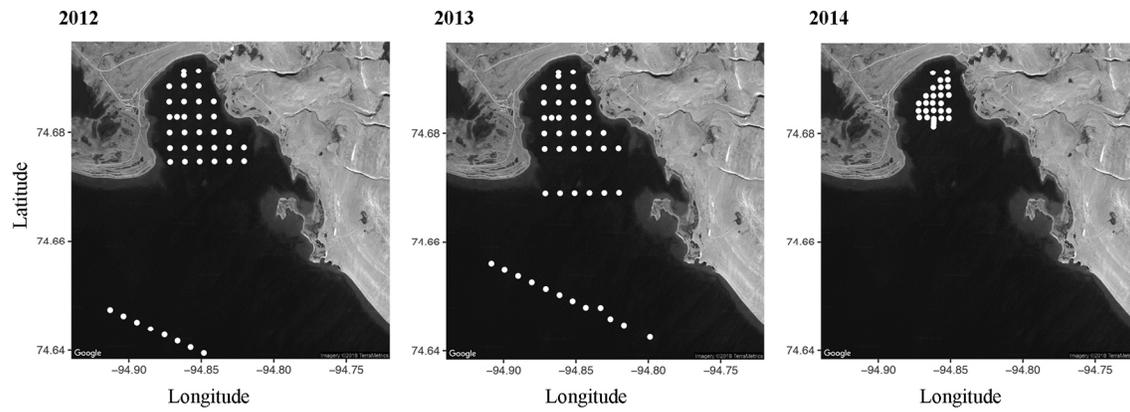
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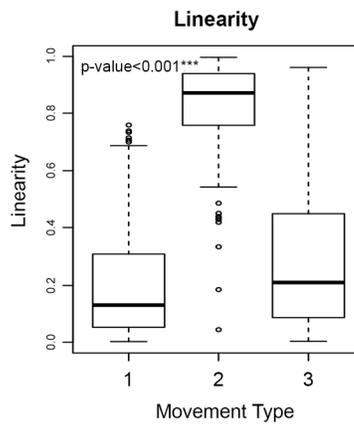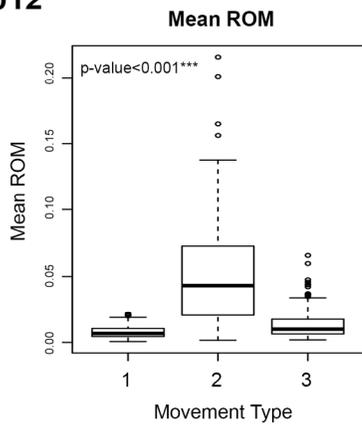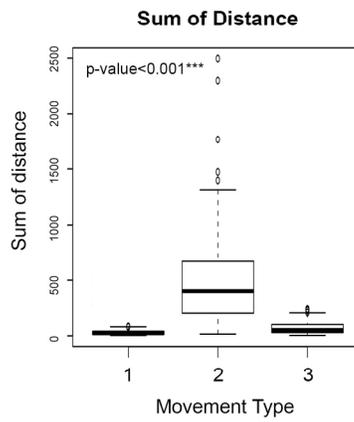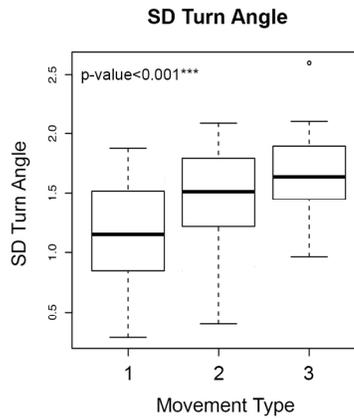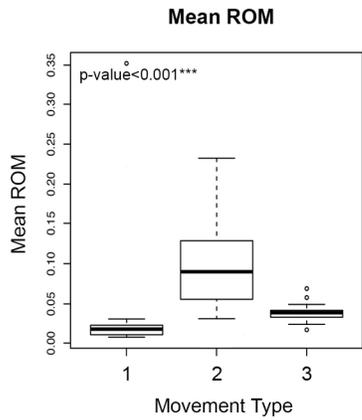
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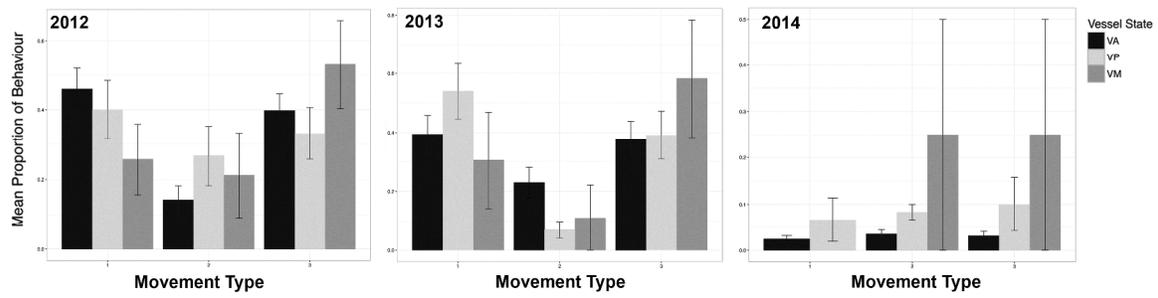
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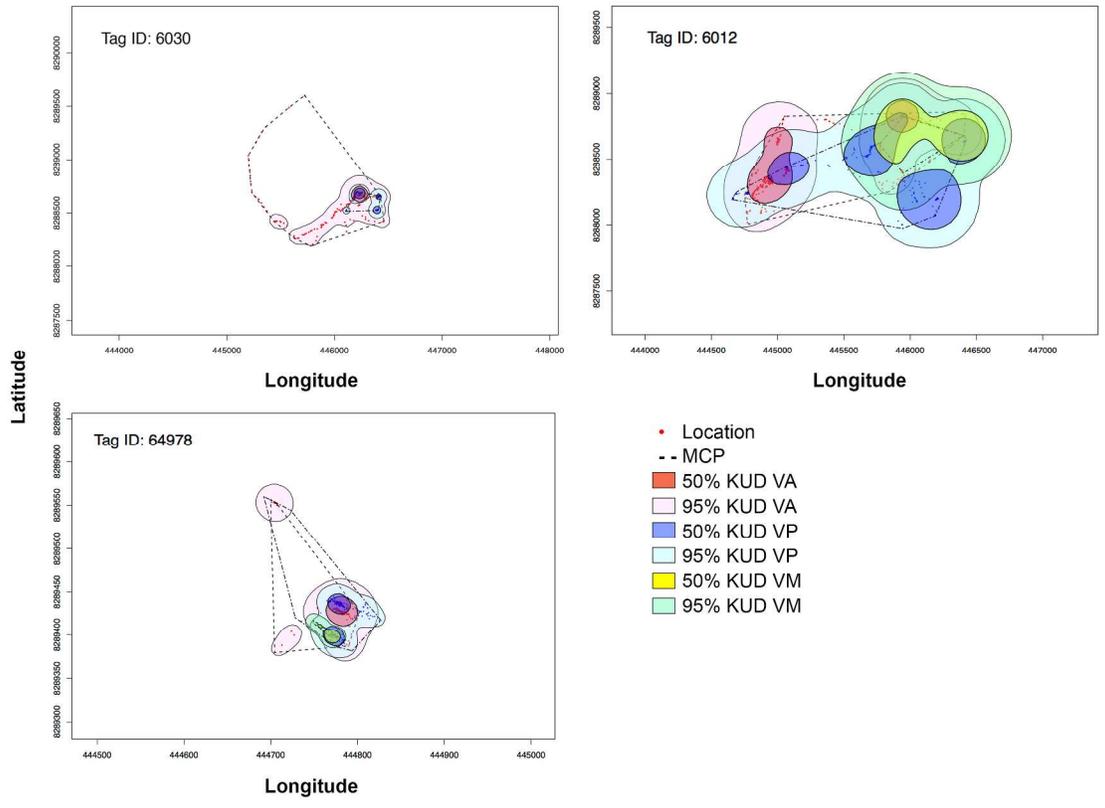
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726   **Figure 4**

727

728   **Figure 5**

2013

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730   **Figure 6**

731
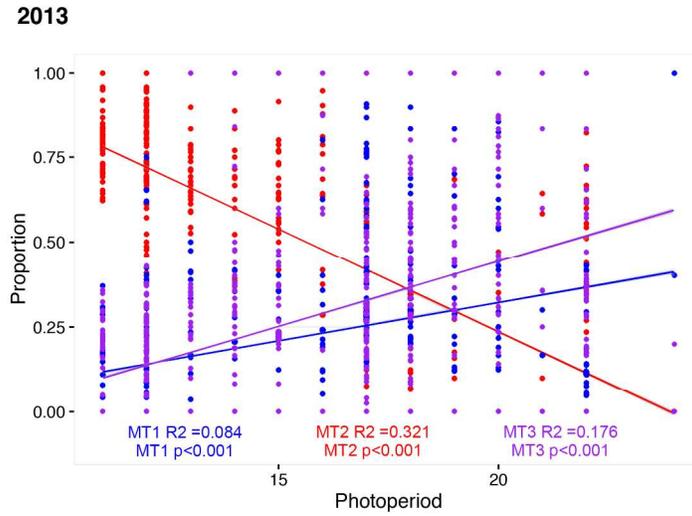
732   **Figure 7**

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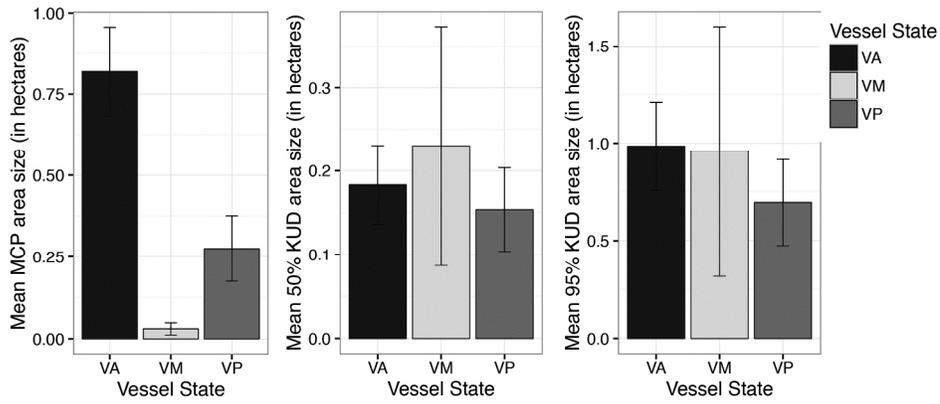
2013

2014

733

734   **Figure 8**