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Transient movements of a deep-water flatfish in coastal waters: Implications of inshore-offshore connectivity for fisheries management

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Abstract

1. Globally, small-scale inshore fisheries are being recognized as highly beneficial for underdeveloped coastal communities since they directly contribute to local economies. Community coastal fisheries, however, may target species that are simultaneously harvested by large commercial vessels in adjacent offshore waters, creating uncertainty over stock units and connectivity that complicate management.
2. Greenland halibut *Reinhardtius hippoglossoides*, a commercially important flatfish species in the Arctic, were tagged in Scott Inlet, coastal Baffin Island, Canada, with acoustic transmitters and tracked for a 1-year period. Our aim was to measure fish movement and connectivity between inshore habitats, where Inuit fisheries are developing, and offshore waters, where an established commercial fishery operates. Four movement metrics were established, and cluster analysis and a mixed effects model were used to define movement types and identify environmental covariates of the presence/absence within the coastal environment respectively.
3. Two distinct movement patterns were characterized for Greenland halibut; the majority were transients that were no longer detected inshore by the end of November (n = 47, 72%), and a smaller group of intermittently resident fish that moved into the offshore at the same time as transient fish, but returned to the coastal environment in the winter (n = 8, 12%), with the remainder being undefined. The presence of Greenland halibut in the inshore was negatively correlated with ice cover, indicating that fish moved offshore as sea ice formed.
4. *Synthesis and applications*. Greenland halibut were previously thought to be highly resident within the coastal environment of Baffin Bay; however, our data demonstrates that this is not true for all areas. In Scott Inlet and adjacent coastal regions, Greenland halibut exhibit complex inshore-offshore connectivity, suggesting inshore and offshore fisheries require a shared quota. We recommend that in the face of developing global small-scale coastal fisheries, improved understanding of stock connectivity between environments is required to sustainably manage commercial fish species.

KEYWORDS
Arctic, coastal, commercial fish, fisheries management, flatfish, Greenland halibut, inshore-offshore connectivity, migration, resident, small-scale fisheries

1 | INTRODUCTION

Small-scale fisheries have the ability to improve the economic stability of underdeveloped coastal communities and are therefore receiving increased attention from governments and international organizations including the United Nations (Béné, 2003; Kurien & Willmann, 2009). The benefit of small-scale fisheries for reducing poverty and providing food security has led to efforts to promote such fisheries through allocating preferential access to locals in designated inshore areas close to their communities (Pomeroy, 1995; Trimble & Berkes, 2015). However, the division of management areas between fisheries that scale from local inshore communities to large offshore operations can lead to the overexploitation of fish stocks when harvesting a common resource, a conflict that is intensified when harvesting targets a single population of migratory fish (Béné, 2006).

Greenland halibut *Reinhardtius hippoglossoides* (Walbaum, 1792) are a deep-water, circumpolar flatfish and a highly valuable commercial species targeted by numerous countries throughout the Arctic and North Atlantic oceans (Bowering & Nedreaas, 2000). Nearshore fishing for Greenland halibut has taken place since the early 1800s in several Nordic countries and continues today, typically through the use of longlines and gillnets (Bowering & Nedreaas, 2000; Nygaard, 2015). These fisheries expanded into the offshore in the 1960s as large commercial fleets with freezers, gillnets and trawling capabilities became more common (Bowering & Nedreaas, 2000). However, because Greenland halibut were not traditionally harvested along the coast of Baffin Island, most commercial fishing in these waters presently occurs solely in the offshore.

In the Canadian Arctic, the Nunavut Wildlife Management Board (NWMB) has extensive decision-making jurisdiction up to 22 km offshore in the northernmost territory of Nunavut (NWMB, 2012); where the territorial lands and waters are collectively known as the Nunavut Settlement Area (NSA). Currently, the community of Pangnirtung, Baffin Island, hosts the only established commercial fishery for Greenland halibut in the NSA. This Inuit fishery uses longlines set through the ice during winter months and provides jobs and substantial revenue for the local community (Dennard, MacNeil, Treble, Campana, & Fisk, 2010; Hussey et al., 2017; Reist, 1997). As a consequence of the economic success of the community-based Greenland halibut fishery in Cumberland Sound, other communities in the Canadian Arctic view the development of coastal fisheries as a lucrative economic opportunity. With declining sea ice extent and longer open-water periods, there is also growing interest in expanding both inshore and offshore fisheries throughout the Arctic (Christiansen, Mecklenburg, & Karamushko, 2014). Continued development without improved knowledge of stock structure and connectivity could have serious implications for the long-term sustainability of fisheries (Begg, Friedland, & Pearce, 1999), further compounded by a lack of basic biological data for Arctic ecosystems (Christiansen et al., 2014; MacNeil et al., 2010; Reist, 1997).

Greenland halibut are thought to be susceptible to overharvesting and notably, the mean size of fish caught in northwest Atlantic fisheries has declined since the 1980s (Merrett & Haedrich, 1997). As a long-lived, slow-growing species (Treble, Campana, Wastle, Jones, & Boje, 2008) with relatively large eggs and low fecundity (Dominguez-Petit, Ouellet, & Lamber, 2012), Greenland halibut potentially lack the resilience to re-establish healthy populations following overharvesting (Koslow et al., 2000). The absence of clear population structure throughout the North Atlantic and Arctic Ocean further complicates defining fisheries stocks, as Greenland halibut are genetically homogenous (Roy, Hardie, Treble, Reist, & Ruzzante, 2013; Vis, Carr, Bowering, & Davidson, 1997) and can migrate long distances (Boje, 2002). Halibut within the northwestern fjords of Greenland are, however, considered to be resident or sink populations that do not contribute to the spawning biomass (Boje, 2002; Boje, Neuenfeldt, Sparrevohn, Rigaard, & Behrens, 2014; Simonsen & Gundersen, 2005). Similarly, Greenland halibut in Cumberland Sound are also thought to be resident (Treble, 2003; but see Hussey et al., 2017), with inshore recruits dependent on broadcast spawning in the Davis Strait (Gundersen et al., 2010; Knutson, Jorde, Albert, Hoelzel, & Stenseth, 2007). The occurrence of resident Greenland halibut in coastal waters consequently led to the decision to create separate management boundaries for inshore and offshore Greenland halibut fisheries in the northwest Greenland fjords (Nygaard, 2015).

Successfully developing sustainable small-scale fisheries for underdeveloped communities hinges on understanding the spatial–temporal movements and connectivity of target species (Reiss, Hoarau, Dickey-Collas, & Wolff, 2009). To this effect, the objective of this study was to determine the habitat use of Greenland halibut within and adjacent to Scott Inlet and Sam Ford Fjord, on Baffin Island, Canada, an area proposed for the development of a coastal fishery by the nearby community of Clyde River. Through the use of acoustic telemetry within the deep-sea environment (200–800 m), this study quantified the connectivity of Greenland halibut between inshore and offshore environments in Baffin Bay (NAFO Subarea 0A, Figure 1) to inform community fishery development in relation to a commercial offshore fishery and the potential management of inshore and offshore stocks as independent units.

2 | MATERIALS AND METHODS

2.1 | Study site

All fishing and telemetry mooring placements were performed aboard the RV Nuliajuk in September 2012 and 2013 within and around Scott Inlet and Sam Ford Fjord on Baffin Island, Nunavut, Canada (*c.* 71°15′N, 70°30′W), located *c.* 120 km north of the community of Clyde River. Scott Inlet and Sam Ford Fjord are deep-water fjords, with depths ranging from 600 to 800 m at their centre. The two fjords are connected along the coast and to offshore waters of Baffin Bay by a trough that is *c.* 800 m deep at its midpoint (Figure 2). Greenland halibut >30 cm fork length (FL) do not commonly inhabit depths <200 m (Bowering & Chumakov, 1989; Bowering & Nedreaas, 2000; Godø & Haug, 1989; Jørgensen, 1997a); therefore, the deep-water trough provides the principle pathway for fish between coastal and offshore habitats as it is surrounded by shallow water banks ≤200 m (Figure 2). The bottom topography of this area allowed for its division

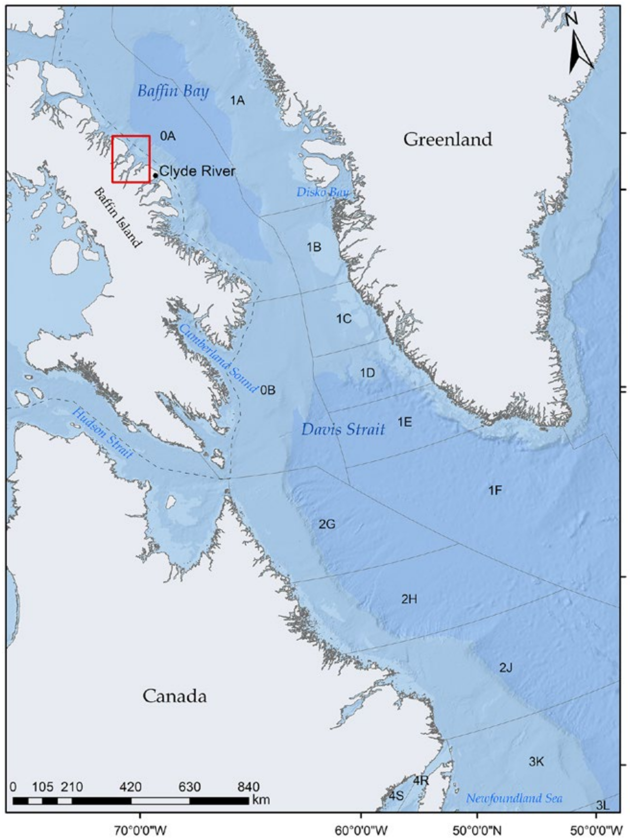

FIGURE 1 Map of Northwest Atlantic Fisheries Organization (NAFO) Divisions within Baffin Bay and the Davis Strait. The square denotes the study area of Scott Inlet and Sam Ford Fjord, and the dashed line is the approximate location of the Nunavut Settlement Area boundary

into three study regions: the fjords (Scott Inlet and Sam Ford Fjord), the middle basin (coastal deep-water area between the fjords), and the exit channel to Baffin Bay.

2.2 | Acoustic telemetry monitoring

In total, 60 moorings were deployed in seven lines in September 2013, with the receivers in a given line spaced *c.* 1 km apart (see Appendix S1). These lines of receivers, termed "gates," were used to divide the study area into the three main regions described above; the deep water fjords of Scott Inlet and Sam Ford (Gates G3, G4 and G6), the middle basin between the two fjords (G1, G2 and G5) and the exit channel connecting the inshore and offshore environments of Baffin Bay (G7; Figure 2). The latter gate was deployed to quantify the number of fish that emigrate from the system and consequently the level of connectivity between these two environments. Moorings were not deployed in depths <100 m given the habitat preference of Greenland halibut (see Appendix S2). Moorings were retrieved *c.* 1 year later in September 2014.

Fishing for Greenland halibut was conducted in both 2012 and 2013 using longlines and bottom trawls; however given poor weather and ice conditions in 2012, few moorings could be deployed, limiting tracking data to the 2013–2014 year. In September 2012, bottom longlines consisted of a standard baseline rope (9.2 mm diameter tarred black sinking line) *c.* 735 m long with 200 × 30 cm rope leader gangions with size 12 and 14 circle hooks spaced 30 cm apart. All hooks were baited with frozen squid. The longlines were set in the evening and retrieved the following morning (*c.* 12 hr set). In September 2013, a Yankee style research bottom trawl was used at depths between 224 and 891 m. The trawl was fished in a straight line at a speed of *c.* 3 knots for 30 min after settling to the bottom (mouth opening 40–60 m).

In total, 39 fish were acoustically tagged in 2012 and 71 fish were tagged in 2013 with Vemco V16 or V13 tags, resulting in a total of 110 tagged fish with a mean size of 52 ± 7 cm FL (range 40–62 cm). Tagging of fish followed standard procedures and was undertaken at several sites throughout the study system (Figure 2; see Appendix S1).

2.3 | Statistical analysis

2.3.1 | Data filtering

All detection data were filtered for false detections using the OTN SandBox application in R (R Core Development Team, 2015), which uses the White-Mihoff False Filtering Tool (see Appendix S1).

2.3.2 | Defining movement criteria

To group Greenland halibut movement types, four movement criteria were developed to characterize raw acoustic detection data:

1. *Relative detection percent:* A measure of individual fish presence in the three different study regions; fjord, middle and exit. Relative detection percent (RDP) in each area was calculated for each individual fish based on the following equation:

$$\mathrm{RDP}_{nA} = \frac{\text{No of detections of fish } n \text{ on gates in study region } A}{\text{total number of detections of all fish on all gates}} \times 100\%$$

   where, n is an individually tagged fish, A refers to the fjord, middle or exit study areas and RDP_{nA} is the RDP score for fish n in study region A. Recall from above that gates G1, G2 and G5 were in the middle basin, G3, G4 and G6 were located in the fjords and G7 was in the exit channel.
2. *Days resident in the system:* A measure of Greenland halibut residency within the coastal area around Scott Inlet. Total number of days resident (DR) was calculated from the day of release (for fish released inshore of G7) until its final detection on G7 under the following criteria: (1) it was not detected again on G7 for a full month (31 days) following its last detection on G7 and (2) it was not detected on any other gates after its last detection on G7. If an individual fish was not detected for a month, after a final detection on G7, the fish was assumed to be absent from the inshore environment until it was redetected again on G7, in which case it was

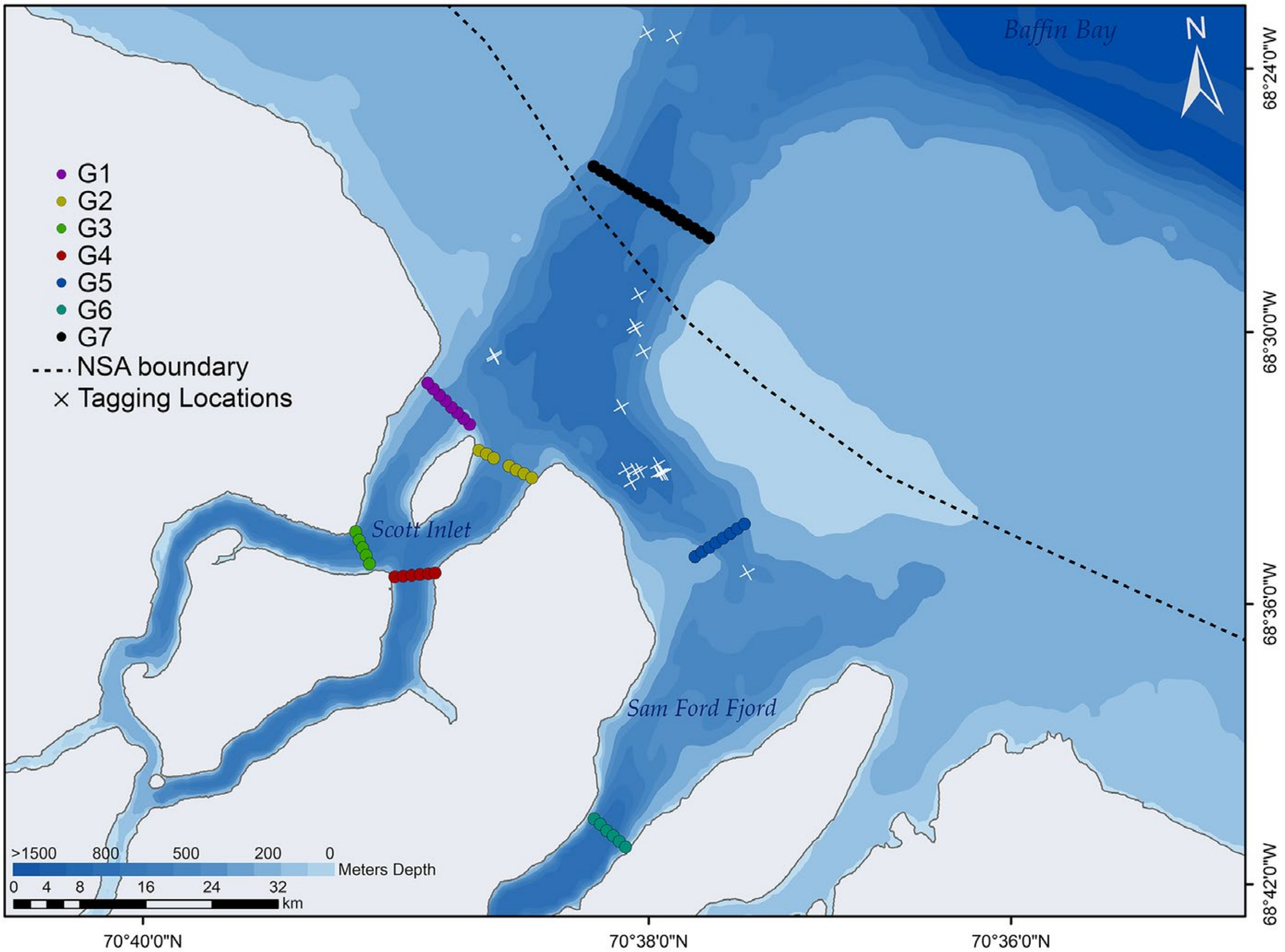

FIGURE 2 Map of the study area, including Scott Inlet and Sam Ford Fjord. The dashed line represents the 22 km boundary of the Nunavut Settlement Area (NSA). Each individual dot represents an acoustic receiver mooring, colour coded to the gate name (G1–G7)

considered to be returning to the system. DR was calculated separately for a second or third period based on the above criteria starting from the date of return and the DR values were summed. Fish tagged and released offshore of G7 were assumed absent until their first detection on G7, at which point the criteria described above were applied (see Appendix S3 for offshore tag return data).

3. *Total distance travelled:* A measure of relative total distance travelled (TDT) within the study site. TDT was calculated for each tagged fish as the distance (km) from the tagging location to the gate where the fish was first detected, plus the sequential distances between all subsequent gates on which the fish was detected. Midpoints were identified between gates, where direct linear distances bisected land. The distance travelled is not a measure of absolute distance travelled but instead a proxy for mobility during the monitoring period.
4. *Average speed*: A measure of relative speed. Average speed (AS, in m/s) was calculated as the distance (measured above) divided by transit time between gates. An AS measure was calculated as a mean for all gate-to-gate values obtained over the monitoring period for each individual fish.

2.3.3 | Quantifying movement types

A Ward hierarchical cluster analysis with Euclidean distance was used to identify unique groupings of Greenland halibut movements based on the four movement criteria defined above (RDP, DR, TDT and AS). All values were scaled by taking the individual value, subtracting the mean of the vector and dividing it by the *SD*. Analyses were performed in R version 3.4.1.

2.3.4 | Biotic and abiotic drivers of fish presence/absence within the inshore environment

A GLMM was used to examine factors driving the presence/absence of Greenland halibut within the study system. Prior to fitting the model, all telemetry detection data were standardized to a binary format. To do this, detection data from all gates were combined for each individual fish; days during which the fish was detected on any gate were assigned a “1” for present, while days during which the fish was not detected were assigned a “0.” Within the model, individual fish ID (as a factor) as well as year tagged (defined by dummy variables, 1 [2012] or 2 [2013]) were set as random effects, while a first-order autoregressive function was used to account for temporal autocorrelation. Fixed variables included weekly ice cover (see Appendix S4) and FL. The GLMM was fit using the glmmPQL command in the MASS R package, and model fit assessed by calculating the marginal and condition r^2 using methods described by Nakagawa and Schielzeth (2013).

2.3.5 | Temporal–spatial distribution of absolute detection data

Absolute detection data for each Greenland halibut were plotted by time and ice cover to visualize transitions through the acoustic gates relative to open water and ice formation, cover and break up periods. Fish were divided into the four movement types identified by the cluster analysis.

3 | RESULTS

In total, 66 tagged Greenland halibut were detected within the coastal region of Scott Inlet and Sam Ford Fjord from 22 September 2013 to 31 August 2014. Of these fish, eight were tagged in 2012 (20.5% of 2012 total) and 58 were tagged in 2013 (80.3% of 2013 total). Among the 2013 fish, 15 were tagged offshore, outside of G7, of which only 7 were detected on gates, suggesting the remaining 8 fish never entered the study area.

Hierarchical cluster analysis of the four movement criteria for 65 fish (one fish tagged in 2012 was detected only on G7, so distance and speed could not be calculated and thus it was excluded) identified four distinct movement types. A plot of the within group sum of squares by number of clusters extracted, and visual inspection of the dendogram validated these groups (Figure 3). Group 1 was the largest (n = 36, 55% of total detected fish) and was characterized by very low RDP in the middle basin and the fjords, with fish being primarily detected on the exit gate, G7 (average ± *SD*; fjord = 0.01 ± 0, middle basin = 0.1 ± 0.2, exit = 0.7 ± 0.8). Group 1 fish also travelled the shortest average distance between gates (29.0 ± 23.7 km), had a relatively low AS (0.04 ± 0.04 m/s) and a low mean DR (10 ± 14 days, Figure 4). Group 2 fish (n = 11, 17% of the total) showed higher RDP in the fjords (0.2 ± 0.1) and middle basin (0.4 ± 0.4) but not the exit gate (0.3 ± 0.3) compared to Group 1; however, they also had a low mean DR (33 ± 10 days). The high number of detections for Group 2 fish in each area combined with the low DR resulted in this group having the highest mean TDT (141.9 ± 37.0 km) and the highest AS (0.2 ± 0.1 m/s, Figure 4). Group 3 fish (n = 10, 15% of the total) were primarily characterized by a low RDP in all areas, particularly the exit gate (fjord = 0.1 ± 0.1, middle basin = 0.3 ± 0.6, exit = 0.1 ± 0.1), which resulted in a high DR (327 ± 33 days). Mean TDT in this group was low but variable among individuals (60.0 ± 35.0 km), as was AS (0.1 ± 0.04 m/s). The final group of fish (Group 4, n = 8, 12% of the total) was defined by high RDP, especially within the fjord and middle basin (fjord = 0.5 ± 0.7, middle = 5.3 ± 4.6, exit = 1.3 ± 1.4). This was associated with a higher mean DR (263 ± 71 days), a high mean TDT (136.4 ± 57.8 km) and a high AS (0.1 ± 0.1 m/s, Figure 4). In summary, Groups 1 and 2 fish were identified as "transients" and Group 4 as "intermittent-residents," as they potentially migrate into the offshore; however, they spend the majority of the study period within the coastal area. Group 3 was undefined, given their detection profile was identical to the transient fish, yet they were never detected leaving the system into the offshore (Figure 4), with exceptions in Groups 3 and 4 (fish IDs GH 63-12 and GH 60).

The GLMM found that ice cover was highly influential in predicting the presence/absence of Greenland halibut within the inshore (Table 1). The negative predicted value indicated that the probability of Greenland halibut being detected on acoustic receivers within the study system decreased as ice formed. Fish size was not a significant factor (p = .16). Both fixed and random effects accounted for the majority of model variation (marginal r^2 = .16 and conditional r^2 = .75).

Absolute detection data for all tagged fish revealed two overall patterns, with the vast majority of fish being solely detected in the first 3 months of the study, with detections mostly stopping after ice formation (Figure 5). This first group is characterized by fish that were both detected leaving the coastal area (on Gate 7) and others that were not. A smaller group of fish were primarily detected after ice formation, remaining within the coastal area for the majority of the study period (Figure 5).

4 | DISCUSSION

Greenland halibut in previous studies within Baffin Bay have been observed to undertake two distinct movement behaviours; coastal fish that are typically resident and form sink populations within deep water fjords, and offshore fish that can be highly migratory. In several cases, this has led regional management to treat inshore and offshore environments as two separate stocks (Boje, 2002; Boje et al., 2014; Nygaard, 2015). In the current study, Greenland halibut were tagged within the 22 km zone prioritized for the development of small-scale community fisheries. The majority of these tagged fish did not exhibit the level of residency previously reported in fjord habitats (Boje, 2002; Boje et al., 2014; Hussey et al., 2017), but were instead highly migratory, using the coastal area in the late summer months then exiting into the offshore as ice formed. Variability in movement measures was observed among individuals while in coastal waters as a result of differing movement rates and residency times within sections of the coastal environment. In addition, a small number of fish returned to the system in the winter and remained for most of the year, demonstrating the potential for complex population movement behaviours within this species. These telemetry data highlight the complexities of managing highly mobile deep water commercial fish species and the need for fisheries management to consider inshore-offshore connectivity to support fisheries sustainability.

In agreement with the seasonal offshore movements exhibited by Greenland halibut in the current study, fish tagged with standard external tags in White Bay, Northern Newfoundland, were recaptured offshore in the winter fishery while fish tagged offshore were recaptured in coastal areas by the summer fishery (Bowering, 1982). These data contrast that of tagged fish in the Greenland fjords of Baffin Bay where Greenland halibut were almost exclusively recaught close to

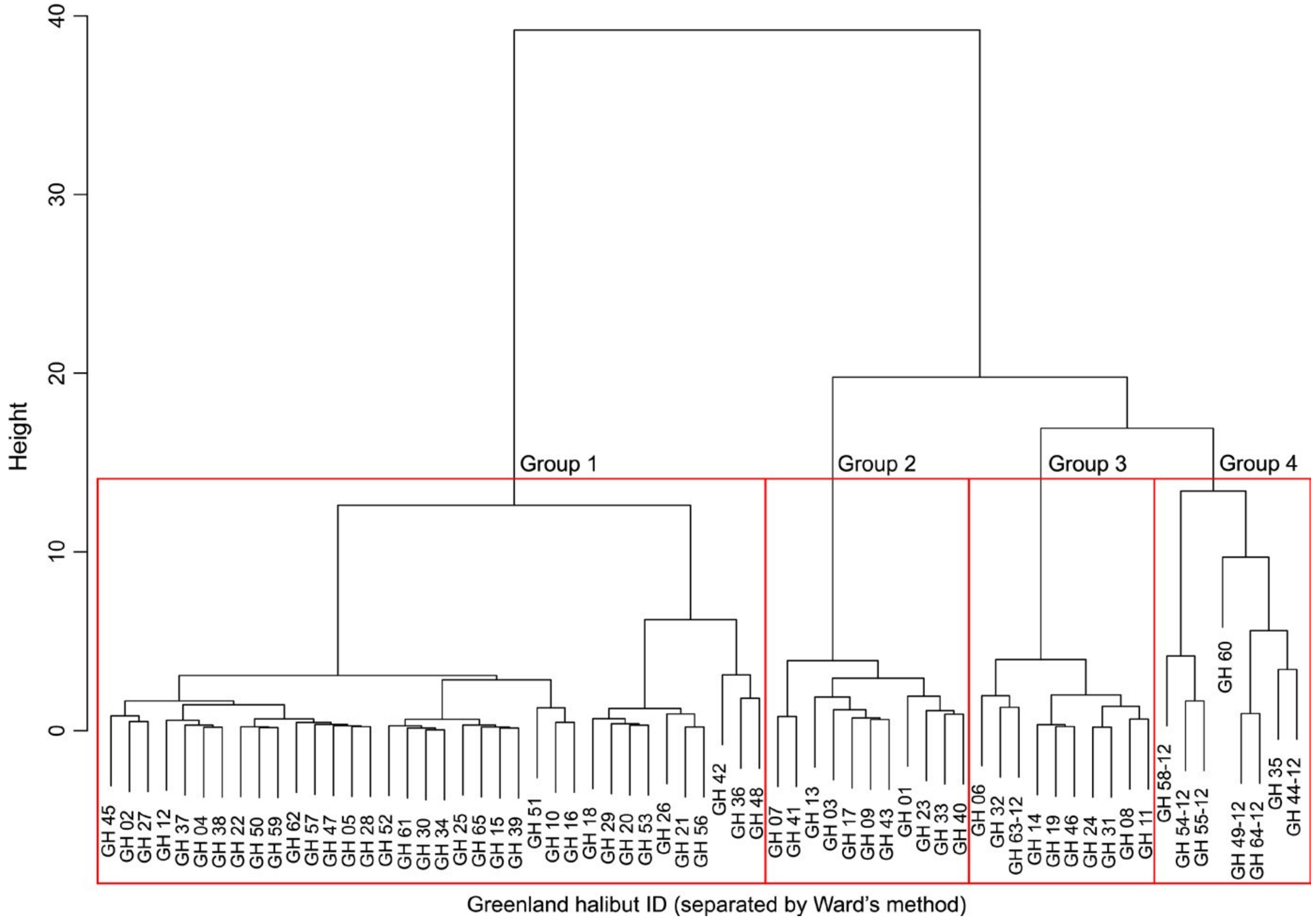

FIGURE 3 Dendogram of the Ward hierarchal cluster analysis with Euclidean distance for acoustically tagged Greenland halibut movement types within the coastal area of Scott Inlet and Sam Ford Fjord. The four selected clusters are highlighted with red boxes, and the group number indicated above the box. Fish with codes ending in "-12" are individuals tagged in September 2012, the remainder were tagged in 2013

tagging sites, suggesting those northern stocks were resident, with minimal intermingling between fjords and limited offshore movements (Boje, 2002). For example, in Disko Bay, Greenland halibut monitored with archival tags were found to move further into Ilulissat Ice fjord during the winter, with no evidence of fish moving offshore (Boje et al., 2014). In the Canadian Arctic, mark–recapture work in Cumberland Sound revealed that fish tagged in the northern end of the Sound were also resident, while fish tagged at the entrance were found to migrate to both inshore and offshore areas (Treble, 2003). More recently, acoustic telemetry found that fish in Cumberland Sound moved from north to south on a seasonal basis (Hussey et al., 2017), undertaking movements similar to fish in Disko Bay (Boje et al., 2014), but with some evidence for emigration. While most studies on Greenland halibut have suggested high levels of residency within coastal deep water fjords, this study suggests that transient movements can occur during the summer–fall period.

The presence of high numbers of migratory Greenland halibut in the coastal area of Scott Inlet in summer–fall may be a result of greater input of organic and inorganic material from terrestrial run-off, rivers and glacial melt, and/or greater upwelling and less stratification which are known to promote primary productivity in coastal waters during the short Arctic summer (Arimitsu, Piatt, & Mueter, 2016; Tremblay et al., 2012). Notably, most Greenland halibut captured in bottom trawls in Scott Inlet had large, distended stomachs that primarily contained Arctic cod *Boreogadus saida* (N. E. Hussey, pers. obs.). This area is also known for the presence of other large predators such as narwhal *Monodon monoceros*, which have been shown to preferentially forage in deep water fjords including Scott Inlet as they migrate south along Baffin Island (Dietz, Heide-Jørgensen, Richard, & Acquarone, 2000; Marcoux, Ferguson, Roy, Bedard, & Simard, 2016).

The emigration of intermittently resident fish from the inshore (November–December) coincides with an increase in the occurrence of reproductively active Greenland halibut in the offshore waters of the Davis Strait. This may suggest the movement represents a spawning migration (Gundersen et al., 2010); however, additional research is required to address this question. The majority of individuals in the intermittently resident group were tagged in 2012, with only one fish from 2013 showing similar movement (1 of 57; 2% of detected 2013 fish). This variation could represent complex interannual seasonal movements among fish, or may be a result of gear selectivity

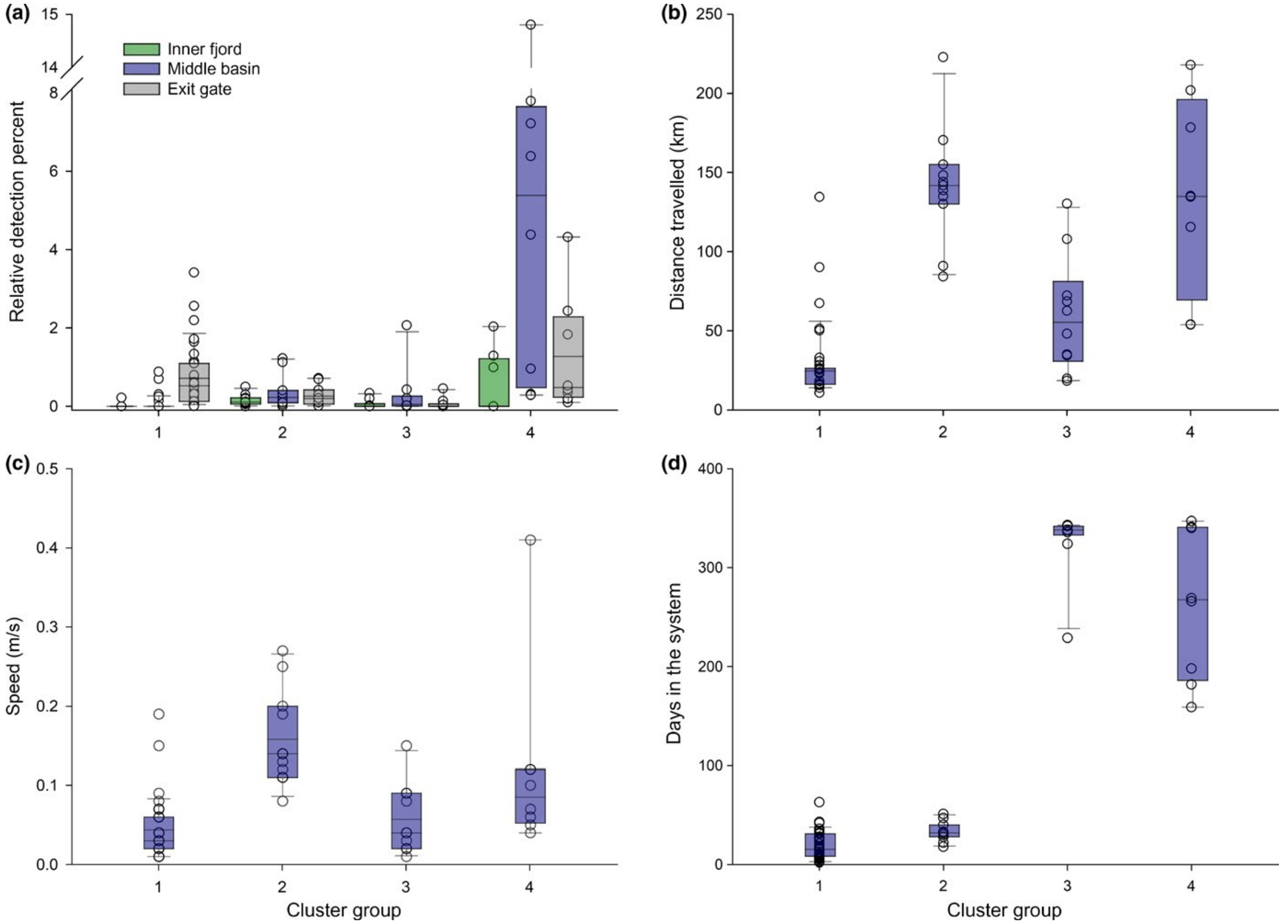

FIGURE 4 Movement types of Greenland halibut within the coastal area of Scott Inlet and Sam Ford Fjord, grouped based on the cluster analysis; (a) relative detection percent in the fjords, in the middle basin and on the exit gate, (b) distance travelled, (c) average speed (m/s) and (d) days spent in the coastal system. The box represents the 25th to the 75th percentiles, and the whiskers extend to the 10th and 90th percentiles. The line within the box is the median value and the clear circles are the raw plotted data. Note the line break in (a)

TABLE 1 Results of the generalized linear mixed effects model performed on Greenland halibut presence/absence data within Scott Inlet

Random effects	Variance	*SE*		
Tag year	0.90	0.95		
Fish number	0.54	0.73		
Fixed effects	**Value estimate**	***SE***	***t*-value**	***p*-value**
Intercept	−1.20	1.27	−0.93	.35
Size	−0.03	0.02	−1.40	.16
Ice	−1.76	0.14	−12.23	**.00**

as longlines typically capture larger Greenland halibut than trawls (Husea, Gundersenb, & Nedreaasa, 1999). Greenland halibut are known to undergo ontogenetic shifts in habitat (pelagic to benthic; Jørgenson, 1997b) shallower to deeper; Jørgensen, 1997a) and diet (pelagic to benthic prey; Hovde, Albert, & Nilssen, 2002). Considering the intermittently resident fish were marginally larger than the other groups (58 ± 6 vs. 51 ± 7 cm FL), it is plausible that size is driving the variability in movement types. Variation in growth rate at a fixed age is common among flatfishes (Morgan & Bowering, 1997; Treble et al., 2008), consequently Greenland halibut of *c.* 55 cm FL could vary in age by several years, confounding the GLMM model size result. Future telemetry work targeting a larger size range of fish in coastal regions will be needed to assess the effect of fish size on movement, or if fishing gear (i.e. trawl or longline) differentially select for specific movement types (Heino, Pauli, & Dieckmann, 2015). Nonetheless, Greenland halibut tagged in this study fall within the size range targeted by both inshore and offshore commercial fishing operations (DFO, 2013), where both longlines and trawls are used, identifying that current fisheries have the potential to impact both movement groups.

The division of inshore and offshore fishery harvests occurs on a global scale, even when distinct management boundaries dividing the two do not explicitly exist. Inshore areas are typically exploited by small vessel fisheries tied to multiple coastal communities, whereas offshore waters are targeted by larger, high production

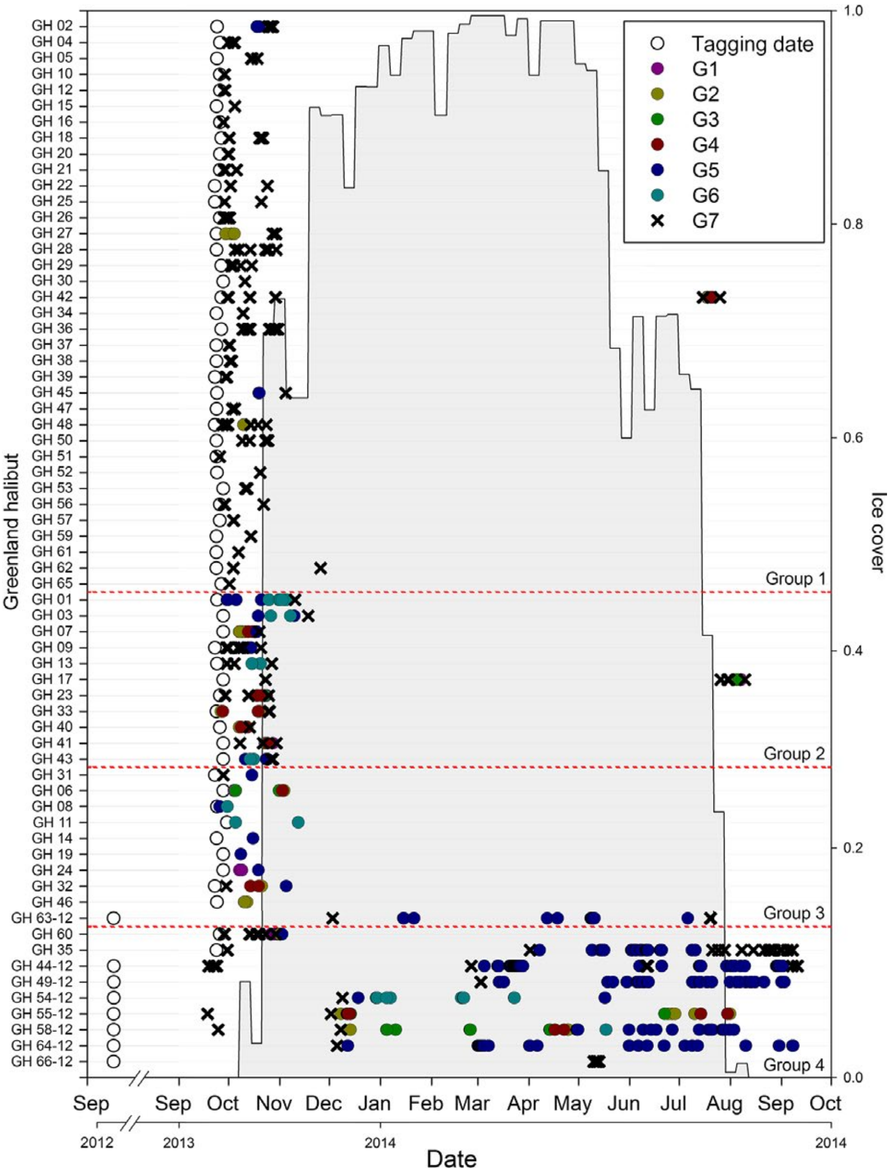

FIGURE 5 Plot of all raw Greenland halibut detections. Open circles indicate the tagging date of each fish, while the rest of the detections are colour coded to the gate on which the fish was detected. The grey shading in the background indicates the amount of ice cover present in the coastal area on each given day during the study period. Fish are grouped based on the results of the cluster analysis, where the horizontal red dashed lines on the plot indicate the divisions between groups. Note the break in the time-scale between September 2012 and September 2013 to account for fish that were tagged in 2012

corporate fleets with quotas assigned based on vessel designation (Parsons, 1993; Shotton, 2001). Contrasting the division of fisheries between these environments, it is not uncommon for commercial species to utilize both areas, and movements between the two may not be consistently timed, or include the entire targeted population. For example, *Pseudopleuronectes americanus* (Sagarese & Frisk, 2011), *Pleuronectes platessa* (Dunn & Pawson, 2002) and *Gadus morhua* (Cote, Moulton, Frampton, Scruton, & McKinley, 2004) all show signs of spatially overlapping resident and migratory subpopulations of fish, similar to that observed here for Greenland halibut. Of primary concern when considering commercially exploited partially migrant fish is the possibility that fisheries unknowingly target only one group of the population (either the migratory or resident portion) which can lead to a reduction in phenotypic and/or genetic diversity and subsequently reduce the stock's resilience to natural and anthropogenic change (Chapman et al., 2012). In the case of *G. morhua* along the coasts of Iceland, selectively targeting large coastal fish removed the most productive individuals from the population, concurrently reducing overall population productivity (Begg & Marteinsdottir, 2003). Intense harvesting of the offshore component of connected fish stocks also carries consequences for the coastal population, often dramatically altering the community structure and size distribution of fish found near shore (McCain, Cull, Schneider, & Lotze, 2016; Svedäng, 2003).

There is currently no fishery for Greenland halibut in the coastal area of Scott Inlet, consequently all harvests are by commercial trawl vessels operating in the offshore waters of Baffin Bay (along the shelf edge; DFO, 2013). Additionally, the offshore fishery of NAFO Division 0A, is ice-dependent and limited to the period between June and November (DFO, 2013). As a result, the Greenland halibut observed in this study that remained inshore are mostly protected from the offshore fishing season, but transient fish are available for harvest. If a winter fishery were developed through the ice in Scott Inlet (and potentially other coastal communities), the intermittently resident

Greenland halibut would be the primary target. Ice fisheries, however, have an uncertain future in the Arctic as climate change is driving unpredictable weather and ice conditions, complicating access to fishing grounds (Hussey et al., 2017). In this scenario, the development of a summer boat-based fishery in Scott Inlet would be more resilient to climate change but would ultimately catch fish of both migratory types, including the transients that are also caught in the offshore. Should a summer fishery develop in Scott Inlet, the assigned quota would ultimately have to be subtracted from that of the offshore commercial harvests.

Acoustic telemetry shows great promise for assisting fisheries management (Crossin et al., 2017); however, as with all approaches, there are limitations (Donaldson et al., 2014; Young, Gingras, Nguyen, Cooke, & Hinch, 2013). In the current study, Gate 7 was effective at detecting movements of Greenland halibut between the inshore and offshore environment, but one group identified in the cluster analysis (Group 3) had acoustic detections similar to the transient fish (Groups 1 and 2), yet were never detected exiting the system. Given the biology of Greenland halibut, it seems unlikely that if fish were alive and within Scott Inlet that they would not be detected. An alternate exit from the coastal region as well as the failure of the gate to detect passing fish are both possible, yet the consistency with which all other fish were detected suggests that the gate design was appropriate. Other possible explanations include mortality, predation or tag failure (Donaldson et al., 2014; Heupel, Semmens, & Hobday, 2006).

The present study represents a 1-year analysis of Greenland halibut movements in a deep water coastal area off Baffin Island. Over this period, the movement of this species was more complex than expected given that Greenland halibut have been shown to be highly resident within other inshore areas of Baffin Bay (Boje, 2002; Boje et al., 2014). Instead, tagged Greenland halibut displayed diverse movement types, including both migratory and non-migratory, that require shared quotas between coastal and offshore fisheries, and careful monitoring of the resident population to maintain the phenotypic diversity currently observed for this species. Small-scale community fisheries bring much needed economic development to coastal communities around the world, yet the risk of overexploitation and population diversity loss increases if the offshore connectivity of exploited fish stocks are poorly understood.

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AUTHORS' CONTRIBUTIONS

A.N.B., N.E.H., A.T.F., K.J.H. and M.A.T. conceived the ideas and designed methodology. A.N.B., N.E.H. and K.J.H. implemented methodology; A.N.B. analysed the data; A.N.B. and N.E.H. led the writing of the manuscript, and all authors contributed critically to the drafts and gave final approval for publication.

DATA ACCESSIBILITY

Data available through the Ocean Tracking Network data portal. https://members.oceantrack.org/data/pblctn_data/data_files/cisti.otndc/10.14286. https://doi.org/10.14286/2017_barkley_greenland_jae (Barkley, Fisk, Hedges, Treble, & Hussey, 2018).

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