SPATIAL AND TEMPORAL VARIABILITY IN THE EGRESS OF SOUTHERN FLOUNDER IN THE NORTHERN GULF OF MEXICO

A Thesis

by

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MASTER OF SCIENCE

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ABSTRACT

Long-term fisheries independent data indicate that southern flounder *(Paralichthys lethostigma)* populations in the northwestern Gulf of Mexico have declined in recent years. Although fishing regulations have been implemented to promote the rebuilding of the southern flounder population in Texas, the specific timing and magnitude of spawning runs is poorly understood, limiting the ability of fishery managers to match regulations (e.g., timing of reduced bag limits) with natural migration patterns. Egress patterns of southern flounder were assessed using conventional tags and acoustic telemetry with receivers strategically placed throughout the Galveston Bay Complex (GBC), including the coverage of tidal passes connecting bays to the Gulf of Mexico (GoM). Vemco V-9 acoustic transmitters were placed inside the peritoneal cavity of adult southern flounder (range: 40-60 cm TL), tagged at several locations within the GBC to ensure that movement behaviors were representative of the GBC population. Southern flounder showed high site fidelity to tagging sites during the summer but made directed movements (> 5 km) out the GBC in the fall and early winter (November-January). Although egress into the GoM was observed for several tagged southern flounder, others were detected in the GBC throughout the suspected spawning season, suggesting that some fraction of the population may overwinter in the bay. This research also demonstrated that southern flounder have the capacity for large-scale movements into adjacent bay systems in Texas, and therefore it is possible that the population in the GBC may rely on production or recruitment from other bay systems along the Texas coast.

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Contributors

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INTRODUCTION

Estuaries support a variety of juvenile and adult fishes, and the population dynamics of many species are linked to events that occur during their estuarine residency (Able 2005, Dalhgren et al. 2006, Gillanders 2002). Although some species complete their life cycles in estuaries, many rely on these ecosystems during the first few years of life (i.e., nursery) -but later migrate through tidal passes into coastal ecosystems, and these egress events are often linked to spawning (Rooker and Secor 2005). Understanding the movement and connectivity of populations that use both estuarine and coastal ecosystems and the environmental drivers that initiate migrations to and/or from estuaries is critical to the conservation and management of estuarine-dependent species (Stephenson 2002).

Southern flounder (*Parlichthys lethostigma*) are one of the most highly targeted finfish along the Texas coast, and this species is important, both economically and ecologically (Matlock 1991, Smith et al. 1999). Estuarine environments are critical habitats for southern flounder serving as both early life and adult habitats, with adults only leaving estuaries to spawn (Hoese and Moore 1997). During annual migrations out of the estuary in the fall and early winter, adult southern flounder move into tidal passes before entering coastal waters, and similar types of spawning runs have been reported for other flatfishes (Hunter et al. 2003, Loher and Seitz 2006, Stokes 1977). Peak recruitment of southern flounder occurs in the winter or early spring when young fish (early post-settlers/juveniles) move back into the bays and estuaries, which serve as nurseries (Ginsburg 1952, Glass et al. 2008). The production and recruitment success of southern flounder is clearly dependent on the success of spawning adults, and thus an understanding of estuarine-coastal connectivity of southern flounder, including the environmental drivers of egress and ingress (leaving and returning to estuaries), is critical to their management (Beck et al. 2001, Burke et al. 1991). An improved understanding of the timing and magnitude of egress is of particular interest to fisheries managers, because this species is highly vulnerable to fishing pressure during the late fall and winter exodus (Froeschke et al. 2011).

Long term fisheries independent data collected by the Texas Parks and Wildlife Department (TPWD) indicates that there has been a decline in the southern flounder population in recent years (Froeschke et al. 2011). Consequently, in 2009, TPWD reduced daily bag limits from 10 to 5 fish per day for recreational anglers, and 30 to 15 fish per day for commercial fishers. In addition, regulations were also introduced to reduce southern flounder fishing pressure during their primary spawning run in Texas (November – December), where gigging is prohibited and daily bag limits are reduced to 2 fish per day for recreational anglers. Although these regulations have been implemented to promote the rebuilding of the southern flounder population in Texas, the specific timing and magnitude of spawning runs is poorly understood, limiting the ability of fishery managers to match regulations (e.g., timing of reduced bag limits) with natural migration patterns.

Similar to other estuarine-dependent species that leave estuaries as adults to spawn (e.g., red drum and spotted seatrout; Adams and Tremain 2000, Bacheler et al. 2009), migrations appear to be heavily influenced and often triggered by cold weather events (Childs et al. 2008). In the Gulf of Mexico and western Atlantic Ocean (e.g., Mid Atlantic Bright), previous research suggests that conspicuous drops in water temperature may be the primary determinant of egress by southern flounder and other flatfishes from estuaries (Casterlin et al. 1982, Gibson 1997). As a result, the variable timing of cold weather events may alter the efficacy of regulations designed to protect spawning adults from fishing pressure because individuals may migrate during periods of higher fishing activity or during periods with relaxed bag limits. Therefore, a better understanding of the link between temperature and egress events by southern flounder (both timing and primary pathways used) will aid in conservation efforts to rebuild this fishery.

The aim of this study was to comprehensively examine the movement dynamics of southern flounder in a large estuarine complex (Galveston Bay), in the northwestern Gulf of Mexico. Egress events were characterized using two tagging methods: acoustic telemetry and conventional tagging. In addition to determining the timing and spatial dynamics of egress events, a goal of this research was to investigate the influence of water temperature on the movement of southern flounder out of the Galveston Bay Complex (GBC).

Objectives

1. Characterize egress events (spawning runs) of the southern flounder in the GBC using acoustic telemetry and conventional tagging methods

    H_1: Residency of southern flounder in the GBC will be high during spring and summer periods, with all reproductively mature fish migrating to coastal habitats occurring during the later fall and winter months.

2. Determine the timing and magnitude of egress events and identify migration pathways used by southern flounder exiting the GBC

H2: A primary egress event will occur among southern flounder with the majority of individuals leaving over a relatively short period of time, and migration pathways may vary for individuals originating from different regions within the GBC.

3. Correlate the timing of egress events of southern flounder to cold weather events (fronts) and resulting shifts in water temperature

   H3: Egress events will be strongly influenced by cold weather events, with water temperature affecting the timing and magnitude of egress.

METHODS

Study site

This study was conducted in the Galveston Bay Complex (GBC) located along the upper Texas coast. The GBC is one of the largest estuaries (1,420 km^2) in the United States and is comprised of several smaller bay systems including Trinity Bay, East Bay, West Bay, Christmas Bay, and Galveston Bay. The GBC includes two tidal inlets or passes that flow into the Gulf of Mexico (San Luis Pass, Galveston Ship Channel), and both tidal passes represent a movement corridor that links estuarine and coastal habitats used by southern flounder and other estuarine-dependent species (Dance et al. 2015, Furey et al. 2013).

Acoustic Telemetry and Conventional Tagging

Bay-scale tracking was completed using an array of 42 acoustic receivers (Vemco VR2W [n=39], and VR2AR [n=3]) that were strategically placed throughout the GBC near shorelines and tidal passages (Fig. 1). Receivers were mounted on channel markers and wood pilings when available, or cable tied to polyvinyl chloride (PVC) piping driven into sediment. Acoustic release receivers (VR2AR) were placed at depth at San Luis Pass and the Galveston Ship Channel. Receivers were downloaded twice each year, and the complete array was in place for the duration of the study with lost receivers (n=7) replaced immediately after discovering they were missing.

Southern flounder were captured using hook-and line techniques. Upon capture, fish were measured (standard length [SL], total length [TL]), and then placed in a cooler with sea water in preparation for surgical implantation of Vemco V9-1H transmitters (69 kHz, 151 dB). Individuals were first placed in a state of tonic immobility as a form of anesthetic, which places the individual in a state of torpor (Henningsen 1994, Kessel et al. 2015). Immediately following, a sterile surgical scalpel was used to make a small incision into the peritoneal cavity and transmitters were then placed gently inside the cavity with one or two uninterrupted sterile stitches (Ethicon 4-0 vicryl) to close the incision (Robillard et al. 2015). A conventional tag (FLOY extra small T-bar anchor) with printed pertinent contact information was anchored in the tissue near the caudal peduncle of each individual. Following the assessment of post-surgical health, individuals were carefully released back into the GBC where initially captured.

Acoustic tagging generally occurred in regions of the GBC that correlated to areas of high receiver coverage within the array (Fig. 1). A total of 60 southern flounder were tagged with V9 transmitters, and spawning females (> 40 cm TL; Fitzhugh et al. 1996) were targeted to characterize egress activity because smaller, immature fish may not participate in spawning runs into the Gulf of Mexico. Delay rates of acoustic transmitters were set at 160-260 seconds to obtain an estimated battery life of 450 days, allowing tracking of individuals for two egress cycles.

In order to better represent the movement of individuals not implanted with acoustic transmitters, all other southern flounder captured, regardless of size, were tagged using a conventional tag (FLOY extra small T-bar anchor). These tags were anchored in the tissue near the caudal peduncle and also released back into the GBC at the initial point of capture. Conventional tagging data was recorded when recreational or commercial fishers recaptured a tagged individual and reported individual information. Upon report, an attempt to gain information regarding tag identification number, total length (cm), and location of recapture was completed.

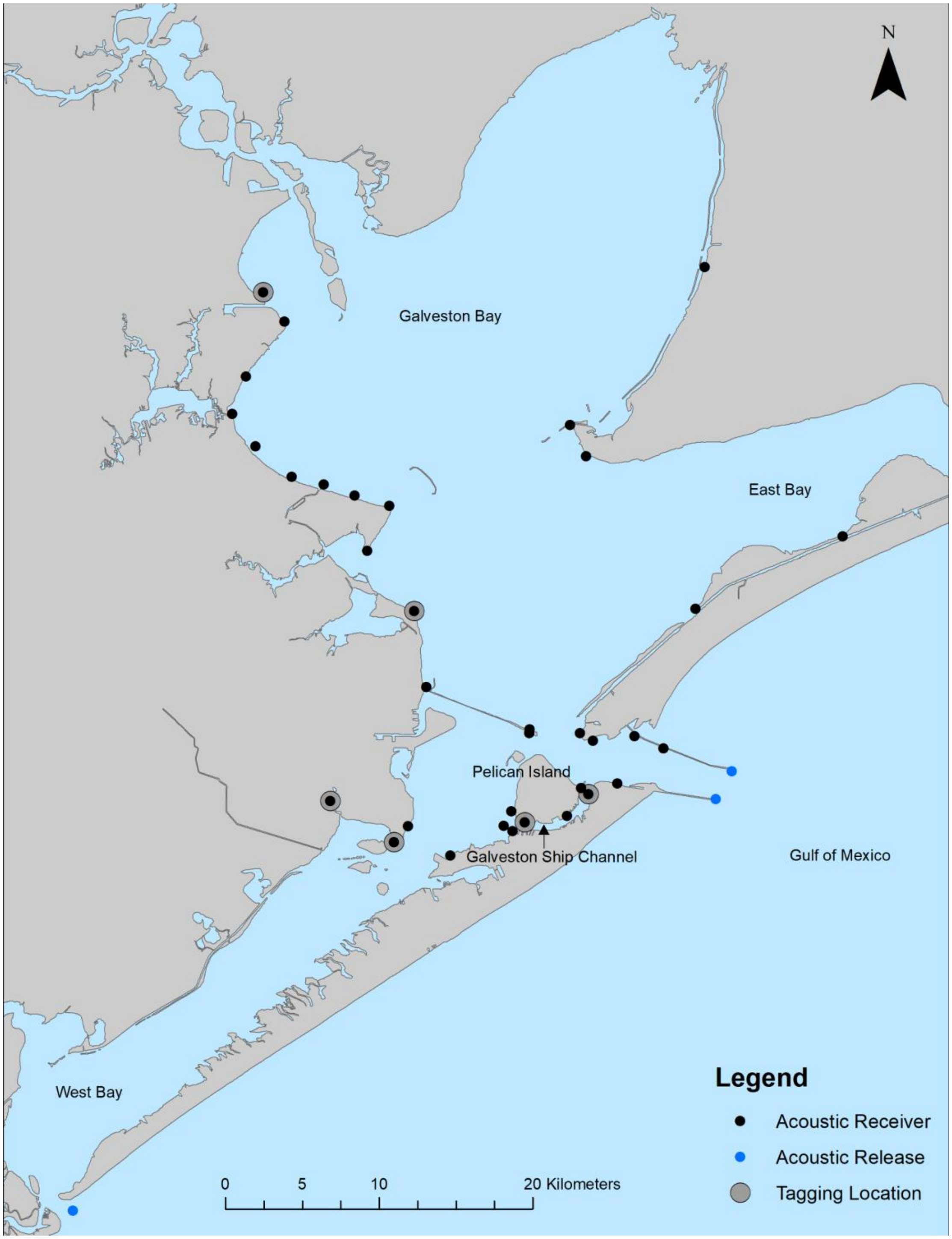

Figure 1. Map showing the spatial configuration of the acoustic array in the Galveston Bay Complex, Texas. Receiver type and tagging location are denoted.

Data Analysis

Maximum step distance (MSD) "through water" in kilometers was estimated for each tagged individual detected within the acoustic array using ArcMap 10.2 software and Geospatial Modelling Environment (GME). Similar to methods defined in a previous large-scale tracking study (Moulton et al. 2017), three classifications were developed in order to characterize the movement pattern of each individual southern flounder: 1) migrator, 2) non-migrator, and 3) unclassified. An individual was considered a migrator if the maximum step distance was greater than 5 kilometers. Individuals were classified as non-migrators if the maximum step distance was less than 5 kilometers, but the individual was detected throughout the fall and winter months. Remaining individuals that did not meet the criteria for the previous classifications were labeled as unclassified. Unclassified individuals were characterized as southern flounder that were released, and only detected at one receiver, then never detected within the array following departure from the initial tagging location.

Total MSD by each individual was calculated as the sum of individual movements throughout the array. MSD per month was calculated in order to identify periods of significantly greater movement, and each annual quarter was tested for significant differences in distance travelled. Rate of movement within the array was calculated to be the MSD by an individual divided by the time elapsed (Dance et al. 2015, Moulton et al. 2017). Additionally, individuals classified as migrators or non-migrators were separated into two different size categories (40.0-49.9 cm and 50.0-60.0 cm) in order to determine if distances travelled and/or days at large were significantly affected by differences in ontogeny (all unclassified individuals excluded). In addition, the number of "days at large" was calculated as the amount of time elapsed between first detection date, and the last date an individual was detected. Also, the total amount of detection events at each receiver was determined for all transmitters in order to gain information about areas with potential high individual presence.

RStudio software was utilized to determine the mean MSD travelled by conventionally tagged fish divided by time in order to characterize times of increased or significant movement by individuals. Conventional tagging data was also used in order to plot the proportion of individuals that could be considered as, "migrators" (MSD > 5 km) based on initial tagging location and recapture location. The proportion of "migrators" was calculated as the number of individuals recaptured at least 5 km from the initial tagging location, divided by the total number of recaptures for that month.

Analysis of variance (ANOVA) was used to investigate the effect of size (independent variable) on number of detections per individual southern flounder. In addition, univariate contrasts employing ANOVA were used to test whether size significantly affected days at large or MSD (km). The level of significance (α) used for all statistical testing was set at 0.05 and tests were run using the statistical software package RStudio.

RESULTS

Acoustic Telemetry

All southern flounder were tagged and released in 2016 (n=10) or 2017 (n=50) (Table 1). A total of 365,714 detections were recorded by the acoustic array in the GBC from November 2016 to July 2018 (2016= 18,857, 2017= 137,066, and 2018=209,791). Nearly half (n=27) of the southern flounder tagged were detected at least 1,000 times over the course of the study, and only 8 individuals were detected less than 100 times in the array. The majority of southern flounder detections were located at or near receivers where individuals were released (Fig. 2). The average number of individuals detected with each receiver in the array was 4, with several receivers in the GBC detecting more than 10 different tagged individuals (Fig. 3).

Average total tracking duration (± 1 SD) across all individuals was 48 days ± 79 days, ranging from 0 days detected to 353 days (Table 1). Several individuals tagged in the GBC were never detected (n=2). The average MSD of all tagged individuals was 3.54 km ± 2.2 km, ranging from 0 kilometers to 22.7 km. The individual with the largest MSD was tagged and released on 11/7/2017 and, detected on 3 receivers in the GBC array before moving out of the estuary 17 days later. No tagged southern flounder leaving the GBC (egress) were detected returning (ingress) back into the GBC.

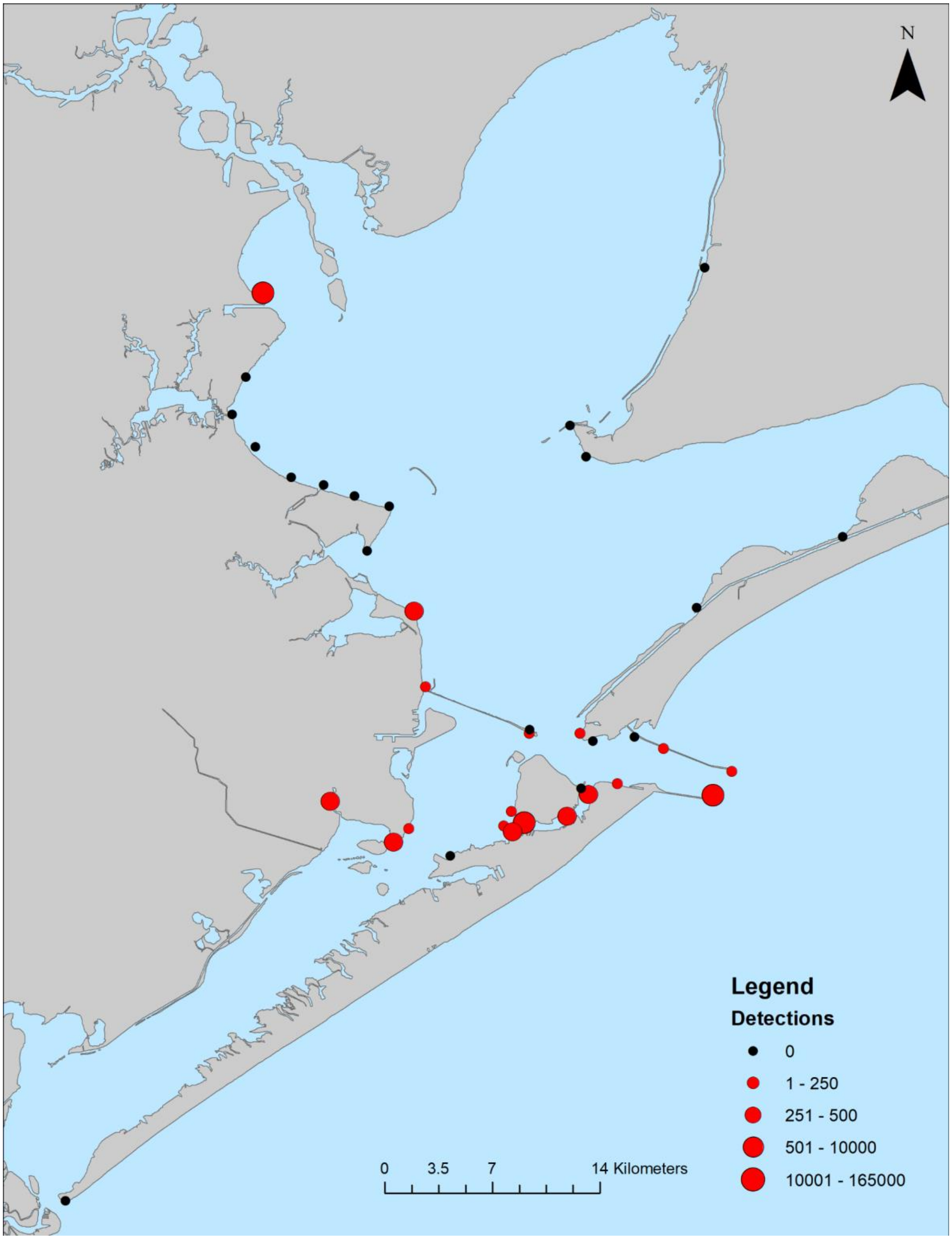

Figure 2. Total number of detections of southern flounder at individual receiver locations within the Galveston Bay Complex, Texas.

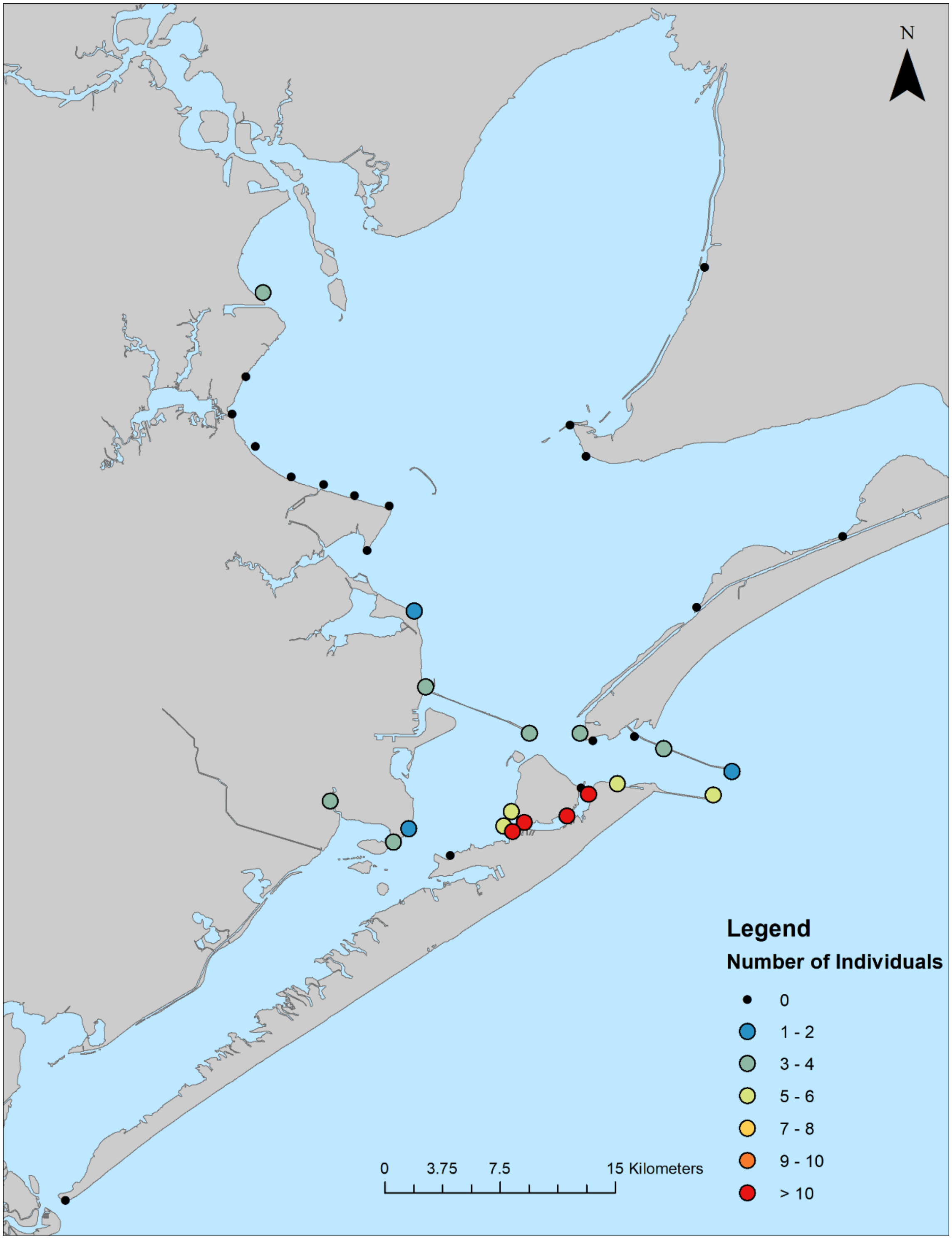

Figure 3. Number of southern flounder detected at individual receiver locations within the Galveston Bay Complex, Texas.

Table 1. Summary data for southern flounder caught, tagged, and released into the Galveston Bay Complex, Texas. Table includes fish identification number, total length, tagging dates, maximum step distances, total tracking duration, and total number of detections for each individual.

Animal ID	Total Length (cm)	Date Tagged	Detection Start Date	Detection End Date	Total Detections	Maximum Step Distance (km)
SF-1-16	47	11/20/2016	11/27/2017	3/1/2018	30678	20.3
SF-2-16	46	11/21/2016	NA	NA	0	0.0
SF-3-16	57	11/29/2016	12/13/2016	12/26/2016	794	3.2
SF-4-16	46	11/29/2016	12/13/2016	12/30/2016	1005	1.2
SF-5-16	46	11/29/2016	12/15/2016	12/3/2017	17981	1.1
SF-6-16	47	11/30/2016	12/15/2016	6/6/2017	45942	1.1
SF-7-16	59	12/16/2016	12/16/2016	12/25/2016	3463	0.0
SF-8-16	51	12/20/2016	12/20/2016	12/29/2016	723	3.2
SF-9-16	57	12/21/2016	12/21/2016	12/24/2016	734	3.2
SF-10-16	56	12/21/2016	12/21/2016	12/28/2016	1626	4.2
SF-11-16	43	12/22/2016	12/22/2016	12/25/2016	1118	0.0
SF-12-17	49	2/4/2017	2/7/2017	3/14/2017	441	0.0
SF-13-17	48	2/4/2017	2/18/2017	3/19/2017	3	0.0
SF-14-17	47	2/5/2017	2/7/2017	2/13/2017	310	0.0
SF-15-17	45	2/11/2017	2/11/2017	3/21/2017	4740	0.0
SF-16-17	47	10/7/2017	10/26/2017	7/27/2018	39862	0.0
SF-17-17	46	10/7/2017	10/26/2017	7/27/2018	74738	0.0
SF-18-17	46	10/7/2017	10/27/2017	2/25/2018	46893	0.0
SF-19-17	48	9/30/2017	NA	NA	0	0.0
SF-20-17	43	10/6/2017	10/6/2017	10/27/2017	2	0.0
SF-21-17	44	11/7/2017	11/7/2017	11/24/2017	4547	22.7
SF-22-17	56	11/11/2017	11/11/2017	11/22/2017	2383	0.0
SF-23-17	48	11/11/2017	11/11/2017	12/18/2017	118	5.5
SF-24-17	51	11/12/2017	11/12/2017	11/28/2017	827	0.0
SF-25-17	46	11/12/2017	11/13/2017	12/19/2017	1044	9.1
SF-26-17	47	11/21/2017	11/22/2017	11/23/2017	55	0.0
SF-27-17	53	11/21/2017	11/21/2017	11/26/2017	759	3.2
SF-28-17	44	11/22/2017	11/22/2017	12/13/2017	954	7.5
SF-29-17	46	11/28/2017	11/28/2017	12/22/2017	1482	3.2
SF-30-17	43	11/28/2017	11/29/2017	8/8/2018	47173	1.1
SF-31-17	45	11/28/2017	11/29/2017	12/27/2017	176	8.9
SF-32-17	56	11/29/2017	12/11/2017	12/22/2017	76	3.2
SF-33-17	52	11/29/2017	11/30/2017	12/20/2017	65	1.1
SF-34-17	60	11/29/2017	12/9/2017	12/21/2017	27	7.5
SF-35-17	47	11/29/2017	12/6/2017	12/14/2017	965	0.0

Table 1 Continued

Animal ID	**Total Length (cm)**	**Date Tagged**	**Detection Start Date**	**Detection End Date**	**Total Detections**	**Maximum Step Distance (km)**
SF-36-17	55	11/30/2017	12/11/2017	2/18/2018	2089	1.1
SF-37-17	52	11/30/2017	11/30/2017	12/18/2017	2189	5.1
SF-38-17	53	11/30/2017	11/30/2017	12/22/2017	648	7.5
SF-39-17	50	12/1/2017	12/1/2107	6/4/2018	810	1.1
SF-40-17	54	12/1/2017	12/1/2017	12/15/2017	773	3.2
SF-41-17	48	12/12/2017	12/12/2017	12/19/2017	1018	1.3
SF-42-17	49	12/12/2017	12/12/2017	12/14/2017	284	0.0
SF-43-17	55	12/12/2017	12/12/2017	12/15/2017	638	0.0
SF-44-17	58	12/14/2017	12/14/2017	12/27/2017	220	10.1
SF-45-17	49	12/17/2017	12/17/2017	12/23/2017	561	3.2
SF-46-17	46	12/4/2017	12/4/2017	12/23/2017	1585	11.1
SF-47-17	47	12/12/2017	12/12/2017	12/20/2017	1027	1.6
SF-48-17	53	12/19/2017	12/19/2017	12/27/2017	680	11.1
SF-49-17	50	12/18/2017	12/18/2017	5/28/2018	8100	1.1
SF-50-17	50	12/18/2017	12/19/2017	12/24/2017	13	3.2
SF-51-17	48	12/19/2017	12/19/2017	12/21/2017	202	1.1
SF-52-17	49	12/19/2017	12/19/2017	12/21/2017	427	0.0
SF-53-17	46	12/4/2017	12/4/2017	12/24/2017	2445	3.2
SF-54-17	44	12/4/2017	12/4/2017	12/23/2017	423	11.1
SF-55-17	54	12/4/2017	12/4/2017	3/7/2018	1504	3.2
SF-56-17	53	12/5/2017	12/5/2017	12/25/2017	2290	9.5
SF-57-17	52	12/5/2017	12/5/2017	12/10/2017	465	0.0
SF-58-17	49	12/10/2017	12/10/2017	12/18/2017	1646	1.1
SF-59-17	51	12/8/2017	12/8/2017	12/17/2017	194	11.1
SF-60-17	49	12/11/2017	12/11/2017	6/8/2018	3779	1.1

Southern flounder classified as migrators with MSD > 5 km (n=15) accounted for 12.7% of detections across all years, and the average MSD for these fish was 10.5 ± 4.9 km (Table 1). Only 10 individuals were classified as non-migrators (MSD < 5 km), but these fish were responsible for a large fraction (78.4%) of the total detections, and detection numbers significantly higher relative to fish classified as migrators (ANOVA, $p < 0.01$). The remaining 35 individuals were assigned to the unclassified category. Movements of southern flounder in the migrator category typically represented egress events, with individuals moving through the tidal passes and channels into the Gulf of Mexico (Fig. 4). In contrast, non-migrators were often detected for extensive periods of time (> 150 days) in the same general location, often moving to adjacent receivers. This was particularly evident for southern flounder in the channel off the southern side of Pelican Island, which serves as a migration corridor to the Galveston Ship Channel (Fig. 5). As expected, the number of detections per tagged southern flounder was positively correlated with the number of months that individual was detected in the array (Fig. 7).

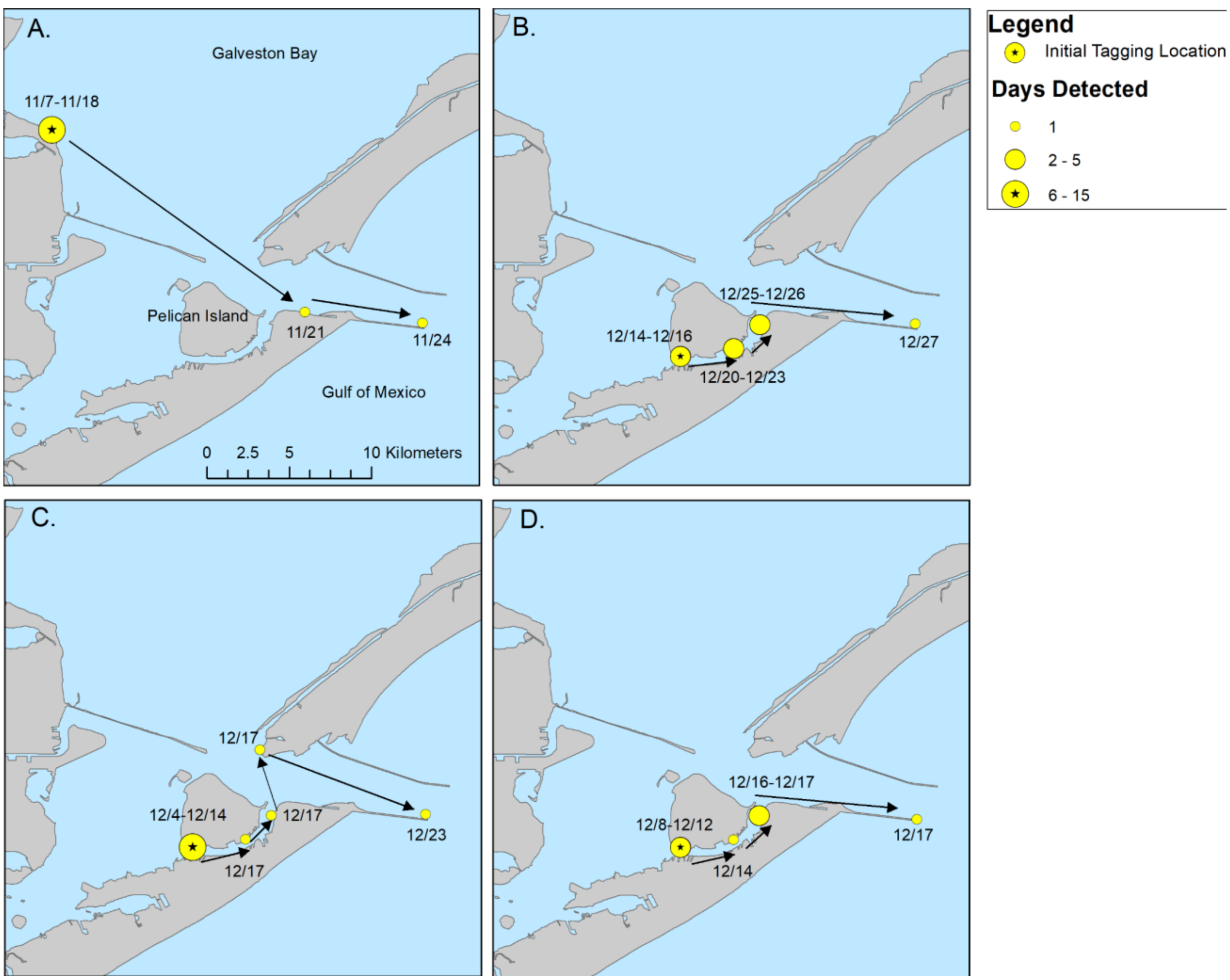

Figure 4. Movement path examples of southern flounder classified as migrators (MSD > 5km): **A.** SF-21-17, **B.** SF-44-17, **C.** SF-54-17, and **D.** SF-59-17.

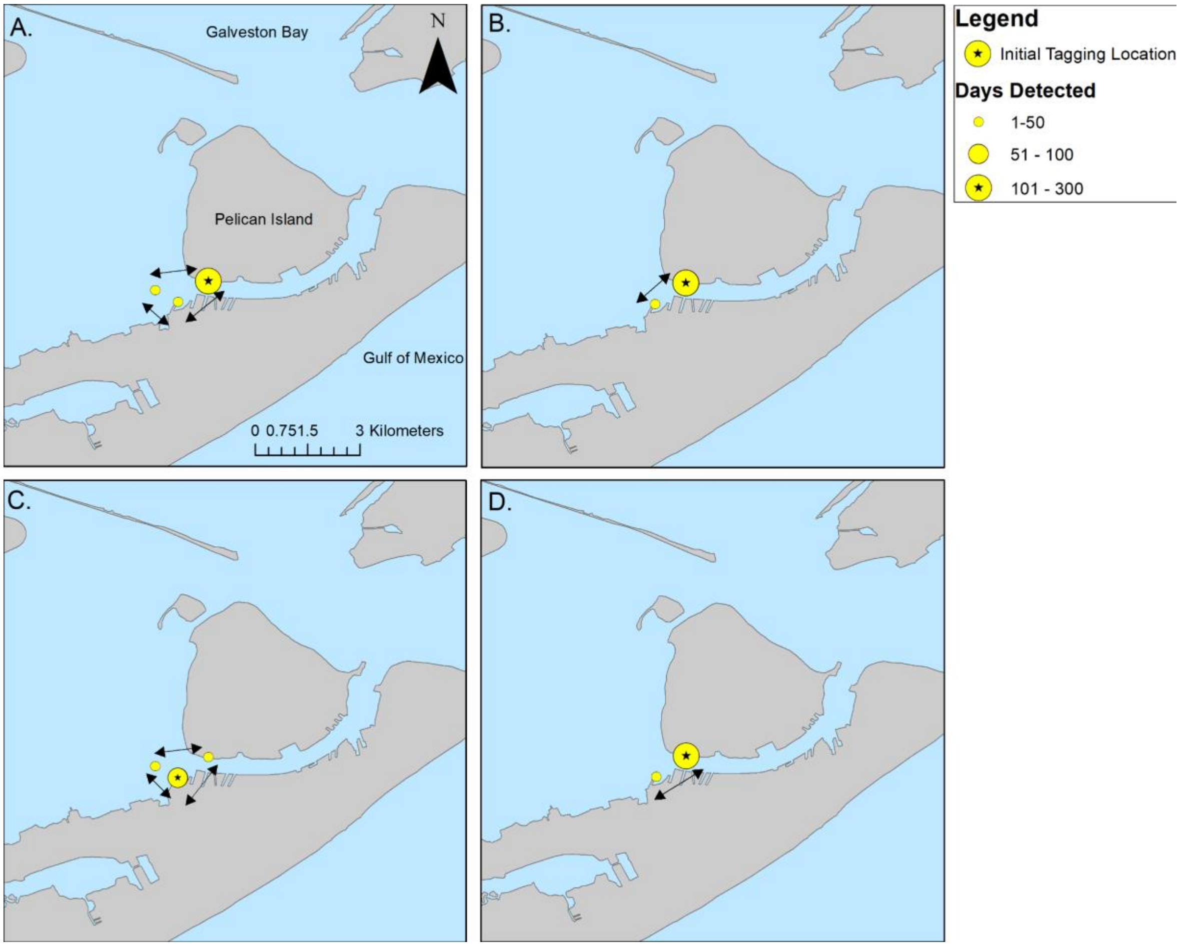

Figure 5. Movement path examples of southern flounder classified as non-migrators. **A.** SF-6-16; tracking duration at 3 receivers from 12/15/2016-6/6/2017. **B.** SF-5-16; tracking duration at 2 receivers from 12/15/2016-12/3/2017. **C.** SF-36-17; tracking duration at 3 receivers from 12/11/2017-2/18/2018. **D.** SF-30-17; tracking duration at 2 receivers from 11/29/2017-8/8/2018.

Separating acoustically tagged individuals into two size classes, 40.0-49.9 cm and 50.0-60.0 cm, did not significantly affect the MSD, or the total number of detections (Fig. 6). There was not a significant effect on maximum step distance (km) (ANOVA, $p > 0.05$). In addition, smaller individuals in size class 40.0-49.9 remained at large within the estuary longer than individuals larger than 50.0 cm (Fig. 6, ANOVA, $p < 0.05$).

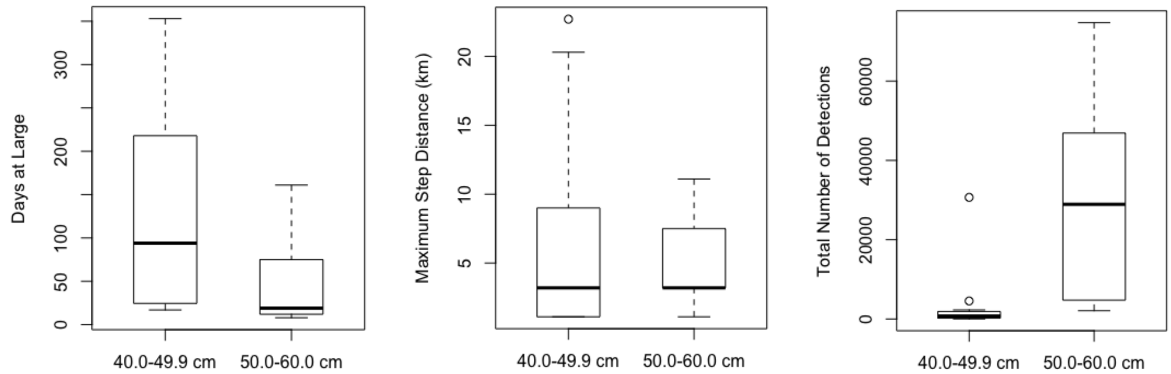

Fig. 6. Boxplots showing the difference between two size classes in acoustically tagged southern flounder for days at large, MSD (km), and total number of detections.

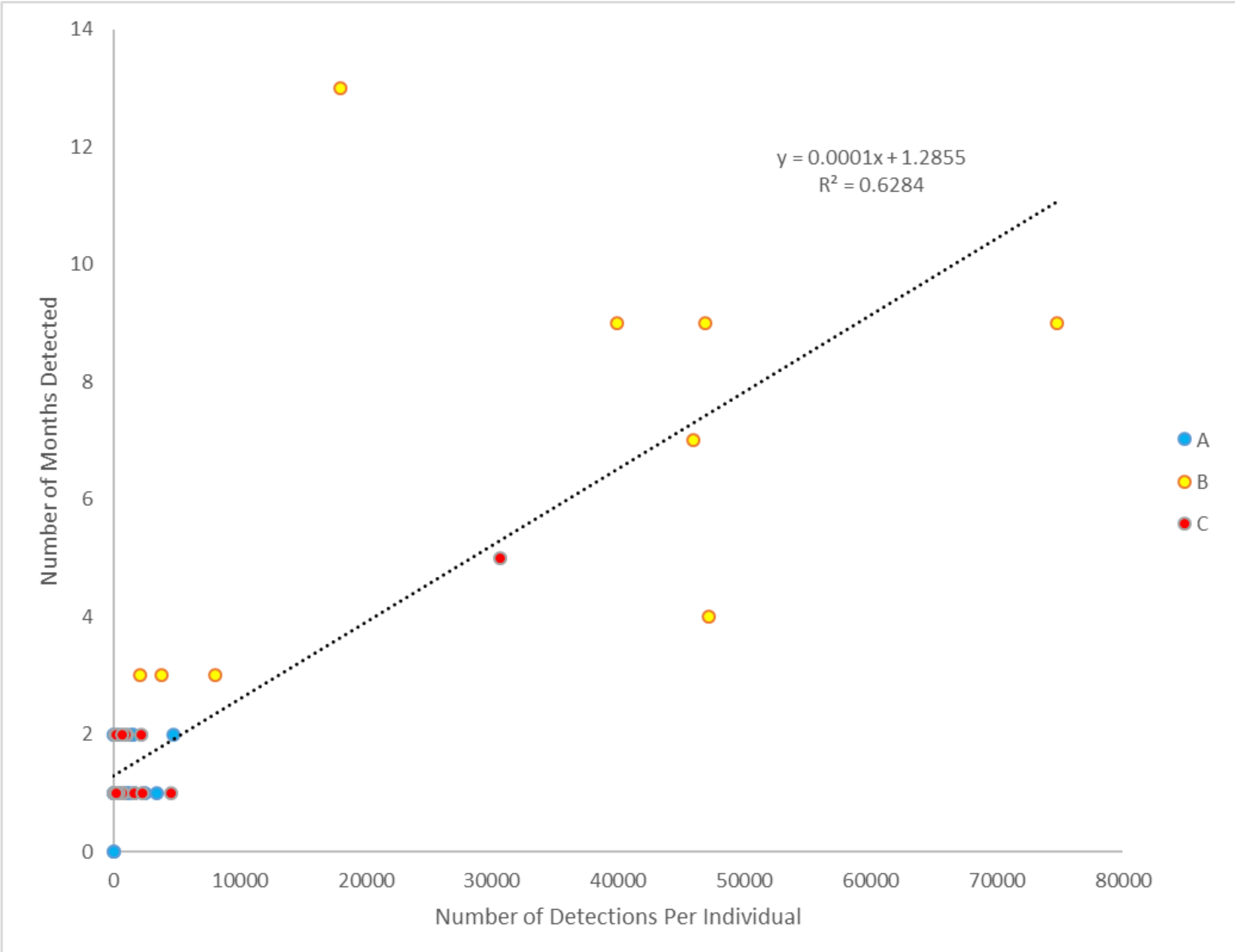

Figure 7. The number of detections and number of months detected for each acoustically tagged southern flounder. Group A= Unclassified, Group B= Non-migrator, Group C= Migrator. ($p < 0.05$).

MSD within the array was used as an indicator of egress with greater distances occurring during putative spawning runs to the Gulf of Mexico. MSD per day (and month) peaked in November and December (Fig. 8), with the highest proportion of individuals classified as migrators (0.74) moving during these two months (Fig. 8). Negligible MSD per month was observed from January through March, and no movement across receivers in the array was detected from April to September in all years even though individuals were consistently detected on single receivers. The rate at which individuals completed egress (movement from Galveston Bay to shipping channel) ranged from 0.94 km/day to 5.6 km/day.

The influence of ontogeny on movement was investigated by comparing MSD and detection days between two size classes of southern flounder (40.0-49.9 cm, 50.0-60.0 cm). Total MSD between the two groups was statistically similar: (5.8 km and 4.7 km, respectively) (ANOVA, $p > 0.05$); however, southern flounder in the smaller size class spent significantly more time (i.e., days detected) within the estuary relative to individuals in the larger size class (ANOVA, $p < 0.05$), suggesting that the movement dynamics of southern flounder may be influenced by ontogeny or size, with larger, older individuals more likely to move completely out of the GBC and into the Gulf of Mexico during fall spawning runs.

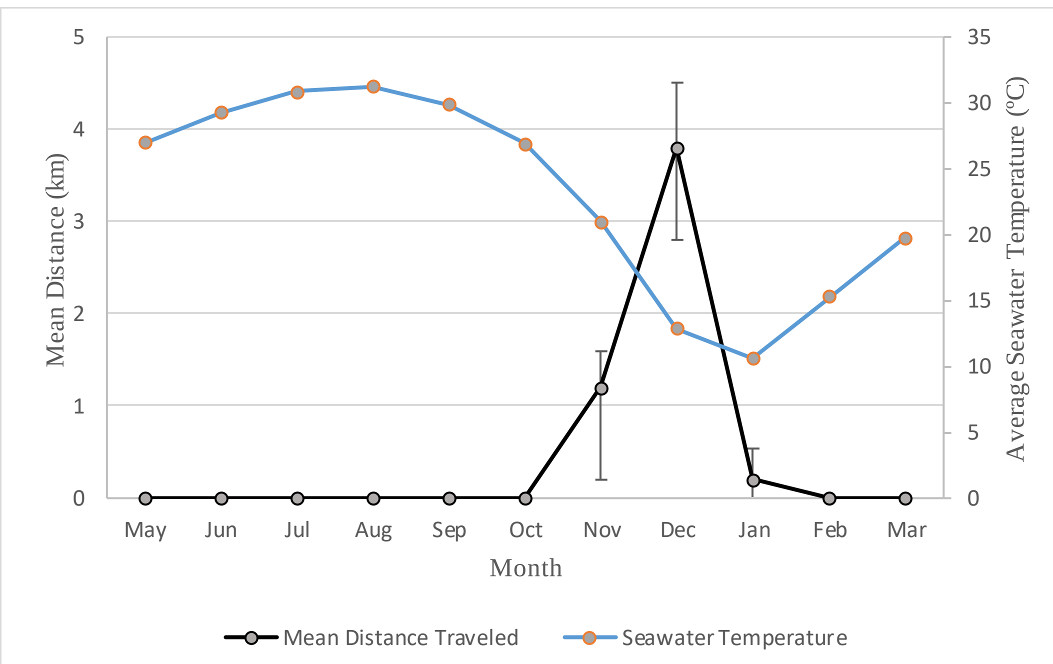

Figure 8. Mean distance traveled between acoustic receivers by all southern flounder, and average seawater temperature (°C) from May-April of both sampling periods, 2016-2018. Temperature data from Quigg et al. (2019).

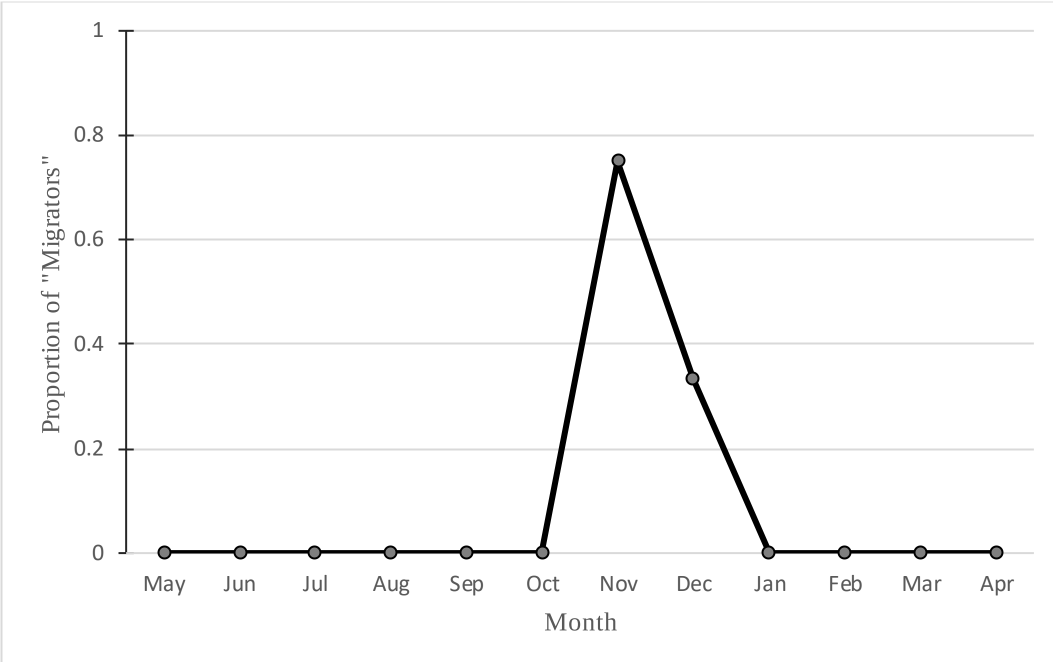

Figure 9. Proportion of acoustically tagged southern flounder migrators (traveled distance > 5 kilometers) from May-April of both sampling periods, 2016-2018.

Conventional Tagging

A total of 1,353 southern flounder were tagged with conventional tags in 2017 (n=843) and 2018 (n=510). In 2017, the recapture rate for all individuals was 12%, with seven individuals being recaptured more than one time. In 2018, the recapture rate was 13.5%, with only one individual being recaptured more than once. Average MSD for all recaptured individuals was 5.7 kilometers and the maximum MSD was 221 km for an individual recaptured in Espiritu Santo Bay 23 days after being released near the Galveston Ship Channel in the GBC.

Movement displayed by conventionally tagged flounder increased during fall and winter months, September-February, with a peak MSD per month peaking at 13.2 kilometers in December (Fig. 10). During the months of May to August, no recaptured individuals indicated movement away from the initial tagging location (ca. > 1 km). The proportion of conventionally tagged individuals considered to be "migrators" (MSD> 5 km) was highest during the months of October-January, with the highest proportion of "migrators" present in December (Fig. 11).

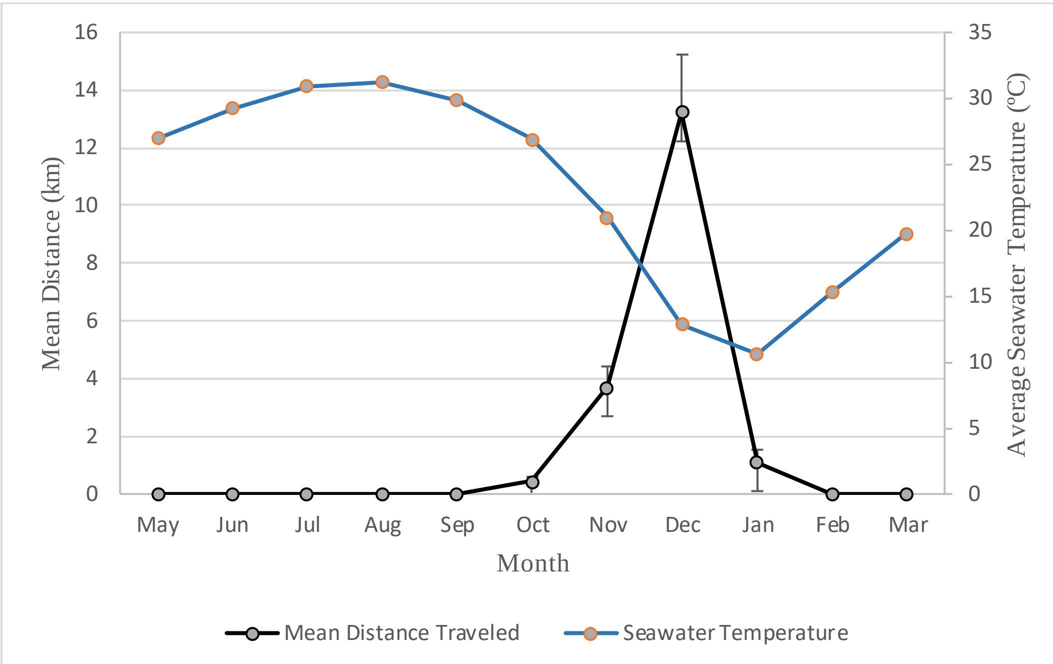

Figure 10. Mean distance traveled by conventionally tagged southern flounder for months May-March of both sampling periods, 2016-2018. Temperature data from Quigg et al. (2019).

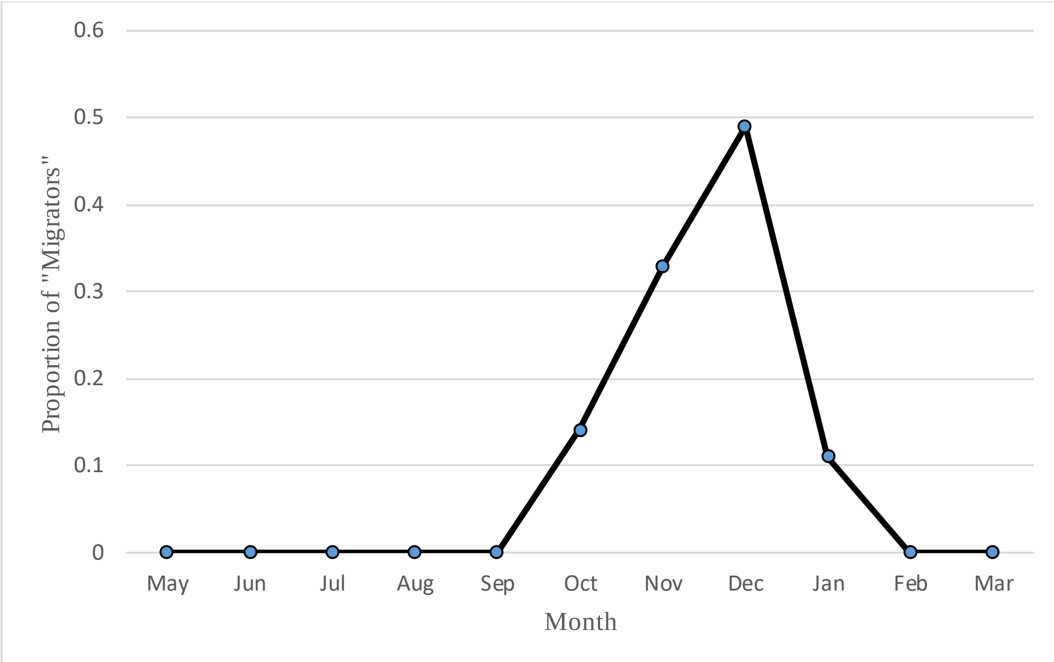

Figure 11. Proportion of conventionally tagged individuals considered to be “migrators” (traveled > 5 kilometers) for months May-March for both sampling periods, 2016-2018.

DISCUSSION

Movement patterns observed for southern flounder were highly variable, ranging from resident behaviors with limited movement to directed migrations with individuals moving from the GBC into coastal waters of the Gulf of Mexico over relatively short periods of time. The presence of different migratory contingents within a population have been previously reported for flatfishes (Morais et al. 2011) as well as other estuarine-dependent species (Secor et al. 2001). DeCellus and Cadrin (2010) reported that a winter flounder (*Pseudopleuronectes americanus*) displayed both resident behavior (non-migrator) and egress from estuaries (migrator) during their presumed spawning period, with non-migrators appearing to remain in the estuary and overwinter in these inshore systems. Similarly, Craig et al. (2015) observed both resident and migratory behaviors for southern flounder in North Carolina.

Southern flounder classified as migrators showed relatively quick, large-scale movements during fall and winter periods and were generally detected within the GBC for relatively short periods of time, often moving across multiple receivers in the bay and through the tidal passes in 1-2 weeks. Large-scale egress and rates of movement detected for southern flounder in this study are in accord with previous studies on this species, which reported that this species commonly moves at distances of up to 1 km per day during fall with many individuals moving over 50 km from initial tagging locations (Craig et al. 2015, Sackett and Grothues 2007). Interestingly, the smaller size class of southern flounder in my study were detected for a greater number of days within the estuary than the larger size class, suggesting that egress or residency behaviors are size dependent with smaller southern flounder displaying resident behaviors (i.e., overwintering) in the GBC. This is similar to observations on winter flounder in the Gulf of St. Lawrence, where smaller fish also remained in the estuary longer than larger, older individuals (Hanson and

Courtenay 1996).

The timing and duration of egress events by southern flounder classified as migrators was well defined, and greatest net movements (MSD per month) occurred in the fall and winter. Both the proportion of southern flounder displaying movements > 5 km as well as the mean distance traveled per month started to increase in October and peaked in November and December for both acoustically and conventionally tagged fish. The remaining spring and summer months were time periods where individuals exhibited little to no movement, which is generally in agreement with other studies on this species. Craig et al. (2015) reported that the majority of conventionally tagged southern flounder in North Carolina were recaptured less than 1 km from their release location during spring and summer, while large-scale movements occurred in the fall and winter. Conspicuous fall and winter egress events have also been reported for a variety of other finfishes, including several species of flatfishes (Capossela et al. 2013, Henderson 2012, Bailey and Picquelle 2002) as well as other estuarine-dependent species in the Gulf of Mexico (Patterson et al., 2004, Secor 2015). The timing of fall and/or winter egress events has been primarily linked to shifts in water temperature, with pronounced drops in water temperature often triggering migrations or serving as a cue to initiate movement out of estuaries (Peters and Angelovic 1971, Sackett et al. 2007). Moreover, water temperature and winter conditions have been shown to influence the activity and movement patterns of southern flounder (Watanabe et al. 2001).

A large portion of the tagged southern flounder were classified as non-migrators and these individuals were often detected on a single receiver or adjacent receiver. Individuals in this category moved less than 5 km from the initial tagging location, potentially suggesting that partial migration and/or overwintering is well developed for the GBC population of southern flounder. Partial migration or migratory dimorphism is defined as when a portion of a population remains resident, while the other fraction of the population is migratory, and this process is highly variable and occurs across many taxa (e.g., Jonsson and Jonsson 1993, Kerr et al. 2009, Chapman et al. 2012). Out of the 25 acoustically tagged southern flounder assigned movement classifications, 10 individuals were non-migrators that were commonly detected throughout the fall and winter months and showed little movement with many individuals detected for 6-12 months. As noted earlier, water temperature is an important abiotic driver of migrations for estuarine-dependent fishes; however, deeper areas of bays and estuaries (dredged channels) are known to function as thermal refuges (Hanson and Courtenay 1996) that are often utilized by fishes during colder periods because water temperatures in these deeper areas are higher than shallower areas in the estuary (Blomqvist 1986). Although the GBC is a relatively shallow estuarine system with an average depth of approximately 2 m, it also includes several channels and dredged areas that reach depths of up to 20 m feet deep that may maintain water temperatures above the threshold or critical level that initiates egress into warmer, coastal waters outside the GBC. In support of this hypothesis, many southern flounder tagged and released near deeper channels experienced less movement and higher residency, suggesting that water temperatures in these channels may be warmer (i.e., thermal refuge), possibly leading to overwintering by southern flounder in the GBC.

Both resident (non-migrator) and migratory behaviors observed with acoustic tags were also evident with conventional tags. Reported recaptures of conventionally tagged southern flounder indicated periods of high residency and limited movement during spring and summer months. Evidence of high residency were also inferred from the recapture locations of conventionally tagged individuals for both sampling years, as the majority of reported recaptures were in close proximity to initial tagging locations. Nearly all of the southern flounder conventionally tagged from April to August were recaptured in very close proximity to the initial tagging location, which is similar to results from a conventional tagging study in North Carolina estuaries (e.g., Craig et al. 2015). The proportion of conventionally tagged southern flounder classified as migrators increased largely in fall and winter months, peaking in early December, coinciding with the findings from telemetry data. Larger scale movements were detected with conventionally tagged individuals, including the 230 km movement by one individual over a 23 day period. Clearly, the combined approach of acoustic and conventional tags provided important insights into the movement of southern flounder, with the latter approach offering valuable information on the capacity for large-scale movements by southern flounder in Texas.

CONCLUSIONS

Conclusions reported here regarding both egress and estuarine residency (i.e., overwintering) have important implications for future management of southern flounder. Despite efforts by TPWD with the imposition of stricter bag limits during the presumed migratory season, the timing of egress and the observation of overwintering reported here serve as valuable information for resource managers at TPWD and other state fisheries agencies in the Gulf of Mexico. Results from this study indicate that peak egress occurs from November to late December, and, consequently many individuals are migrating during periods of increased fishing pressure (i.e., higher bag limits). Of the 15 southern flounder classified as migrators, a large portion of these fish were actively moving through the GBC and into the Gulf of Mexico during late December, when TPWD bag limits increase. Additionally, the occurrence of partial migration into deeper channels and/or overwintering in the GBC also renders southern flounder susceptible to increased fishing pressure outside of the reduced bag limit season. In fact, individuals that show limited movement often occupy and aggregate in specific areas (channels) for extended periods of time, and these areas are commonly targeted and exploited by commercial and recreational fishers.

Without detailed information on the migratory patterns of southern flounder, it is difficult to establish effective regulations (i.e., harvest scenarios) to rebuild southern flounder population(s) in Texas and other parts of their range. Results from tagging platforms used here afford valuable information on the nature and timing of southern flounder movements, which is necessary for determining the efficacy of current bag limits and seasons. Given that peak movement was observed from mid to late

December, the primary egress period occurs when bag limits set by TPWD increases from 2 to 5 fish per day. This creates the potential for increased fishing during periods when spawning runs by mature southern flounder are in full swing, leaving these individuals more vulnerable to commercial and recreational fishing activity. Consequently, additional research is needed to assess the effectiveness of current bag limits and the timing of seasonal closures.

The present study is the first to comprehensively investigate the seasonal movements of southern flounder in Texas, and the application of both acoustic and conventional tagging platforms significantly increases our current understanding of this species' migratory behaviors. My study shows that a fraction of the adult population exhibits rapid and directed egress movements in the late fall and winter, which was not unexpected but the timing and the extent of movements detected sheds new light on the migratory behaviors of this species. In particular, this research extends the egress periods later into December and early January, and also demonstrates that a fraction of adult population overwinters in the GBC or associated channels or passes. This research also shows that southern flounder have the capacity for large-scale movements into adjacent bay systems in Texas, and therefore it is possible that the population in the GBC may rely on production or recruitment from other bay systems along the Texas coast.

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