Cobia Telemetry Working Paper

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SEDAR58-SID-08

Submitted: 29 March 2018
Revised: 10 April 2018

Please cite this document as:

Young, J., M. Perkinson, K. Brenkert, E. Reyier, and J. Whittington. 2018. Cobia Telemetry Working Paper. SEDAR58-SID-08. SEDAR, North Charleston, SC. 15 pp.

Cobia Telemetry Working paper

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INTRODUCTION

Acoustic Telemetry

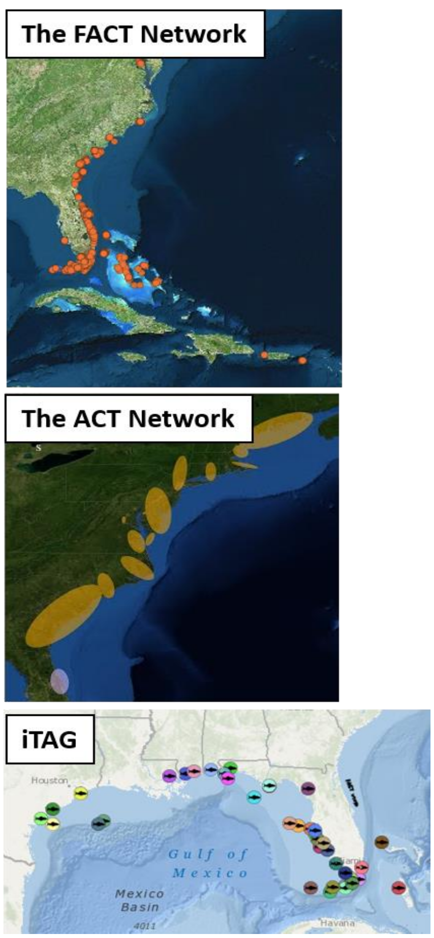

Figure 1. Regional acoustic networks along the Unites States east coast and Gulf of Mexico.

Passive telemetry utilizes an array of submerged acoustic receivers deployed to continuously and autonomously record the presence of fish carrying acoustic transmitters. Each receiver contains an omni-directional hydrophone and data logger that records the presence of nearby (typically ≤400 m) animals tagged with acoustic transmitters. When combined, detection data from multiple receivers can reveal seasonal and annual movement patterns that are unobtainable with traditional mark-recapture studies. Individual animals can therefore be tracked for intervals much longer than is possible with manual telemetry where movements are recorded with a mobile (usually boat-based) receiver.

The FACT, ACT, and iTAG Networks are organized as part of a regional-scale cooperative network of passive acoustic receiver arrays along the US Atlantic coast and Gulf of Mexico (Figure 1). As of 2017, the FACT Network consists of >900 acoustic receivers deployed in a variety of habitats including coastal rivers, open estuarine waters, tidal inlets, beachfronts, offshore reefs, wrecks, and sand shoals from South Carolina south to the Florida Keys and out into the Bahamas and US Caribbean. FACT currently has 43 partner groups including state and federal government agencies (e.g. Florida Fish & Wildlife Conservation Commission, Georgia Dept. of Natural Resources, Kennedy Space Center, US Navy, BOEM), academic institutions (major universities from Florida, Georgia, North Carolina and New York), and independent marine research organizations (e.g. Bimini Biological Field Station, Shedd Aquarium, Georgia Aquarium, Cape Eleuthera Institute, Mote Marine Laboratory). Similarly, the ACT Network has grown over the years to encompass 120 researchers from Maine to Florida. The iTAG Network was formed in 2014 to establish a network of scientists in the Gulf of Mexico. The networks are vital for effective data exchange and provide a platform for collaborative research. The networks are made up of individual arrays managed by single organizations, and therefore are affected by organizational research interests and funding. As a result, the conclusions of this study may evolve as new detection data becomes available, such as a new group joins one of the networks or a lost receiver is recovered.

Objectives

This working paper was created specifically for the Cobia Stock ID Data Workshop to both summarize and expand on findings from the NOAA Cooperative Research Program Final Report, Grant Number NA15NMF4540105. The overall goal of the CRP project was to utilize acoustic telemetry and population genetics to determine the biological stock boundary between Gulf of Mexico and South Atlantic stocks of cobia. The working paper expands specifically on describing exchange of cobia across the current management boundary line and characterizing movements of cobia within the Gulf and Atlantic Migratory stocks.

METHODS

Tagging

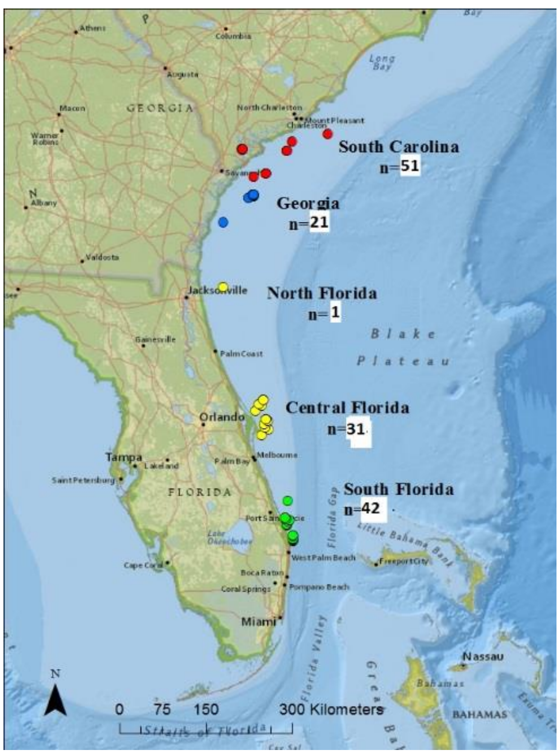

Figure 2. Map of tagging locations.

Fishing trips targeted cobia near artificial/natural reefs offshore, locations inshore that are known spawning sites in South Carolina, and nearshore zones that typically produce cobia. Cobia were landed via hook and line using either dead bait, live bait, or artificial lures throughout the water column. A total of 146 cobia were implanted with acoustic transmitters during the project. Cobia tagging was clustered in four main locations throughout the study area due to availability of fish, participating charter captains, and staff: inshore and offshore locations in South Carolina, offshore locations in Georgia, offshore locations around Cape Canaveral, Florida and offshore locations near Jupiter, Florida (Figure 2). One additional cobia was tagged in Jacksonville, FL. Tagging duties were split geographically among project collaborators for logistical reasons. South Carolina Department of Natural Resources (SCDNR) staff were responsible for all tagging in South Carolina and Georgia. Kennedy Space Center (NASA) Ecological Program staff were responsible for tagging in Central Florida and FWC staff were responsible for tagging in South Florida.

Data Analysis

Several methods of validating data have been employed in telemetry-based studies to ensure the accuracy of detections. In this study, detection data for tagged fish were validated before analysis by applying four rules: (1) removal of any detections before the date of surgery, (2) removal of any detections after a tag's published expiration date or after a known harvest date, (3) removal of detections that exceed a maximum swim velocity, specifically detections that occur within one hour at receiver stations over 10.5 km apart (2.9 meters/second), and (4) removal of continuous detections on a single receiver station for 2 months or more. In addition, a series of detections reported from Mobile Bay, Alabama were eliminated because the salinity and water temperature at the time of detection were deemed out of the physical tolerances for cobia and a large number of tagged individuals (red drum) were present in the estuary, suggesting that tag interference may have led to false detections.

Exchange between regions- Network Analysis

To quantify spatial relationships throughout the study area, we developed a directed movement network, where each node represents an area and the tie between them an associative link. Directed movements were defined as the number of individuals that moved between two locations. Due to the unequal distribution of receivers and the potential bias for overestimation of movement in areas of high receiver density, all receiver locations within a region were binned into daily presence or absence at each node.

Node level metrics were calculated to examine how each node contributes to the overall structure of the network. Markov clustering was used to partition the network into non-overlapping clusters, based on random walk expansion and inflation procedures.

Visualization was achieved using a theoretical layout based on 100 random permutations, resulting in a layout based on the relationship between areas, not geographic location. Locations more closely related are closer together, while dissimilar areas are repelled. Arrows indicate direction of movement and line thickness indicate number of movements between locations.

Factors affecting movement – General Linear Models

General linear models (GLM) were used to model latitude and distance to shore as a function of sea surface temperature (SST), month and year of detection, tagging location, and fork length (Table 2). See NOAA Cooperative Research Program Final Report, Grant Number NA15NMF4540105 for description on how SST was calculated. Candidate models for the response variable that differed 3 or less from the model with the lowest AICc score were furthered explored using GLM with Restricted Maximum Likelihood (REML) estimation. When main effects were significant, Least Squares Mean (LSM) post hoc tests were used to compare differences between groups. The AICc for best-fit model(s) for each migratory group were compared with the AICc value of the best fit model(s) for the entire study population. If the combined AICc score of the migratory groups totaled less than the AICc for the inclusive model, the separate migratory models were retained. Analyses were conducted using SAS© Enterprise 7.1 software.

RESULTS

One hundred and forty-six cobia were implanted with acoustic transmitters. Of those, three were determined to have died or shed their tag shortly after surgery and have been excluded from analysis. Of the remaining 143, 130 have been detected to date (91%). After the detection validation process, tagged cobia were detected a total of 98,701 times. Individual fish detections ranged from 2 to 5,080 (mean of 759 ± 89 detections). The first detection occurred on 12/15/2014 and the last detection included occurred on 1/7/2018. The time between first and last detections for individual fish varied from less than one day to 908 days (mean of 334 ± 16 days). Individual fish were detected on 1- 74 receiver stations (mean of 15 ± 1 stations) between 1 and 109 days (mean of 17 ± 2 days). A total of 372 receiver stations within the ACT, FACT, and iTAG networks have been visited by tagged cobia to date.

Cobia detection rates the same year tags were deployments averaged 88%, and between 72-100% one to two years following tag deployments (Table 1). As more detection data become available, these values may become higher. These re-sighting rates showcase the effectiveness of the current structure of acoustic arrays and are critical for determining temporal variation in behavior such as migration patterns and site fidelity. Additionally, between year detection provide useful insight into annual survival rates.

Table 1. Multi-year detection matrix for cobia tagged with acoustic transmitters. An asterisk (*) means only partial data (less than one month) for the year and are not included in the calculation of redetection rates.

		Year detected								
Year	N tagged	2014	2015	2016	2017	2018*	2019	2020	2021	2022
2014	1	1	1	1	0	0				
2015	5	---	4	3	4	1				
2016	110	---	---	92	66	1				
2017	28	---	---	---	25	0				
2018	2	---	---	---	---	---				

Detection Summaries- South Carolina and Georgia

Cobia tagged in South Carolina and Georgia (currently part of the Atlantic Migratory Group) had relatively similar geographic detection ranges and patterns and will be combined for the purpose of this paper. Separate analysis of each group can be found in NOAA Cooperative Research Program Final Report, Grant Number NA15NMF4540105. Cobia tagged in South Carolina and Georgia were detected as far south as Brunswick, Georgia (n=24) and as far north as the Chesapeake Bay (n=2). No cobia tagged in South Carolina or Georgia were detected south of Georgia, although one fish tagged in South Carolina was recaptured by an angler approximately 50 km offshore of Jacksonville, Florida in December 2017. Detections of this group peaked during May and June with a secondary peak during October (Figure 3).

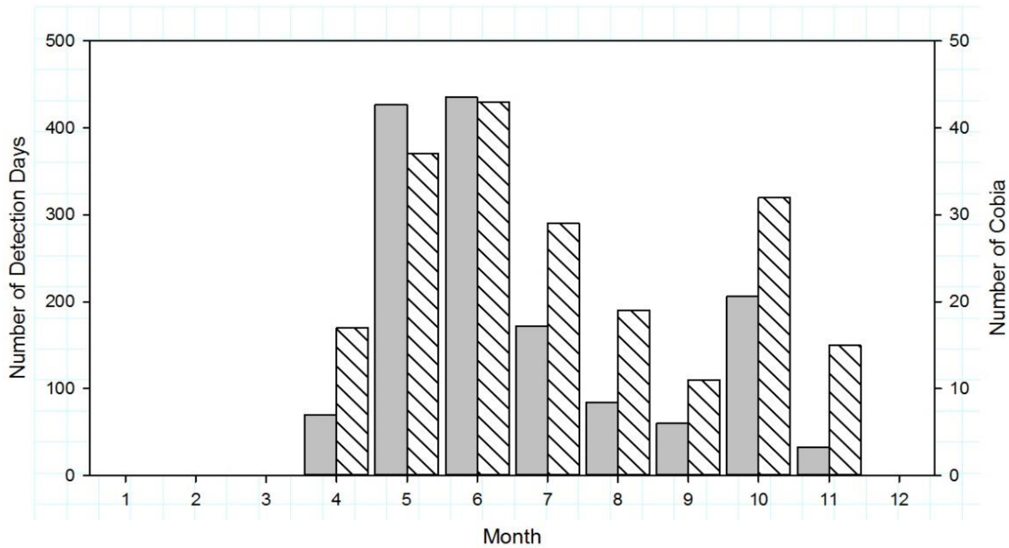

Figure 3. Total detection days (gray bars) and number detected (striped bars) of cobia tagged in Georgia and South Carolina.

Between these peaks of detection, cobia tagged in South Carolina and Georgia were relatively absent from coastal arrays (which are mostly sited within 20 km of shore) during August and September. During winter, cobia were completely absent as no fish tagged in South Carolina or Georgia were detected on any receiver between December and March (Figure 4).

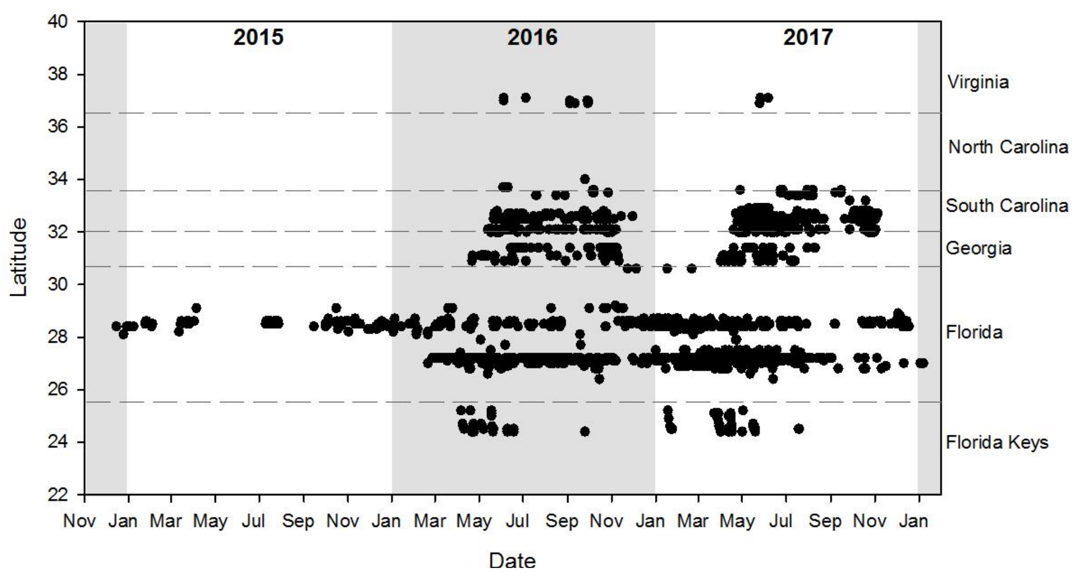

Figure 4. Detections of tagged cobia by latitude.

Detection Summaries- Central and South Florida

Cobia tagged as part of the current Gulf of Mexico Migratory Group in central Florida (Cape Canaveral) and south Florida (mostly between St. Lucie and Jupiter Inlets) had similar geographic detection ranges and patterns and will be combined here for analysis. Cobia tagged in Florida waters were detected in every month of the year, with a peak in detections during March-May (Figure 5).

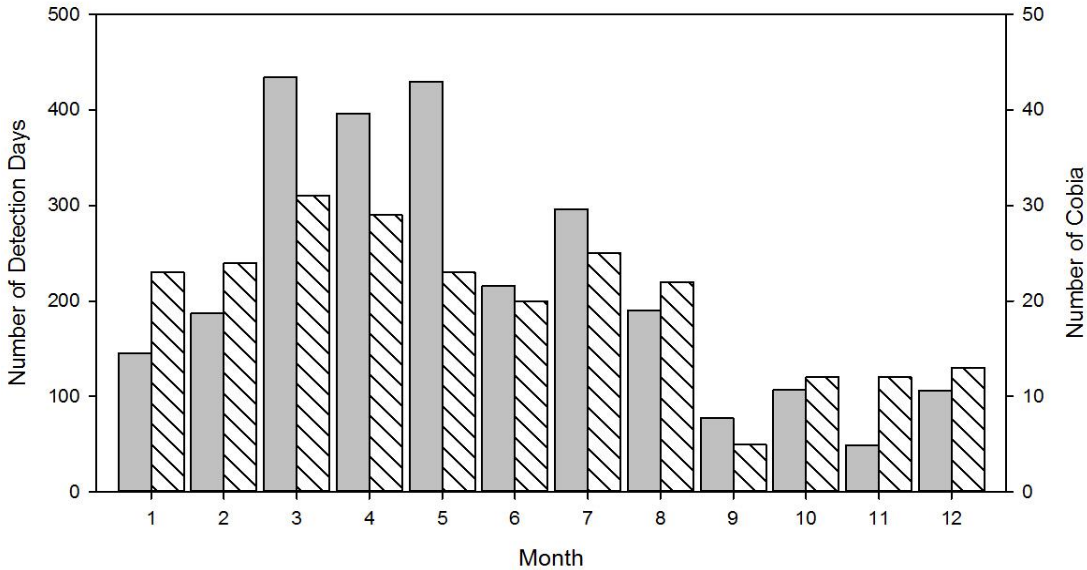

Figure 5. Total detection days (gray bars) and number detected (striped bars) of cobia tagged in Florida..

During the winter months (December-February) cobia tagged in Florida were most often detected on receiver stations in central Florida with an increase in detections in south Florida during spring (March-May). Of the 65 cobia tagged in Florida for which detection data are available, 38 (58.5%) have only been detected on receiver stations in central or south Florida, indicating that a portion of the population may be largely resident to the east coast of Florida (Figure 4).

Exchange between regions- Network Analysis

The entire movement network of tagged cobia was modeled to better understand its organization using centrality measures. Nodes were defined as all receiver stations within a state or region. The network contains ten nodes: Virginia (VA), South Carolina (SC), Georgia (GA), North Florida (NFL), Central Florida (CFL), South Florida (SF), Florida Keys (FLKEYS), West Florida (WFL), the NE Gulf of Mexico (GULF) and Bahamas (BAH). Each node contained between 2-78 receiver stations that cobia were detected on (Table 2).

Table 2. Number of receiver stations cobia were detected in in each node.

Node	Number of Receiver Stations
Virginia	16
South Carolina	76
Georgia	52
North Florida	2
Central Florida	78
South Florida	57
Florida Keys	60
West Florida	4
Bahamas	23

For the time inclusive graph (Figure 6), the links are defined as the number of animals that moved between two nodes (directed ties). The resulting graph shows the areas of highest exchange (thicker lines with more connections), and peripheral, more disconnected areas (thinner lines means less connections). If cobia move randomly along the Atlantic coast, we expect the network to be uniform. However, the networks suggest heterogeneous spatial use with some exchange.

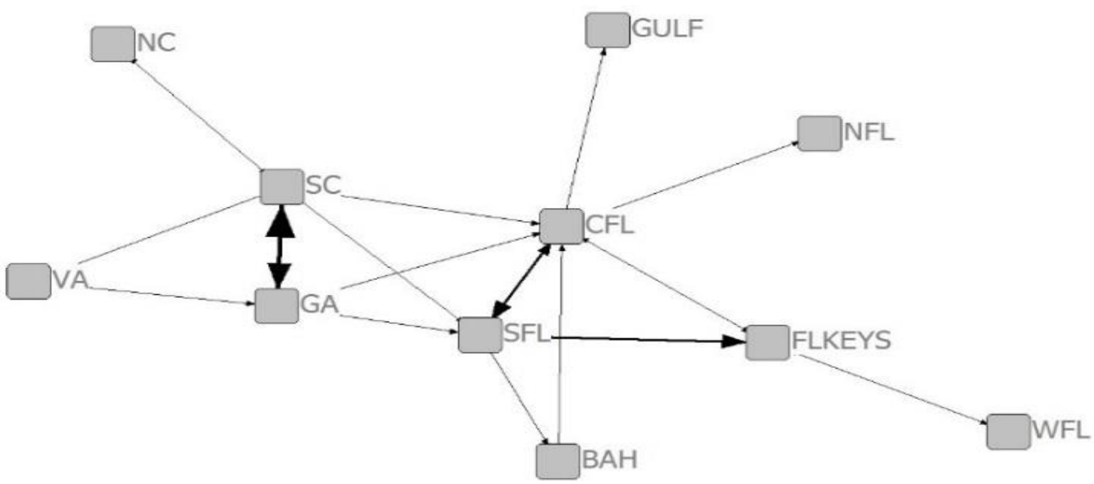

Figure 6. Time inclusive graph of cobia movement.

Three clusters were identified with a Markov clustering with cluster one and two divided at the current migratory stock boundary. Strong clustering groups included: 1) BAH, CFL, FLKEYS, NFL, SFL, and WFL; 2) GA, SC, NC, and VA; and 3) GULF. The Central Florida node (CFL) exhibited the highest betweeness score (48) followed by SC (24), FLKEYS (17), SFL (12), and GA (9), suggesting their importance as areas of connectedness.

In general, cobia moved more freely within subgroups consisting of Georgia/South Carolina and central/south Florida/Florida Keys than between subgroups. Movement between SC and GA, and between FLKEYS, SFL, and CFL, represent 30% and 39% of the movements, respectively (Figure 7).

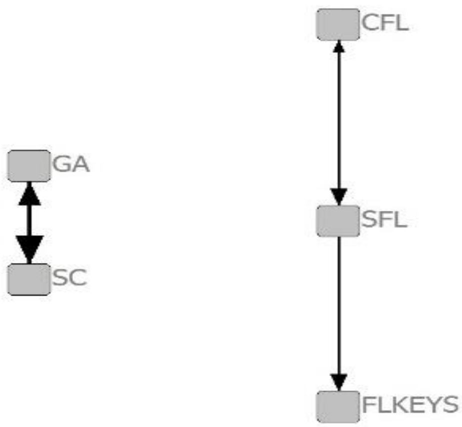

Figure 7. Time inclusive graph of cobia movement where the number of movements are greater than three.

However, movement between regions was not documented for all tagged cobia. For example, 27 fish in SC and 18 fish in SFL were only observed within those regions (Table 3).

Table 3. Number of fish that moved between regions. Reflexive ties indicate the number of individuals that were not detected outside of a single region.

		To										
		BAH	**CFL**	**FLKEYS**	**GA**	**NC**	**NFL**	**SC**	**SFL**	**VA**	**WFL**	**GULF**
From	**BAH**	0	1	0	0	0	0	0	0	0	0	0
	CFL	0	4	2	3	0	4	2	18	0	0	1
	FLKEYS	0	3	1	0	0	0	0	4	0	2	0
	GA	0	1	0	2	0	0	31	1	0	0	0
	NC	0	0	0	0	0	0	1	0	0	0	0
	NFL	0	3	0	0	0	0	0	0	0	0	0
	SC	0	2	0	27	1	0	24	1	2	0	0
	SFL	1	13	16	0	0	0	0	18	0	0	0
	VA	0	0	0	1	0	0	0	0	0	0	0
	WFL	0	0	1	0	0	0	0	0	0	0	0
	GULF	0	0	0	0	0	0	0	0	0	0	0

To date, six cobia tagged in Florida have been detected on receiver stations in Georgia or South Carolina. (Figure 8). All movements across the current management line originated and terminated, in Florida, save for one tag. Two were detected in southern or central Georgia during April and May before returning to Florida waters. The remaining four were detected in both Georgia and South Carolina (n=1) or South Carolina only (n=3) during late September-October. One fish, tag 54488, repeated its migration in Oct 2016 and 2017. There was no overlap between cobia that were detected moving into the Florida Keys and those that were detected moving into Georgia and South Carolina. One additional cobia was detected on receiver stations located in Grand Bahama during December 2016-March 2017.

Three of the six tags were harvested in Florida: 54488 (harvested 12/12/17), 54494 (harvested 5/9/17), and 19048 (harvested 7/1/17).

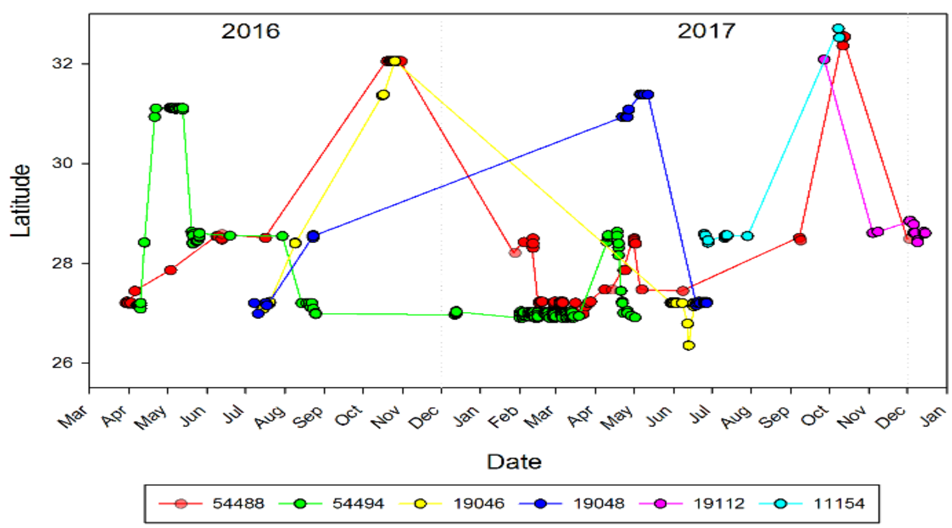

Figure 8. Detections of six tagged cobia that moved across the FL/GA border.

Factors affecting movement – General Linear Models

Detection data were collapsed into one location per station per day, resulting in 4,113 observations total (Gulf=2,617; Atlantic= 1,496). The sum of the AICc values from the best fit models by migratory group were less than the AICc value for the inclusive model for latitude and distance to shore (Table 4). Therefore, the inclusive models were discarded.

Table 4. All candidate model based on GLM with variance components.

Response	Model No.	Predictor variables				AICc
Latitude						
All	1	SST_C	Year	Month		4438.1
	2	SST_C		Month		4439.0
Gulf	1	SST_C	Year	Month	FL	3076.5
	2	SST_C	Year	Month		3078.6
Atlantic	1	SST_C	Year	Month		1112.7
Distance to Shore						
All	1	SST_C	Year	Month		24907.0
Gulf	1	SST_C	Year	Month		14956.3
Atlantic	1	SST_C	Year	Month		9649.1
	2	SST_C		Month		9652.8

Extended exploration of candidate models using GLM revealed that for latitude and distance from shore, the AICc of the alternate candidate models differed by greater than five. Therefore, all alternate candidate models for latitude and distance from shore were discarded and the original candidate model with the lowest AICc score from GLM with Variance Components was retained. GLM revealed varying influences of sea surface temperature, year and month of detection, and fork length on the location of tagged cobia (Table 5). Sea surface temperature and month appeared in the best fit models, demonstrating the importance of these variables in the north-south and east-west movements of cobia.

Table 5. Best fit model based on lowest corrected Akaike information criterion (AICc) values and significance of main effects specified in the GLMM model for daily locations of cobia.

Index	Effects	df	*F*	*P*
Latitude				
Gulf	SST_C	1, 2540	1147.27	<.0001
	Year	3, 2540	15.71	<.0001
	Month	11, 2540	79.72	<.0001
	FL	1, 2540	0.98	.3233
Atlantic	SST_C	1, 1409	48.99	<.0001
	Year	1, 1409	29.60	<.0001
	Month	7, 1409	34.94	<.0001
Distance to Shore				
Gulf	SST_C	1, 2540	36.14	<.0001
	Year	3, 2540	4.48	0.0038
	Month	11, 2540	31.26	<.0001
Atlantic	SST_C	1, 1409	4.62	0.0318
	Year	1, 1409	111.25	<.0001
	Month	7, 1409	13.86	<.0001

Cobia were detected at temperatures ranging from 18.3-32.4 C, with 50% of recorded locations between 25.1 and 28.5 C. Sea surface temperature was a significant predictor of latitude and distance to shore for the Gulf and Atlantic migratory stock groups. In the best fit models, temperature is positively related to distance from shore with a slope of 0.35 (Atlantic group) and

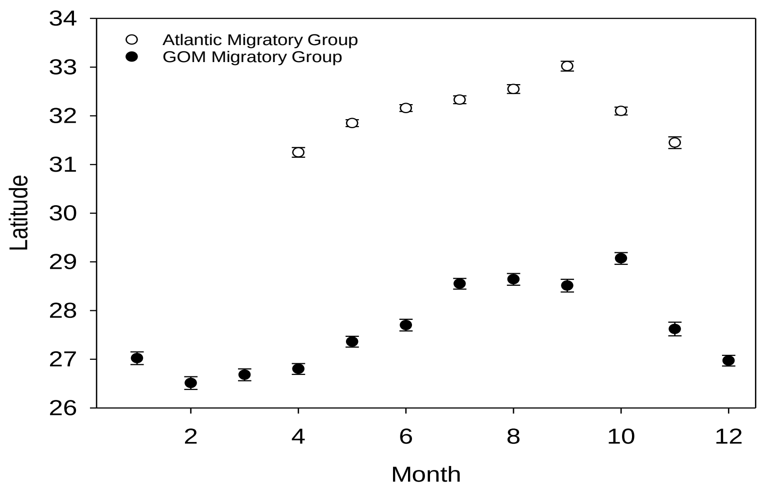

Figure 9. Mean latitude of cobia detections per month. Numbers are presented as the mean response (estimate marginal mean, EMM ± SE) for each month adjusted for all other variables in the model.

.09 (Gulf group) and negatively related with latitude with a slope of -0.08 (Atlantic group) and -0.40 (Gulf group). Thus, cobia were more often detected further from shore and further north at warmer water temperatures.

The temporal effect of month was a significant factor for the prediction of latitude and distance from shore for the Gulf and Atlantic migratory group. Fish are predicted to be significantly further south in February, March, and April, followed by a northward migration, peaking in September before returning south (Figure 9). While the northward trend is evident for both migratory groups, more observations of the Atlantic migratory group fish (i.e., SC and GA) during December-March

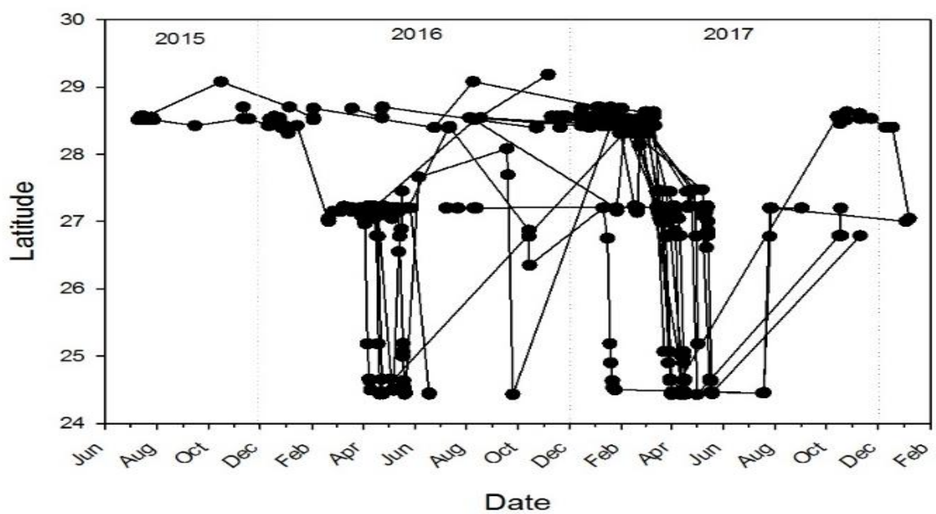

Figure 10. Detections of tagged cobia that migrated south to the Florida Keys (n=20).

are needed to fully understand the extent of the north-south movement. In addition, the southern-most detections from the Gulf Migratory Group peak in early spring, and are absent in the summer, suggesting the tagged fish migrate north from the keys to the GOM or Atlantic coast (Figure 10). During 2016-2017, 20 cobia were detected on receiver stations in the Florida Keys, with 17 of these initial Keys detections occurring during March-May (Figure 4). All but one were detected in either central Florida, south Florida, or both immediately prior to detection in the Florida Keys. These detections indicated a directional migration of a subset of tagged fish from central and south Florida that occurred during spring. Additionally, three cobia, all tagged in Florida, have been detected in the Gulf of Mexico to date.

Tagged fish in the Gulf migratory group were detected closer to shore from March to August, moving further offshore in the fall and winter (Figure 11). The predicted trend in the Atlantic migratory group is less clear; lacking a clear inshore/offshore migration pattern for the entire population. Migratory subgroups, such as inshore and offshore spawners, within the Atlantic stock may exist and need to be further explored.

While year was a significant variable for the prediction of latitude and distance from shore, the result may be an artifact of tagging effort. In 2014 and 2015, only six tags were deployed, all south of the Florida/Georgia border. In addition, the difference between years is minor.

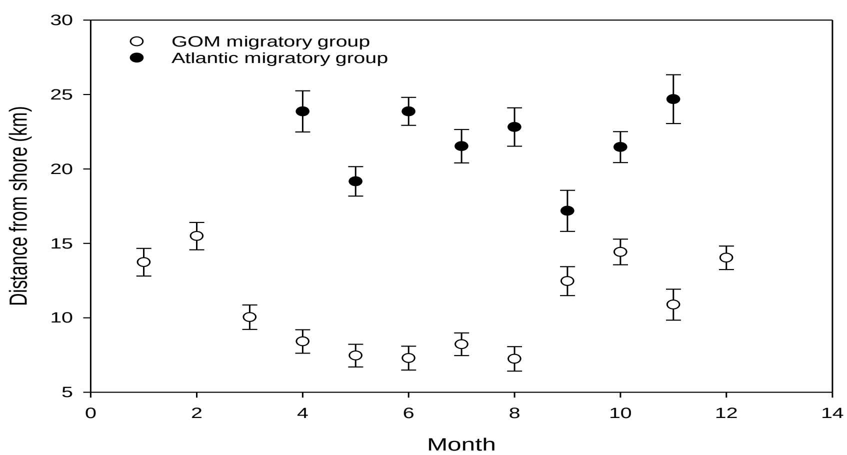

Figure 11. Mean distance from shore of cobia detections per month. Numbers are presented as the mean response (estimate marginal mean, EMM ± SE) for each month adjusted for all other variables in the model.

SUMMARY

This project was conceived largely to answer questions about the biological mixing zone between South Atlantic and Gulf of Mexico migratory groups as well as collect data on cobia stock structure and behavior as a whole. Overall, our results indicate **a break between South Atlantic and Florida east coast migratory groups that occurs somewhere between north of Cape Canaveral and Georgia,** which is consistent with the results of genetic and traditional external tagging analyses submitted for the SEDAR 58 stock ID workshop.

Major Points

- Cobia tagged in Georgia and South Carolina were not detected across the current management boundary at the Florida/Georgia line.

There is currently very little receiver coverage along the northeast coast of Florida and it's possible that cobia tagged in Georgia and South Carolina moved into that region without detection. However, receiver coverage along central and south Florida is substantial and it is unlikely that fish could utilize this area and avoid detection.

- A small proportion of cobia tagged in Florida were detected in Georgia and South Carolina (6/74, 8.1%).

Most of these movements (n=4) occurring during fall and for brief periods of time. Despite multiple efforts to tag cobia in northeast Florida and southern Georgia, data from this area are still largely unavailable.

- Additional efforts to tag cobia and build receiver infrastructure within Northern Florida, as well as planned tagging efforts in North Carolina and Virginia should provide additional information about regional stock structure.

APPENDIX

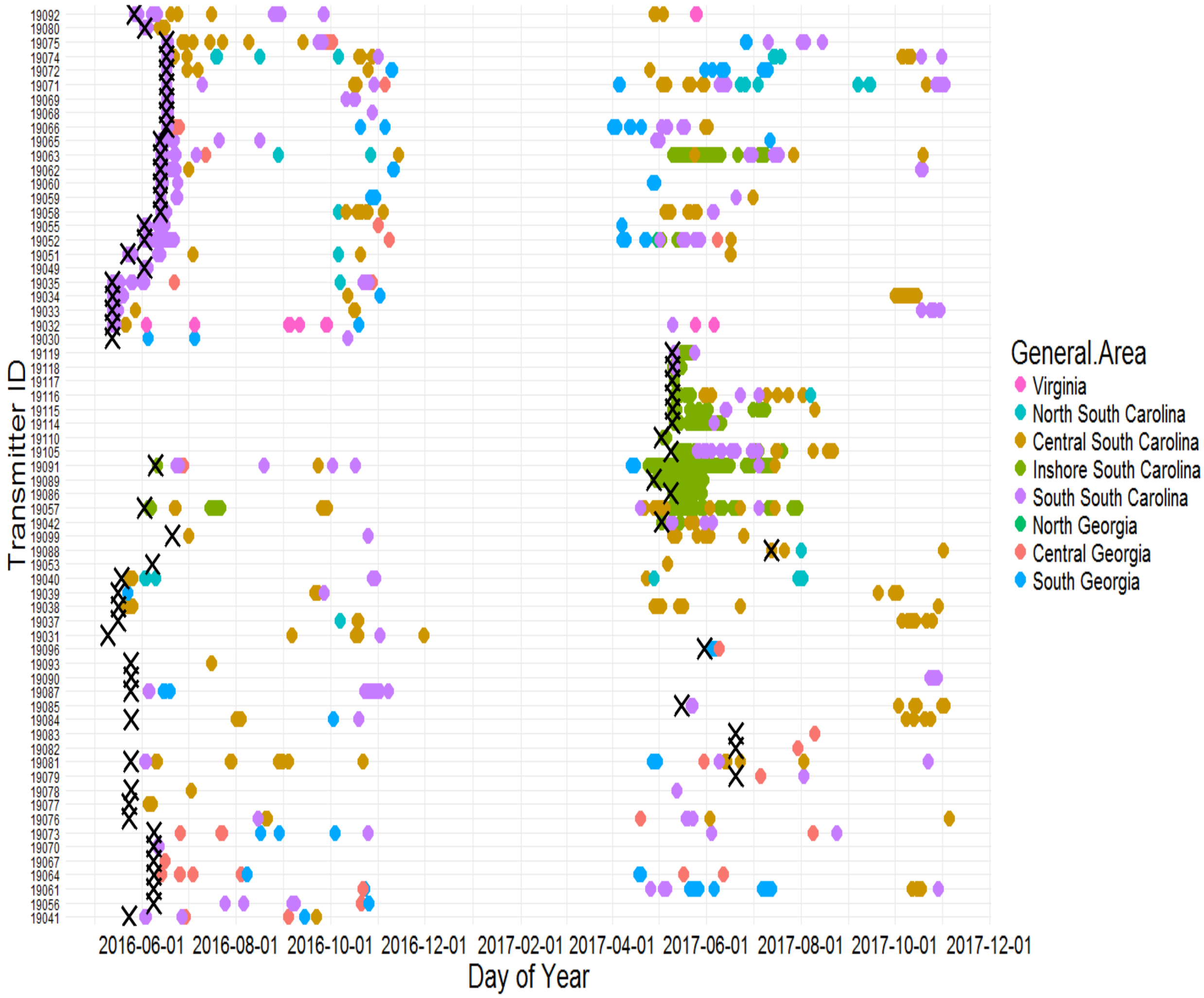

Figure 12. Abacus plot of cobia tagged in South Carolina and Georgia, indicating detection of individuals by general geographic area over time. The "X" indicates tagging date.

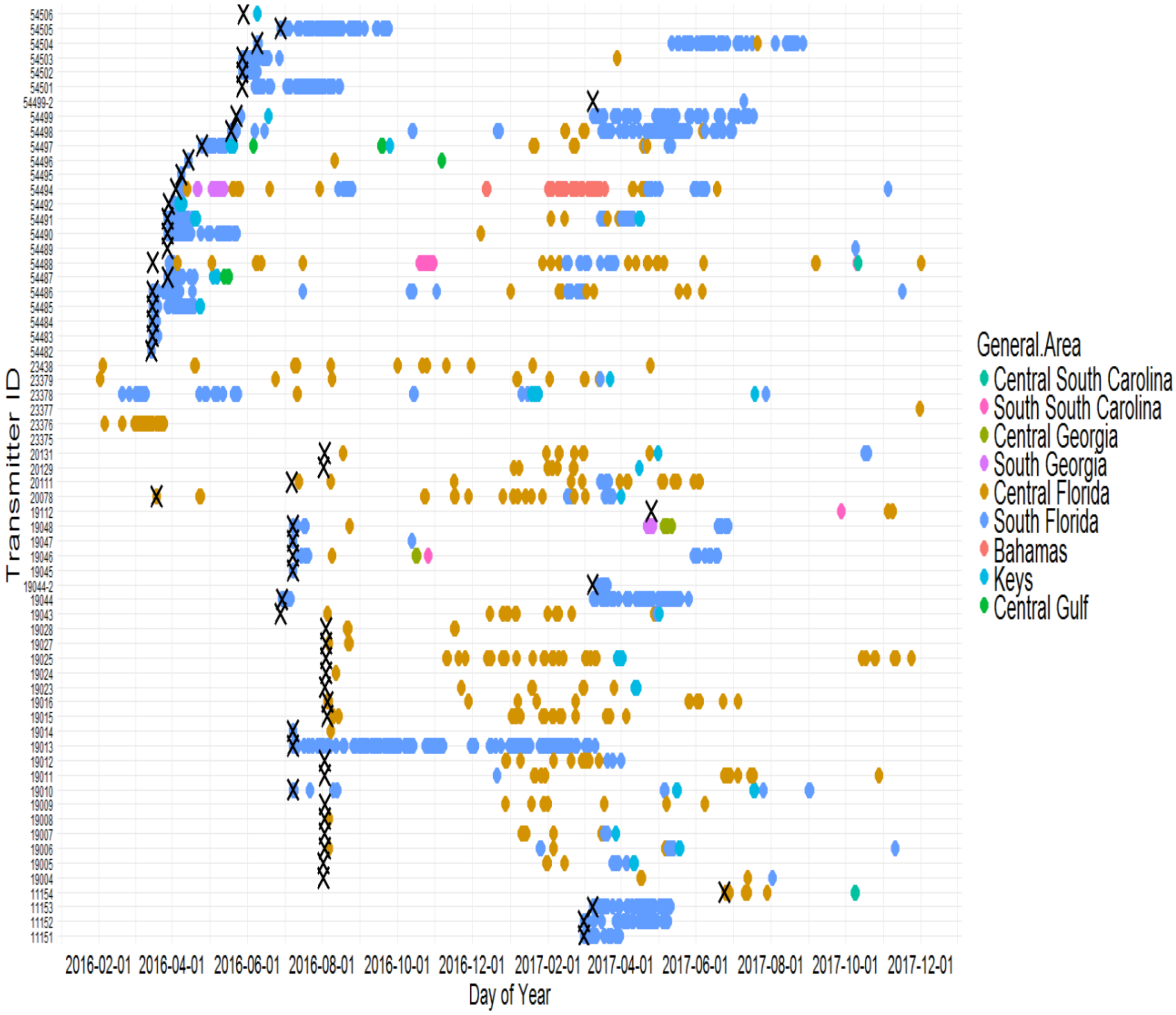

Figure 13. . Abacus plot of cobia tagged in Florida, indicating detection of individuals by general geographic area over time. The "X" indicates tagging date. The X axis (time) has been truncated to begin at the time period when the majority of tagging occurred.