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Evaluation of cobia movements using tag-recapture data from the Gulf of Mexico and South Atlantic coast of the United States

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Introduction

This paper serves as an update to SEDAR 28 DW5, “Evaluation of cobia movements and distribution using tagging data from the Gulf of Mexico and South Atlantic coast of the United States”, and incorporates new tagging data sources and updated tag data from existing sources through the end of 2017. Tag data was incorporated from eight individual programs with recapture data for cobia in the southeastern United States: the Virginia Game Fish Tagging Program (VGFTP, <http://www.vims.edu/vgftp/>), North Carolina Division of Marine Fisheries Tagging Program (NCDMF, <http://portal.ncdenr.org/web/mf/tagged-fish>), South Carolina Marine Game Fish Tagging Program (SCDNR; Wiggers, 2010, <http://dnr.sc.gov/marine/tagfish/tagfish.html>), Hilton Head Reef Foundation (HHRF), Southeast Fisheries Science Center Cooperative Tagging Center (NOAA), Gray Fishtag Research (GFT, <http://grayfishtagresearch.org/>), Mote Marine Laboratory Tagging Program (MOTE; Burns and Neidig, 1992), and the Gulf Coast Research Laboratory Sport Fish Tagging Program (GCRL, Hendon and Franks, 2010). Each of these programs utilized volunteer anglers who were trained on the proper methods of handling, tagging, and releasing cobia along with collecting data associated with each fish. Programs utilized both nylon and stainless steel barbed dart tags with a plastic streamer indicating contact information in the event of a recapture. Compensation for anglers reporting tag recaptures ranged from t-shirts to monetary rewards.

Methods

In total, over 25,000 cobia have been tagged collectively by these programs, with over 2,000 recaptures (Table 1).

Table 1. Total number of cobia tagged, recaptures, and recapture percentage of the included data sources.

Data Source	Total Tagged	Total Recaptured	Recapture %	Years Covered
VGFTP	3,899	433	11.1	1995-2017
NCDMF	73	5	6.8	2017
SCDNR	1,170	214	18.3	1990-2014
HHRF	95	14	14.7	2007-2012
SEFSC	1,557	159	10.2	1986-2014

MOTE	920	100	10.9	1991-2001
GFT	24	2	8.3	2015-2017
GCRL	18,129	1,197	6.6	1988-2017
TOTAL	25,867	2,124	8.2	1986-2017

The majority of tag recaptures occurred from 1986-1999 (n=1,048) while 544 have occurred during the last 10 years. While there are minor differences, methodologies between the various programs are similar. Because we are interested in describing migratory trends over a large geographic area based on positive recapture data (as opposed to determining tag retention, fishing mortality, etc.) data sources have been deemed comparable enough to pool into a comprehensive dataset. Analysis will focus on fish that were tagged and subsequently recaptured. When reporting captures, anglers often use generalizations instead of exact GPS coordinate locations, and in some cases only report the nearest city to the capture location. In these cases, coordinates have been assigned using the best available information. Coordinates were assigned to all tag interactions which originated in the Florida Keys and along the Atlantic Coast. Exact coordinates were not estimated for fish which were tagged and subsequently recaptured in the Gulf of Mexico as these movements were not the primary goal of this analysis. To reduce the potential for location bias, only recaptures of cobia which were at large for greater than thirty days were included in our analysis. Where tagging programs recorded total length, rather than fork length of fish tagged, the formula $FL=13.52399+0.878671*TL$ (SEDAR 28) was used to transform data. Of note, length data are primarily provided by cooperating anglers and are a combination of estimated and measured lengths. Recaptures where tag or recapture location as well as tag or capture date are unavailable were removed from analysis.

Tagging areas and recapture areas were partitioned into ten different zones for the purpose of data analysis (Figure 1). The east coast of the United States north of Florida was segmented into five zones: the areas within and extending offshore north of Virginia, Virginia, North Carolina, South Carolina, and Georgia. Tagging and recapture events that occurred within the Chesapeake Bay were assigned to Virginia. Because preliminary genetic results suggested a break along the east coast of Florida, the area was segmented into three zones: north of Brevard (N-BR), encompassing the area from the Florida/Georgia line south to the Volusia/Brevard County border; Brevard County (BR) including Cape Canaveral; and south of Brevard (S-BR), encompassing the area from the Brevard/Indian River County border to Biscayne Bay. County lines were chosen because of their congruency with recreational and commercial catch data used in the stock assessment process. To the South, the Florida Keys zone covered the area from Biscayne Bay around to Marco Island in Southwest Florida. Although cobia both tagged and recaptured within the Gulf of Mexico constituted a majority of the data available, the main goal of this paper is to evaluate the potential stock boundary between Gulf and Atlantic migratory groups. To simplify this analysis, Gulf of Mexico locations have been grouped together into a single Gulf of Mexico zone (Marco Island, FL to the Texas/Mexico border) for the majority of analysis and movements from specific locations can be found in appendix A.



Figure 1. Tagging and recapture zones of cobia in the southeastern United States designated for the purpose of partitioning and analyzing tag-recapture data. Zones include both inshore and ocean waters.

Results

After removing recaptures that were missing location or date information ($n=114$) as well as those that occurred less than 30 days after tagging ($n=264$), the combined dataset consisted of 1,745 recaptures. Mean fork length at tagging was largest in Virginia, South Carolina, and North Carolina (Table 2) and shorter along the coast of Florida and Gulf of Mexico. Overall, mean fork length at tagging was 786 mm, indicating that most tagging efforts were focused on sublegal cobia as the legal minimum size was 838 mm until September 2017 in federal waters (2016 in North Carolina and Virginia state waters). Mean fork length at recapture (Table 3) was largest from cobia recaptured in North Carolina, South Carolina, and Virginia, but didn't vary greatly from zone to zone. Mean days at large ranged from roughly 1-2 years, depending on tagging zone (note that recaptures that occurred within 30 days of tagging were excluded from analysis).

Table 2. Cobia fork length (FL) at tagging by tagging zone. Georgia ($n=1$) and north of Brevard ($n=2$) were excluded due to small sample sizes.

Tag Zone	Tagging FL (mm)
Virginia	853±9
North Carolina	803±19
South Carolina	825±10
Brevard	774±15
South of Brevard	740±30
Keys	750±6
Gulf of Mexico	764±25
Total	786±19

Table 3. *Cobia* fork length (FL) at recapture by recapture zone.

Recapture Zone	Recapture FL (mm)
Virginia	964±10
North Carolina	1008±29
South Carolina	985±13
North of Brevard	957±19
Brevard	921±21
South of Brevard	972±20
Keys	903±8
Gulf of Mexico	935±6

Table 4. Days at large for *cofia* by tagging zone.

Tag Zone	Mean Days at Large
Virginia	539±25
North Carolina	766±190
South Carolina	496±33
Brevard	400±38
South of Brevard	430±86
Keys	362±22
Gulf of Mexico	449±13
Total	464±10

Recapture data for fish tagged in each zone are described below, followed by an overall synopsis.

Virginia

Tagging efforts in Virginia are largely focused on the Chesapeake Bay fishery and account for a majority of recent *cofia* tagging data on the East Coast, with 233 recaptures in the last 10 years. The majority of recaptures came from fish tagged in June (n=117), July (n=120), and August (n=84) (Figure 2).

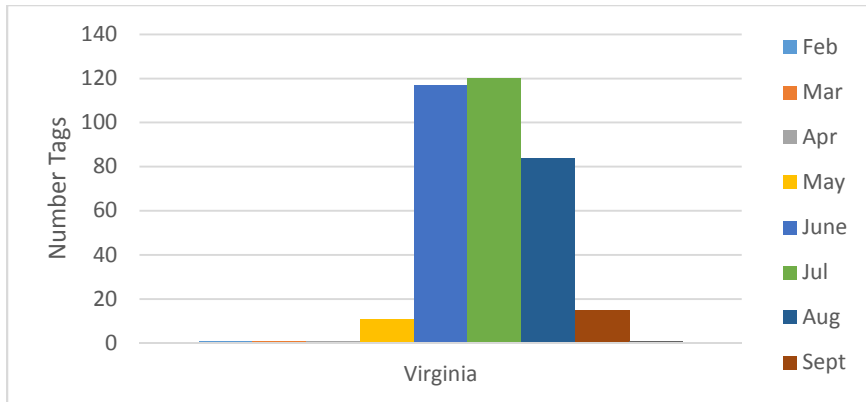


Figure 2. Month of tagging of cobia recaptured from Virginia.

The majority of fish tagged in the Virginia zone were also recaptured in this region, almost exclusively occurring within Chesapeake Bay (83.5%, Figure 3, Table 5). There was also considerable exchange with the Outer Banks-Morehead City area, where all but one of the Virginia fish recaptured in North Carolina occurred. Fish tagged in the Chesapeake Bay, primarily during July-September were recaptured in North Carolina during April-July (n=35) or October-December (n=8), potentially indicating an Outer Banks fishery that targets fish migrating to or from Virginia. The small subset of fish that were recaptured off the north and central coast of Florida were all tagged between June-September and mostly recaptured during March-May (6/8, 75.0%). Additionally, three cobia tagged in Virginia were recaptured in the northern Gulf of Mexico after 1,367, 1,003, and 619 days at large (these data include recaptures from the VGFTP and NOAA datasets). Overall, 11/351 recaptures (3.1%) were recaptured across the current management boundary at the Florida/Georgia line.

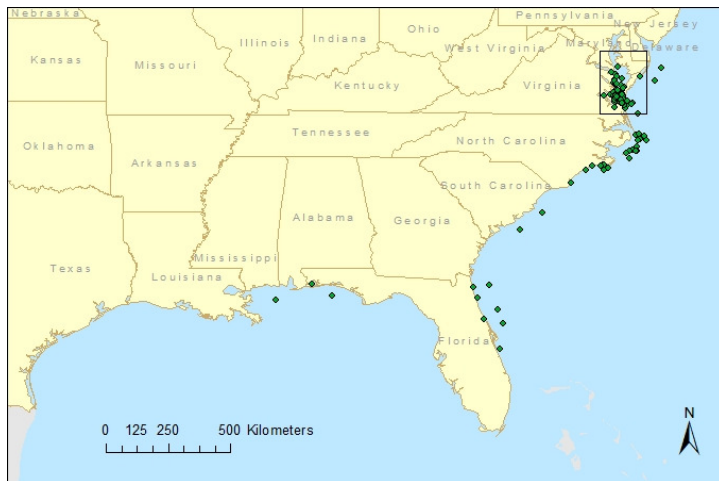


Figure 3. Recaptures of cobia tagged in Virginia, including all waters of the Chesapeake Bay. Rectangle indicates the general tagging area.

Table 4. Recapture location of cobia tagged in Virginia.

Recapture Zone	Number Recaptured	Percentage of Recaptures
North of Virginia	2	0.6

Virginia	293	83.5
North Carolina	42	12.0
South Carolina	2	0.6
Georgia	1	0.3
North of Brevard	7	2.0
Brevard	1	0.3
Gulf of Mexico	3	0.9
Total	351	

North Carolina

The North Carolina Division of Marine Fisheries began a recreational tagging program during 2017 with cobia tagged by both volunteer anglers and project staff. Those tagged fish have been at large for less than a year. The majority of the 21 recaptures in this data set came from VGFTP (n=6) and GCRL (n=9). All recaptured cobia were initially tagged in the Outer Banks from Hatteras Island northward and the majority were tagged in May (n=9) or September (n=5).

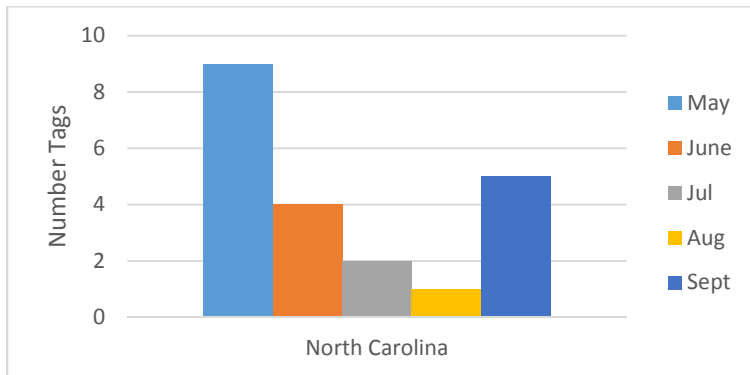


Figure 4. Month of tagging of cobia recaptured from North Carolina.

The overwhelming movement trend of cobia tagged in North Carolina was a directional movement north into the Chesapeake Bay (85.7%, Table 6). Fish were primarily tagged in May-June and were all recaptured in the Chesapeake during June-September. Additionally, three of the five cobia recaptures excluded from analysis (because of time at liberty of less than thirty days) occurred in the Chesapeake Bay. These movements further indicate an Outer Banks, NC fishery that may primarily target fish migrating into the Chesapeake Bay. To date, no cobia tagged in North Carolina have been recaptured south of Georgia.

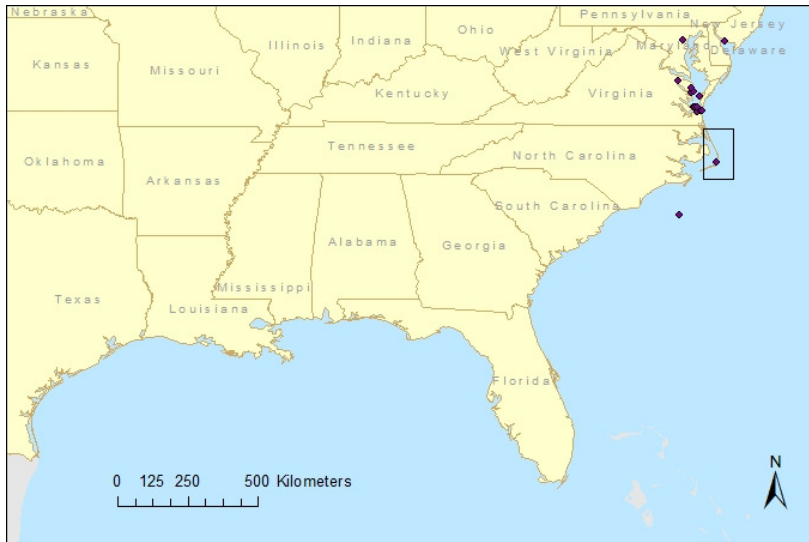


Figure 5. Recaptures of cobia tagged in North Carolina. Rectangle indicates the general tagging area.

Table 5. Recapture location of cobia tagged in North Carolina.

Recapture Zone	Number Recaptured	Percentage of Recaptures
North of Virginia	1	4.8
Virginia	18	85.7
North Carolina	1	4.8
South Carolina	1	4.8
Total	21	

South Carolina

The majority of recaptures from cobia tagged in South Carolina were originally tagged in Port Royal Sound (113 of 128, 88.3%), a high salinity estuary in the southern part of the state that supports a distinct population segment of cobia that return to the estuary to spawn each year (Lefebvre and Denson, 2012; Darden et. al, 2014). The remaining 15 were tagged on artificial and natural reefs off the coasts of Port Royal Sound, Charleston, and Myrtle Beach. Recaptured cobia were primarily tagged during May and June (Figure 6).

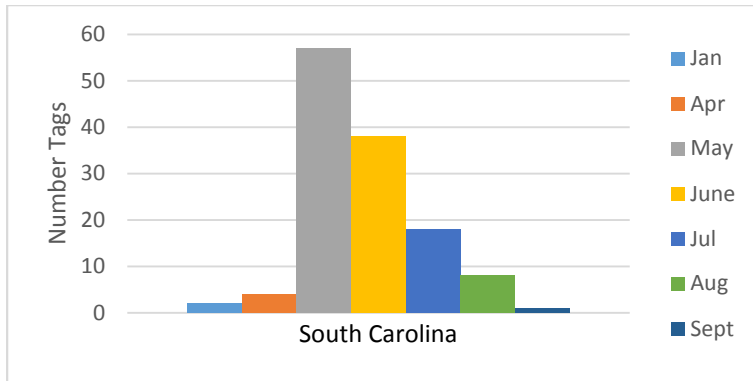


Figure 6. Month of tagging of fish recaptured from South Carolina.

The majority of fish tagged in South Carolina were also recaptured in South Carolina (87.5%, Figure 6) and 92.0% of those recaptures occurred within the Port Royal Sound estuary (Table 7). The next largest area of exchange was central and north Florida, where 11 cobia were recaptured, mostly during March-April (n=6) or November-December (n=3). Additionally, two fish were recaptured “off the Florida Coast” although more detailed information is not available and they aren’t included in Figure 7 below. Overall, 14/128 (10.9%) of cobia tagged in South Carolina were recaptured south of Georgia with 1/128 (0.8%) recaptured beyond Cape Canaveral.

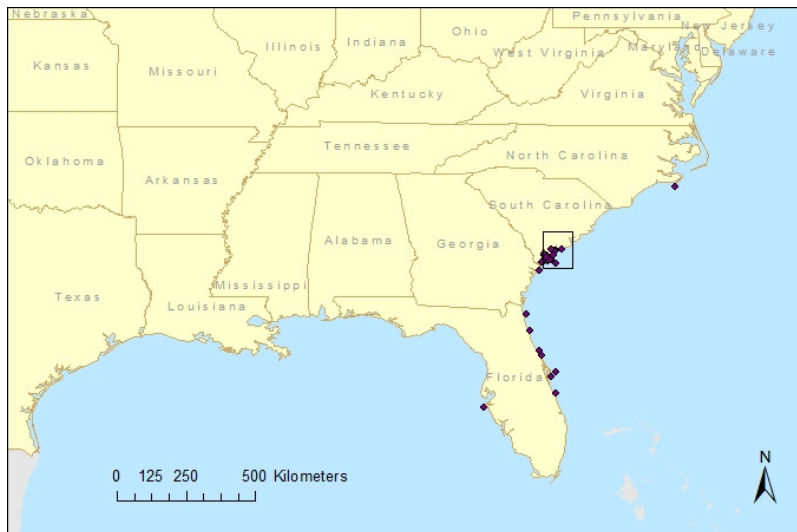


Figure 7. Recaptures of cobia tagged in South Carolina. Rectangle indicates the general tagging area.

Table 6. Recapture location of cobia tagged in South Carolina.

Recapture Zone	Number Recaptured	Percentage of Recaptures
North Carolina	1	0.8
South Carolina	112	87.5
North of Brevard	4	3.1
Georgia	1	0.8

Brevard	7	5.5
Florida (unspecified)	2	1.6
Gulf of Mexico	1	0.8
Total	128	

Georgia and North of Brevard, FL (N-BR)

Cobia tagged in Georgia and the N-BR zones only resulted in two and one recaptures, respectively. Both recaptures of a Georgia-tagged fish occurred in North Carolina after four and seven years at large. The recapture of the cobia from the N-BR zone occurred in South Carolina three years after tagging.

Brevard, FL (BR)

The majority of recaptures occurred from fish tagged in March (n=35) and April (n=21).

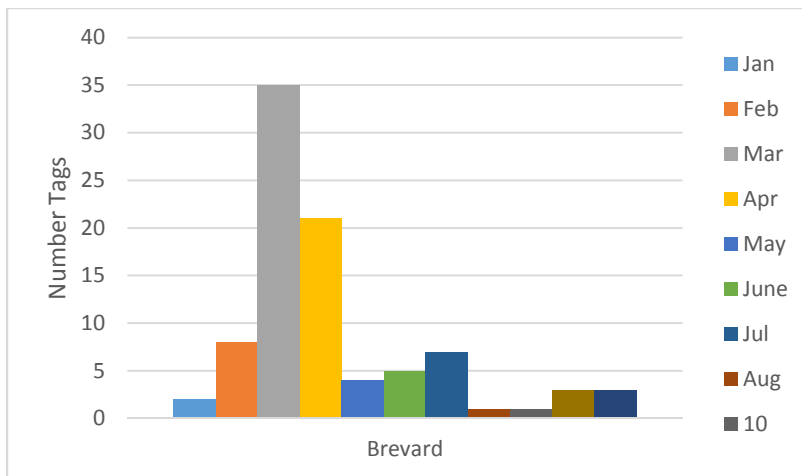


Figure 8. Month of tagging of cobia recaptured from Brevard zone.

Cobia tagged in Brevard County, Florida were recaptured over a very wide geographic area, from Texas to New Jersey, and recaptures were reported in every zone (Figure 9, Table 8). Unlike other locations, where the majority of cobia were recaptured in the same zone where tagging occurred, only 36.7% of Brevard cobia were also recaptured in the Brevard zone. The next largest group of exchange was the Gulf of Mexico, where 22.2% of recaptures occurred with a peak during April-June (n=15, 75%). Thirteen cobia tagged in Brevard were recaptured north of the current management boundary (14.4%) with all recaptures occurring during May-September.



Figure 9. Recaptures of cobia tagged in Brevard County, FL. Rectangle indicates general tagging location.

Table 7. Recapture location of cobia tagged in Brevard County, FL.

Recapture Zone	Number Recaptured	Percentage of Recaptures
North of Virginia	1	1.1
Virginia	5	5.6
North Carolina	4	4.4
South Carolina	1	1.1
Georgia	2	2.2
North of Brevard	10	11.1
Brevard	33	36.7
South of Brevard	9	10.0
Keys	5	5.6
Gulf of Mexico	20	22.2
Total	90	

South of Brevard (S-BR)

Only 7 recaptures have occurred from cobia tagged in the S-BR zone. Three were recaptured in the same zone, two were recaptured in the Florida Keys, and two were recaptured in the Gulf of Mexico (Figure 10). No cobia tagged in the South of Brevard zone were recaptured north of Florida on the Atlantic coast.

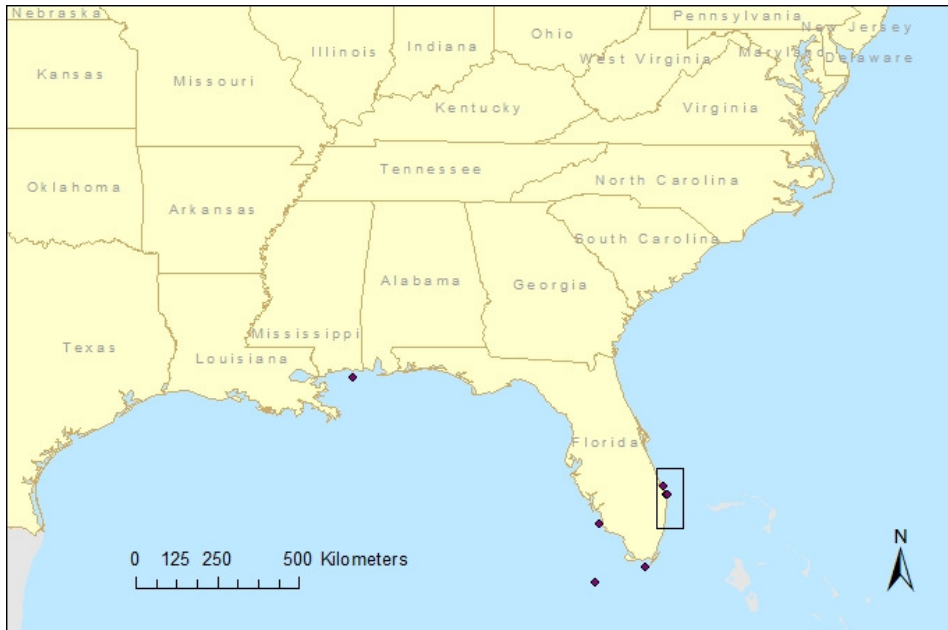


Figure 10. Recaptures of cobia tagged in the south of Brevard zone. Rectangle indicates the general tagging area.

Table 8. Recapture location of cobia tagged south of Brevard County, FL.

Recapture Location	Number Recaptured	Percentage of Recaptures
South of Brevard	3	42.9
Keys	2	28.6
Gulf of Mexico	2	28.6
Total	7	

Florida Keys

The Florida Keys served as the management boundary between Gulf of Mexico and Atlantic Migratory Groups until amendment 20B to the Coastal Migratory Pelagics Fishery Management Plan took effect in 2015, moving the boundary to the Florida/Georgia line. Recaptures occurred from fish tagged in every month of the year, with the majority in February (n=35), March (n=29), and December (n=32).

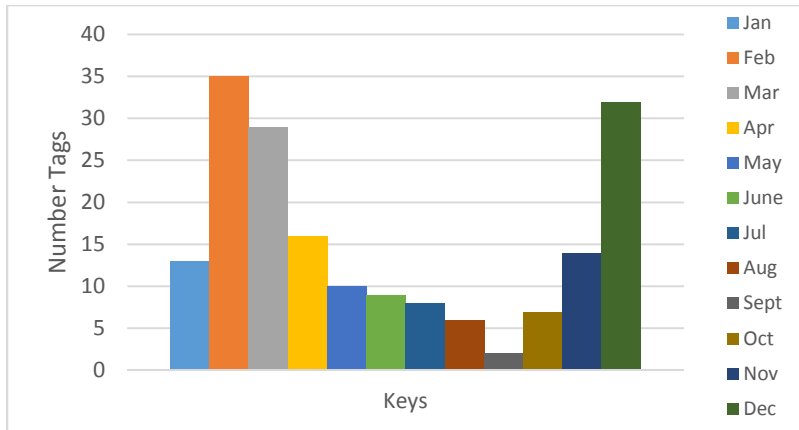


Figure 11. Month of tagging of cobia recaptured from the Florida Keys.

The majority of cobia tagged in the Keys zone were recaptured in the Keys (57.5%, Figure 11, Table 10). The next greatest area of exchange was the Gulf of Mexico, where 37% of recaptures occurred. Almost 2/3 (n=42, 63.6%) of these recaptures occurred during April and May, indicating a pattern of fish tagged in the Keys zone in winter migrating into the northern Gulf of Mexico during spring. A small portion of fish tagged in the Keys zone were caught along the east coast of Florida (n=10, 5.5%) and no fish were recaptured north of Cape Canaveral.



Figure 12. Recaptures of cobia tagged in the Florida Keys. Rectangle indicates the general tagging area.

Table 9. Recapture location of cobia tagged in the Florida Keys.

Recapture Location	Number Recaptured	Percentage of Recaptures
Brevard	2	1.1
South of Brevard	8	4.4
Keys	104	57.5
Gulf of Mexico	67	37.0
Total	181	

Gulf of Mexico (combined)

Of the cobia that were recaptured, Gulf of Mexico tagging peaked in April (n=341, 35.2%), followed by May, August, and July (Figure 12). The most recaptures came from fish tagged in the Florida Panhandle (n=366, 37.7%) and April was the time of peak tagging in that zone.

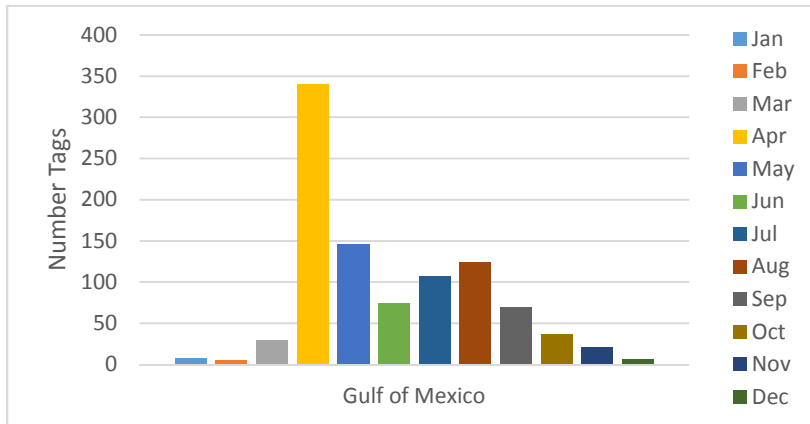


Figure 13. Month of tagging of fish recaptured from the Gulf of Mexico.

Cobia tagged in the Gulf of Mexico account for the largest number of recaptures of any zone (970/1,746, 65.7%). Overall, most of the cobia tagged in the combined Gulf of Mexico zone were recaptured within the Gulf of Mexico (84.6%, Table 11). The next largest area of exchange was with the Florida Keys, where 9.3% (n=90) of recaptures occurred. The east coast of Florida (north of Brevard, Brevard, and South of Brevard combined) accounted for 54 recaptures (5.6%). Four cobia tagged in the Gulf of Mexico were recaptured north of the Georgia/Florida line (0.4%). Intra-zone movements of cobia within the Gulf of Mexico were largely beyond the scope of this analysis. However, detailed recapture tables for individual zones in the Gulf of Mexico can be found in appendix A.

Table 10. Recapture locations of cobia tagged in the Gulf of Mexico.

Recapture Location	Number Recaptured	Percentage of Recaptures
North Carolina	1	0.1
South Carolina	2	0.2
Georgia	1	0.1
North of Brevard	9	0.9
Brevard	15	1.5
South of Brevard	29	3.0
Keys	90	9.3
Gulf of Mexico	822	84.6
Total	970	

Network Analysis

An additional network analysis was performed on all conventional tagging data during the stock ID workshop to further illustrate the connectivity between tag and recapture zones and visualize fish movements collectively. Figure 14 below depicts all movements of cobia between regions, with thicker lines indicating a greater level of movement and arrows indicating the direction of travel. It is important to note that the analysis can be influenced by the overall number of fish tagged and recaptured within any given zone as well as fishing pressure, which is not constant throughout the entire area. However, the plots generated by this analysis provide a way to visualize the connectivity of zones. Figure 15 uses similar methods, but only uses the top 89% of movement (the analysis looks for natural breaks in the data) to exclude outliers in movement and visualize the core behaviors seen in the tagging data. Because only movements between zones are depicted, zones without a large degree of movement into other areas (i.e., South Carolina) are not seen. Abbreviations are as follows: Brevard-CFL; Georgia-GA; Keys-FLKEYS; North Carolina-NC; North of Brevard-NFL; North of Virginia-NofVA; South Carolina-SC; South of Brevard-SFL; Virginia-VA; Gulf of Mexico-GLF.

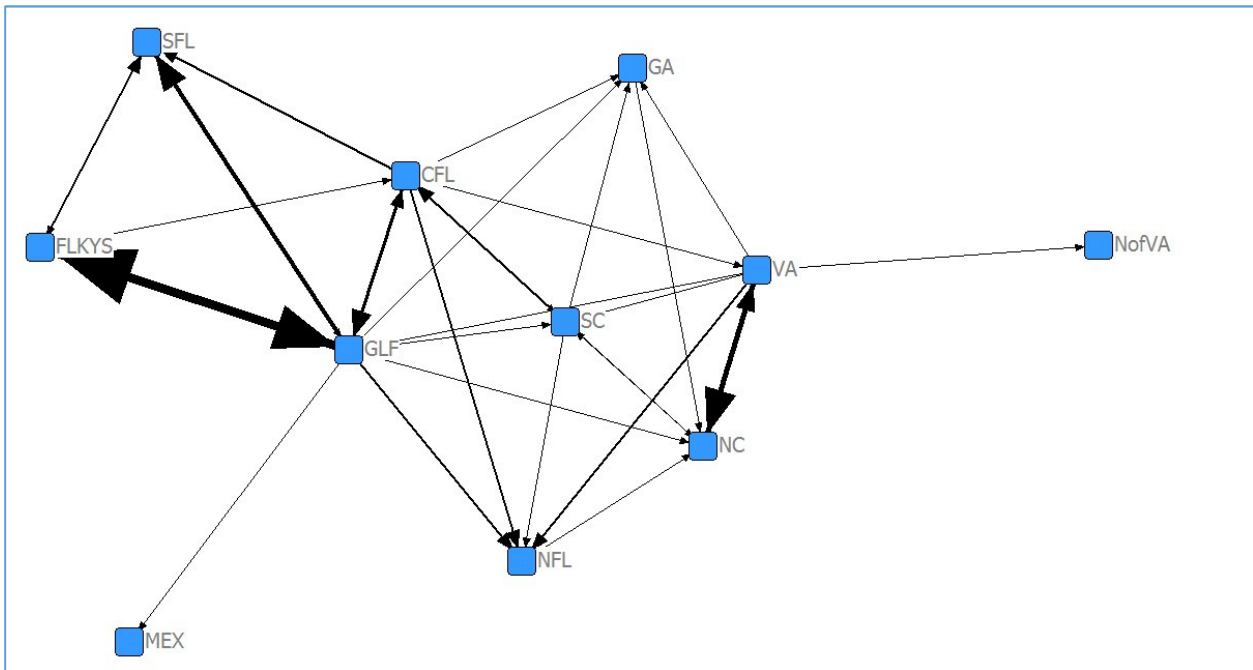


Figure 144. Visualization of one mode matrix showing connectivity between zones.

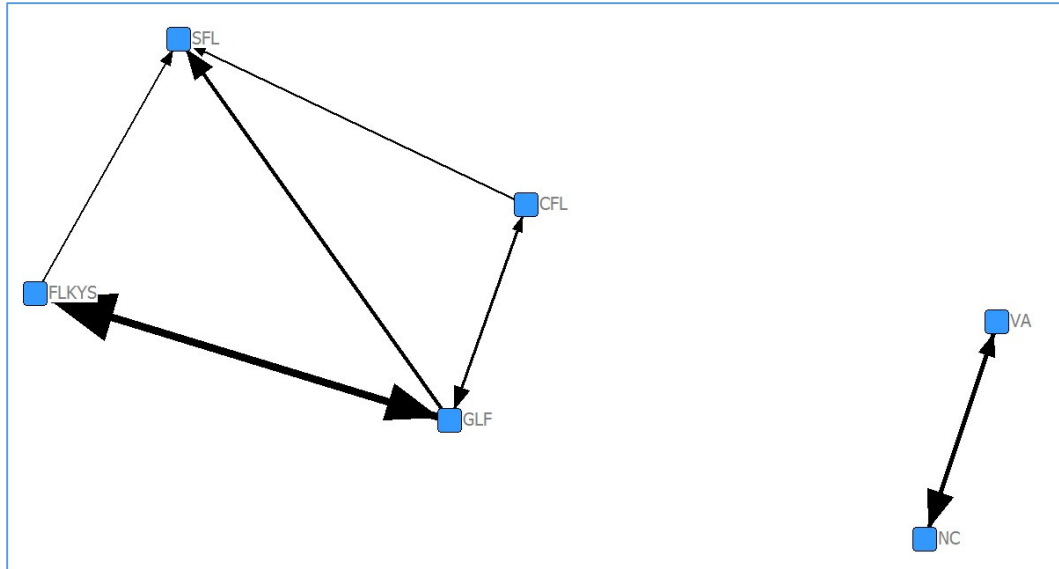


Figure 155. Visualization of one mode matrix showing top 89% of movements between zones.

Summary

While amendment 18 to the Coastal Migratory Pelagics Fishery Management Plan established the boundary between Gulf and Atlantic migratory groups in the Florida Keys, the available tag data does not support a biological boundary between stocks in this zone. Of 182 recaptures of cobia tagged in the Florida Keys, none were recaptured north of Cape Canaveral on the East Coast, suggesting that the Florida Keys does not serve as an overwintering ground for cobia that migrate into South Carolina, North Carolina, Virginia, and north as was previously hypothesized. The Florida Keys zone, however, may serve as an overwintering ground for cobia that migrate into the northern Gulf of Mexico during spring. Additionally, the recapture data suggests that some portion of the cobia population may be year round residents of this area. The biological mixing zone between the Gulf of Mexico and Atlantic populations likely occurs somewhere from Cape Canaveral, FL through northern Florida and Georgia, where little data is available. Cobia tagged in the Canaveral area moved both north and south, with a stronger trend of recaptures in south Florida, the Florida Keys, and the Gulf of Mexico. In the areas north of Florida, tagging data suggest South Carolina and Virginia cobia may have very little exchange with each other, whereas there appears to be significant movement between the North Carolina Outer Banks and Virginia. In Virginia and South Carolina, the majority of cobia (83.5% and 86.7% respectively) were recaptured back in the same estuary where tagging initially occurred, both indicating site fidelity and suggesting that overwintering locations for each group may largely occur in areas that have not been subjected to heavy fishing pressure during the winter months. There are instances presented here where cobia tagged in the Gulf of Mexico are recaptured in the Atlantic, north of Florida (n=4, 0.4%) or cobia tagged north of Florida are recaptured in the Gulf of Mexico (n=4, 0.8%). However, these data represent a very small percentage of recaptures and are not representative of the two populations. Overall, the data indicates a mixing zone of the Atlantic and the Gulf of Mexico populations that occurs somewhere from Cape Canaveral through Georgia.

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Appendix A

The tables below detail the movement of fish from individual zones in the Gulf of Mexico. Louisiana east of the Mississippi River, Mississippi, and Alabama have been combined into a single zone to simplify analysis.

Table 11. Recapture location of cobia tagged in Texas.

Recapture Location	Number Recaptured	Percentage of Recaptures
Texas	8	72.7
West LA	2	18.2
Yucatan	1	0.9
Total	11	

Table 12. Recapture location of cobia tagged in west Louisiana, west of the Mississippi River.

Recapture Location	Number Recaptured	Percentage of Recaptures
West LA	43	63.2
Central Gulf	7	10.3
Texas	6	8.8
Panhandle	5	7.4
Keys	3	4.4
South of Brevard	2	2.9
West Florida	1	1.5
North of Brevard	1	1.5
Total	68	

Table 13. Recapture location of cobia tagged in the central Gulf (east Louisiana, Mississippi, and Alabama combined)

Recapture Location	Number Recaptured	Percentage of Recaptures
Central Gulf	219	53.5
Panhandle	59	14.4
West LA	50	11.9
Keys	41	10.0
West Florida	12	2.9
South of Brevard	9	2.2
Texas	8	2.0
Brevard	4	1.0
North of Brevard	4	1.0
Georgia	1	0.2
South Carolina	1	0.2
North Carolina	1	0.2
Total	409	

Table 14. Recapture location of cobia tagged in the Panhandle of Florida.

Recapture Location	Number Recaptured	Percentage of Recaptures
Panhandle	114	31.2
Central Gulf	75	20.5
West LA	68	18.6
Keys	33	9.0
West Florida	22	6.0
Texas	19	5.2
South of Brevard	18	4.9
Brevard	11	3.0
North of Brevard	4	1.1
South Carolina	1	0.3
Total	365	

Table 15. Recapture location of cobia tagged on the west coast of Florida.

Recapture Location	Number Recaptured	Percentage of Recaptures
West Florida	86	74.1
Keys	13	11.2
Panhandle	13	11.2
West LA	3	2.6
Central Gulf	1	0.9
Total	116	

Table 17. One mode matrix of fish that moved between zones.

	CFL	FLKYS	GA	GLF	NC	NFL	SC	SFL	VA	NofVA	MEX
CFL	33	5	2	20	4	10	1	9	6	0	0
FLKYS	2	104	0	66	0	0	0	8	0	0	0
GA	0	0	0	0	2	0	0	0	0	0	0
GLF	15	90	1	820	1	9	2	29	0	0	2
NC	0	0	0	0	1	0	1	0	19	0	0
NFL	0	0	0	0	1	0	0	0	0	0	0
SC	7	0	1	1	1	4	112	0	0	0	0
SFL	0	2	0	2	0	0	0	3	0	0	0
VA	1	0	1	3	42	7	2	0	293	2	0
NofVA	0	0	0	0	0	0	0	0	0	0	0
MEX	0	0	0	0	0	0	0	0	0	0	0

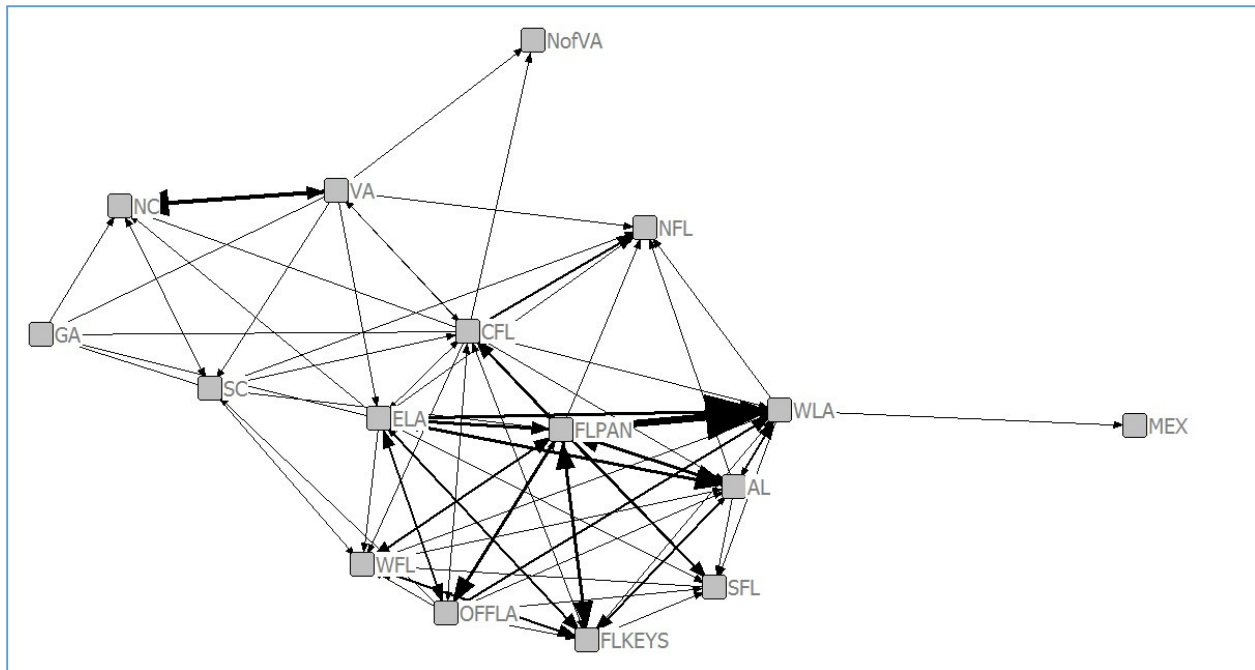


Figure 16. One mode matrix of all cobia (including those at liberty for <30 days) with Gulf of Mexico collective zone broken into individual zones. Thicker lines indicate more movements and arrows indicate direction of movement. Abbreviations are as follows: Alabama-AL; Brevard-CFL; East Louisiana/Mississippi-ELA; Georgia-GA; Keys-FLKEYS; North Carolina-NC; North of Brevard-NFL; North of Virginia-NoVA; Offshore Louisiana/Mississippi-OFFLA; Panhandle-FLPAN; South Carolina-SC; South of Brevard-SFL; Virginia-VA; West Florida-WFL; West Louisiana-WLA, Yucatan-MEX.

Figure 17. One mode matrix as described above with only 10 or more movements between zones depicted. Note that number of movements is influenced by sample size of recaptures.

