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Nikolai Klibansky

SEDAR50-DW23

Submitted: 25 January 2017

Please cite this document as:

Klibansky, N. 2017. Estimating dispersal of blueline tilefish (*Caulolatilus microps*) eggs and larvae from drifter data. SEDAR50-DW23. SEDAR, North Charleston, SC. 22 pp.

Estimating dispersal of blueline tilefish (*Caulolatilus microps*) eggs and larvae from drifter data SEDAR50-DW23

Nikolai Klibansky

Southeast Fisheries Science Center,
National Marine Fisheries Service, NOAA,
101 Pivers Island Road,
Beaufort, North Carolina, 28516, USA

Introduction

Recent efforts synthesized the available data for blueline tilefish (*Caulolatilus microps*) collected at precise locations (i.e. latitude and longitude Klibansky 2016; Farmer 2016) resulting in updated maps of the distribution of the species throughout its US range. These analyses suggested that waters on the West Florida Shelf, 100-400m deep, hold most of the blueline tilefish biomass in the Gulf of Mexico, representing one of the largest concentrations of blueline tilefish throughout its range. This area is adjacent to the rapidly flowing Loop Current, and the larger Gulf Stream, moving large volumes of water from the Gulf of Mexico to the US South Atlantic. Plots of surface drifter tracks confirmed that many planktonic objects passing near the West Florida Shelf are carried by these currents from the Gulf of Mexico, around Florida, into the Atlantic. Other work has shown blueline to be genetically very homogeneous from the Gulf of Mexico to the Mid-Atlantic (O'Donnell and Darden 2016; McDowell 2016), and larval drift via the Loop Current and Gulf Stream has been proposed as a likely mechanism for maintaining connectivity between these regions.

In this paper, I analyzed relationships between surface drifter tracks and known blueline tilefish habitat, to further investigate dispersal of planktonic life history stages. I considered a wide range of planktonic durations (1-6 weeks) and calculated proportions of drifters, originating in confirmed blueline habitat, between council regions after different periods of time. All durations showed substantial movement of drifters between council regions, with the greatest movement of drifters from the eastern Gulf of Mexico to the South Atlantic, and from the South Atlantic to the Mid-Atlantic.

Materials and Methods

Spatially precise records of blueline tilefish, with latitude, longitude, and date information, were obtained from several sources: Northeast Fisheries Science Center Bottom Trawl Survey (NEFSC BTS; Nitschke and Miller 2016*b*), the Northeast Fisheries Observed Program (NEFOP; Nitschke and Miller 2016*a*), the Southeast Reef Fish Survey (SERFS; Kolmos et al. 2016), the Cooperative-With-Industry Data Collection Project (CDCP; Kellison 2016), the Southeast Reef Fish Observer Program (RFOP; Scott-Denton et al. 2011; Farmer 2016), observer data from shark-directed bottom longline fisheries in the Southeast U.S. (SBLL; Gulak et al. 2013; Enzenauer et al. 2015), and the National Marine Fisheries Service Bottom Longline Survey in the Gulf of Mexico (NFMSBLL; https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.nodc:0147683). Most of these data were also considered and presented in earlier documents (Klibansky 2016; Farmer 2016), with the exception of the SBLL data and the sampling locations for the NMFSBLL data.

Considering all of these data sets together, presence or absence of blueline tilefish was determined for 0.1X0.1 degree lon-lat grid cell in the data. For this analysis, blueline tilefish habitat was identified as grid cells where blueline were present. Council regions were defined as the Mid-Atlantic (MA), north of 36.55N; South Atlantic (SA), south of 36.55N and east of 83W, excluding waters inshore of the Florida Keys; and the Gulf of Mexico (GM), west of 83W, , but also including waters inshore of the Florida Keys. The GM was further divided at 85W into asymmetrical subregions, GM west (GMw) and GM east (GMe), due to the large concentration of blueline tilefish on the West Florida Shelf.

Drifter data were obtained from the Surface Velocity Program (SVP) worldwide drifter database, to include all drifter data from 100-65W longitude and 20-45N latitude. The drifters included in this database are drogued surface drifters, consisting of a 30.5-40cm surface float and trailing a drogue (i.e. sea anchor; Fig. 1) 15m below the surface so that the movement of drifters represents the flow of mixed layer currents.

Drifter tracks that passed through blueline habitat were selected from the SVP data for further analysis. For each of these drifters, the date and time that the drifter first entered blueline habitat were identified, along with associated longitude (lon), latitude (lat), and council region. These positions were considered time zero (t_0) for each drifter. These t_0 points were then treated as if the drifters had been released at that point, and only subsequent track information was analyzed. Positions and associated data for each drifter, one, two, four, and six weeks after t_0 were identified and extracted; these time points are referred to as t_1, t_2, t_4, and t_6. For each time point t_1 to t_6, I estimated the proportion of drifters in each council region relative to where they were released at t_0. Pairwise tables of these proportions summarize the directionality and magnitude of drifter movement among council regions.

Because of large scale flow of drifters and the spatial distribution of blueline habitat, in this first analysis, most of the drifter t_0 points originated in the Gulf of Mexico at the edges of large areas blueline habitat. Thus I conducted an alternative version of this analysis where drifter tracks were resampled, so that if a drifter passed through multiple grid cells of blueline habitat, a t_0 point was identified for each grid cell-drifter combination. A separate time series was then identified for each grid cell-drifter combination for time points t_1 to t_6. Pairwise tables of proportions were then calculated as above.

Results and interpretation

Sampling from all data sources combined was widespread, covering much of continental shelf between the US-Mexico border in the Gulf of Mexico, northward beyond the US-Canada border to Nova Scotia (Fig. 2). Most grid cells containing blueline tilefish were between 100m and 400m depth contours. Previous analysis of these data show that blueline are rarely caught deeper than 250m (Klibansky 2016; Pulver and Whatley 2016), though extensive sampling has been conducted at deeper depths. So although there are grid cells within the lat-long and depth range of known blueline tilefish habitat which have not been sampled or not extensively, it appears that most blueline tilefish habitat has probably been identified.

A total of 1353 drifters have passed through the entire study area, with 237 of these passing through blueline habitat. Analysis of these 237 individual drifters identified 45, 74, 56, and 62 t_0 points in the GMw, GMe, SA, and MA, respectively (Fig. 3). After 1-week, drifters from all regions dispersed across council boundaries, and some had already moved long distances (Table 1; Fig. 4). Over the course of six weeks, the major movement of drifters was flow from the GMe to the SA and from the SA to the MA (Figs. 5,6,7). The GMw and MA had the highest rates of drifter retention with 0.72 and 0.92 of drifters that originated in these respective regions remaining there at the end of six weeks. Retention rates in the SA and GMe were much lower (0.4 and 0.23 respectively). Reanalysis of drifter data where drifters were resampled for every habitat grid cell they entered produced very similar results (Table 2; Figs. 9,10,11,12).

The degree to which movement of drogue drifters reflects dispersal of blueline tilefish eggs and larvae depends upon several assumptions. We know that their eggs are pelagic and can be collected with vertical plankton nets between the surface and 200m depth (Lewis et al. 2016). Buoyant eggs and larvae of a related and cooccurring species golden tilefish (*Lopholatilus chamaeleonticeps*) have been caught extensively along the US continental shelf with these same type of plankton nets (Berrien and Sibunka 1999). Despite the deep depths occupied by adult golden tilefish, planktonic larvae are primarily found in the upper water column from 50-150m (Steimle et al. 1999). Though the Gulf Stream, the major current along the US Southeast Coast, decreases with depth, it is still quite rapid at 150m (Tomczak and Godfrey 2013); thus surface drifter movement may tend to be faster then the movement of eggs and larvae at deeper depths, but the major movements are probably similar. The planktonic larval duration (PLD) for blueline tilefish is unknown, though a review of PLD for 256 marine fish species showed found an average duration of about 38 days (i.e. 5.4 weeks; Bradbury et al. 2008). They also found that PLD was positively associated with latitude, maximum adult body size, and depth. For fish in the same latitudes as blueline, PLD greater than ≈75 days is uncommon; but many fish as large and deep dwelling as blueline tilefish exhibited PLD in the range of ≈75-100 days. These authors also showed that more genetically homogeneous species tend to have longer larval durations, and we know from recent work that blueline tilefish from the West Florida Shelf in the Gulf of Mexico through the Mid-Atlantic are highly related (O'Donnell and Darden 2016; McDowell 2016). Thus the time period examined here contains the average PLD, but a 4-6 week planktonic larval duration may be considered a lower estimate for blueline tilefish. Thus although movement of larvae at deeper depths than the drifter drogues will tend to be slower, actual blueline larvae may well be planktonic for longer than the durations considered here.

So although information specific to blueline tilefish eggs and larvae are very limited, information from other fish species suggests that drifter movements observed here provide a useful contribution to our understanding of how blueline tilefish larvae are dispersed. As is shown in the drifter analyses, it seems likely that substantial numbers of blueline tilefish larvae are transported out of the eastern Gulf of Mexico, to the South Atlantic, and from the South Atlantic into the Mid-Atlantic over the course of a few weeks.

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Table 1 Summary of movement of individual drifters between council regions, 1, 2, 4, and 6 weeks after release. Rows represent the council region where the drifter originated while columns represent the region where the drifter was found in a subsequent week. Values in each row sum to one, indicating proportions of drifters released in each region, that were present in each region at weeks 1-6.

Origin	GMw	GMe	SA	MA
Week 1				
GMw	0.93	0.07	0.00	0.00
GMe	0.17	0.40	0.43	0.00
SA	0.00	0.02	0.65	0.33
MA	0.00	0.00	0.07	0.93
Week 2				
GMw	0.88	0.12	0.00	0.00
GMe	0.23	0.32	0.44	0.02
SA	0.00	0.02	0.61	0.36
MA	0.00	0.00	0.11	0.89
Week 4				
GMw	0.74	0.23	0.03	0.00
GMe	0.20	0.30	0.41	0.09
SA	0.00	0.03	0.44	0.53
MA	0.00	0.00	0.22	0.78
Week 6				
GMw	0.72	0.20	0.08	0.00
GMe	0.25	0.23	0.38	0.15
SA	0.00	0.04	0.40	0.56
MA	0.00	0.00	0.08	0.92

Table 2 Summary of movement of resampled drifters between council regions, 1, 2, 4, and 6 weeks after release. Rows represent the council region where the drifter originated while columns represent the region where the drifter was found in a subsequent week. Values in each row sum to one, indicating proportions of drifters released in each region, that were present in each region at weeks 1-6.

Origin	GMw	GMe	SA	MA
Week 1				
GMw	0.93	0.07	0.00	0.00
GMe	0.21	0.52	0.27	0.00
SA	0.00	0.01	0.77	0.21
MA	0.00	0.00	0.16	0.84
Week 2				
GMw	0.90	0.10	0.00	0.00
GMe	0.22	0.43	0.34	0.01
SA	0.00	0.00	0.70	0.30
MA	0.00	0.00	0.20	0.80
Week 4				
GMw	0.81	0.16	0.03	0.00
GMe	0.24	0.31	0.39	0.06
SA	0.00	0.01	0.46	0.54
MA	0.00	0.00	0.16	0.84
Week 6				
GMw	0.76	0.17	0.07	0.00
GMe	0.25	0.26	0.38	0.12
SA	0.00	0.01	0.40	0.59
MA	0.00	0.00	0.09	0.91

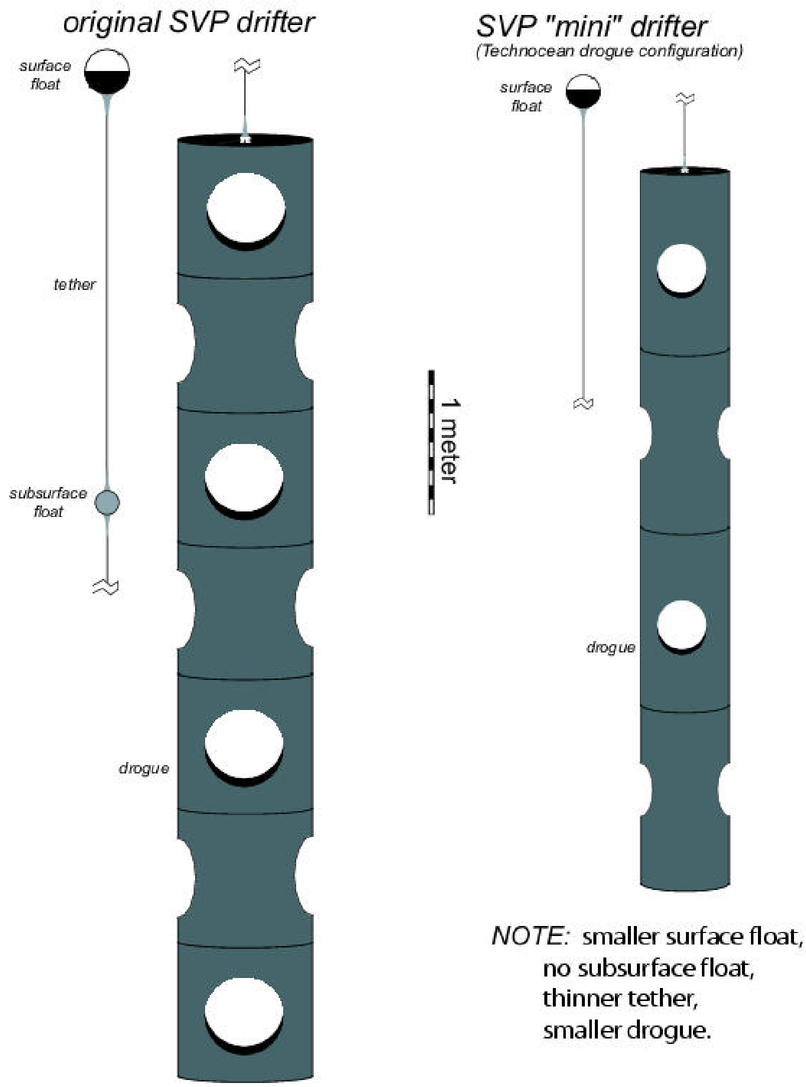

FIG. 1 Basic schematic of drogue drifters used by the internationally funded Surface Velocity Program (SVP). Images reprinted from: http://www.aoml.noaa.gov/phod/dac/gdp_drifter.php. See this site for additional details about these drifters.

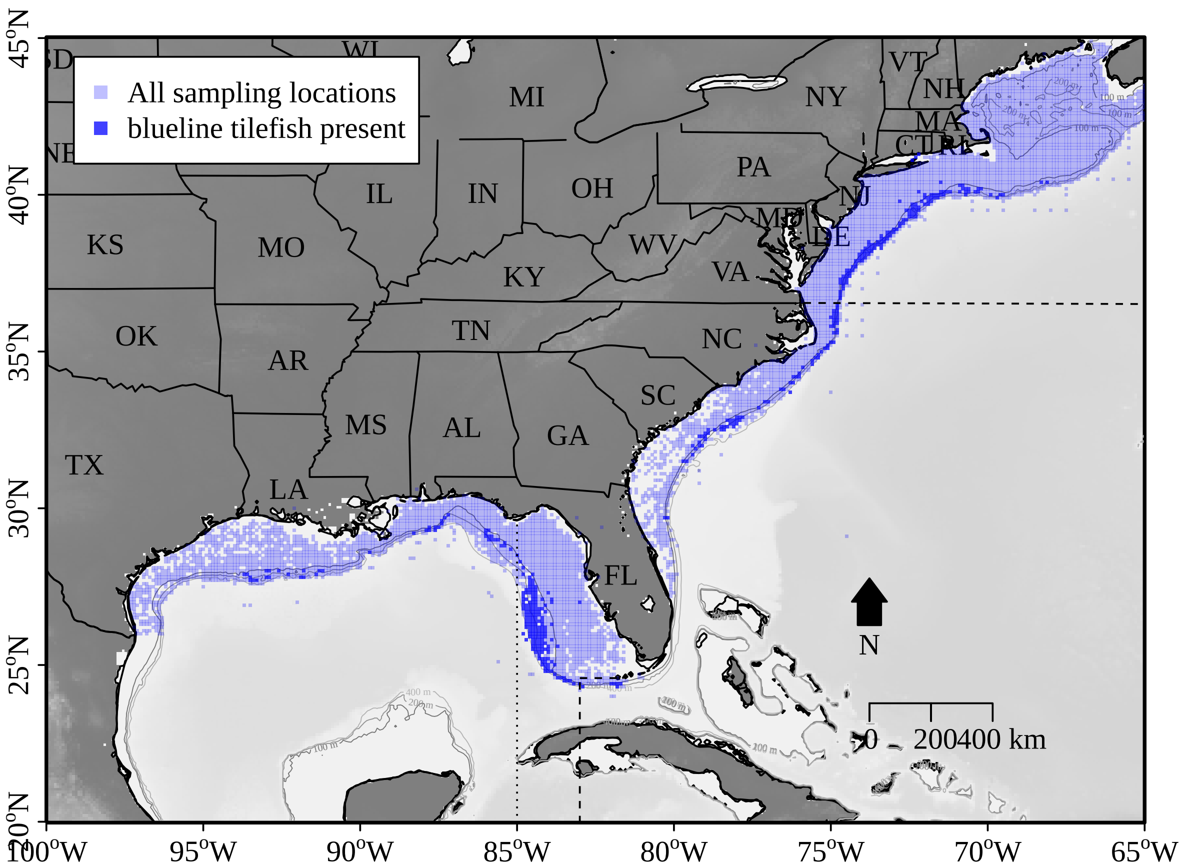

Fig. 2 Map of all positive blueline tilefish collection locations and all sampling locations for data from all sources. Dashed lines indicate council boundaries. A dotted vertical line at 83W in the Gulf of Mexico marks the boundary between the western and eastern Gulf of Mexico (GMw and GMe) as described in the main text.

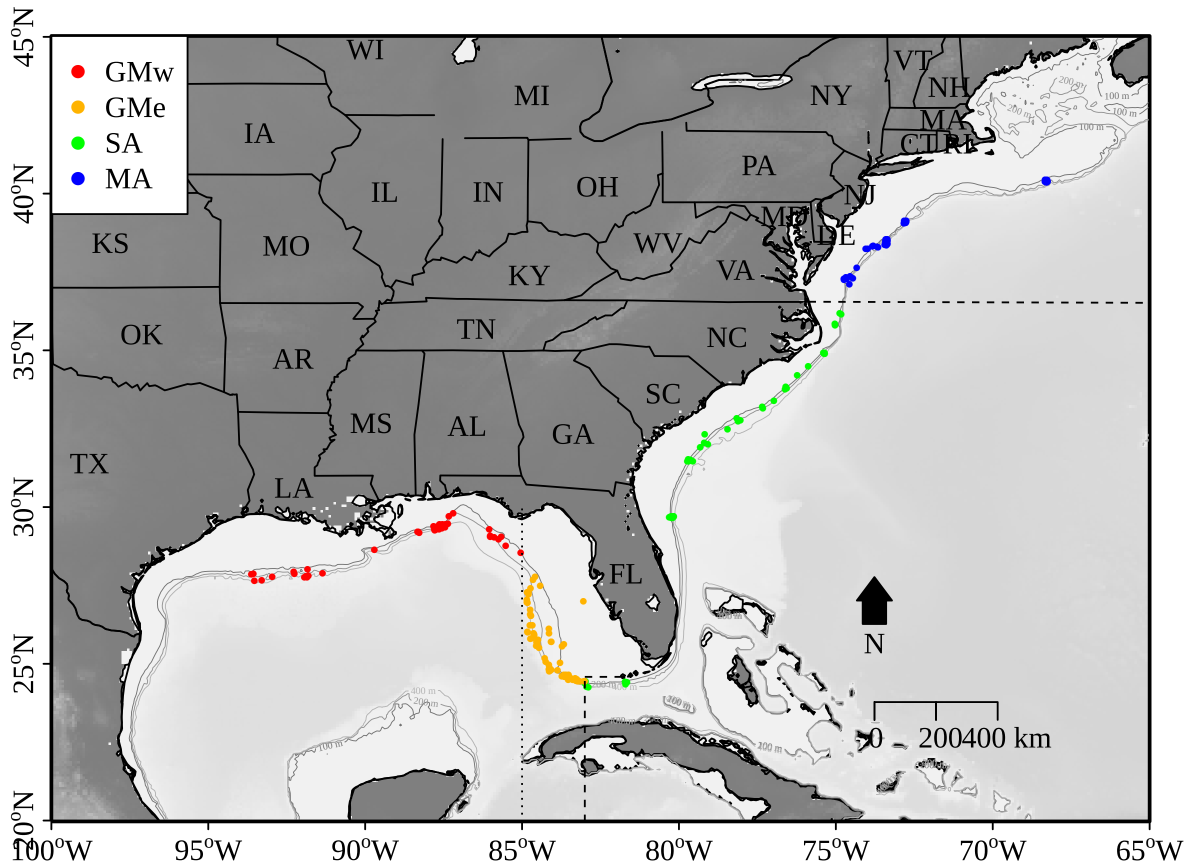

Fig. 3 Locations of individual drogue (surface water) drifters at time zero (t_0). The first record of a drogue track entering blueline tilefish habitat (i.e. 0.1 X 0.1 degree lat-lon grid squares in which blueline tilefish have been found) is considered time zero. Points are color coded to indicate the council region where the t_0 point was located (GM = Gulf of Mexico, SA = South Atlantic, MA = Mid-Atlantic). Dashed lines indicate council boundaries. A dotted vertical line at 83W in the Gulf of Mexico marks the boundary between the western and eastern Gulf of Mexico (GMw and GMe) as described in the main text.

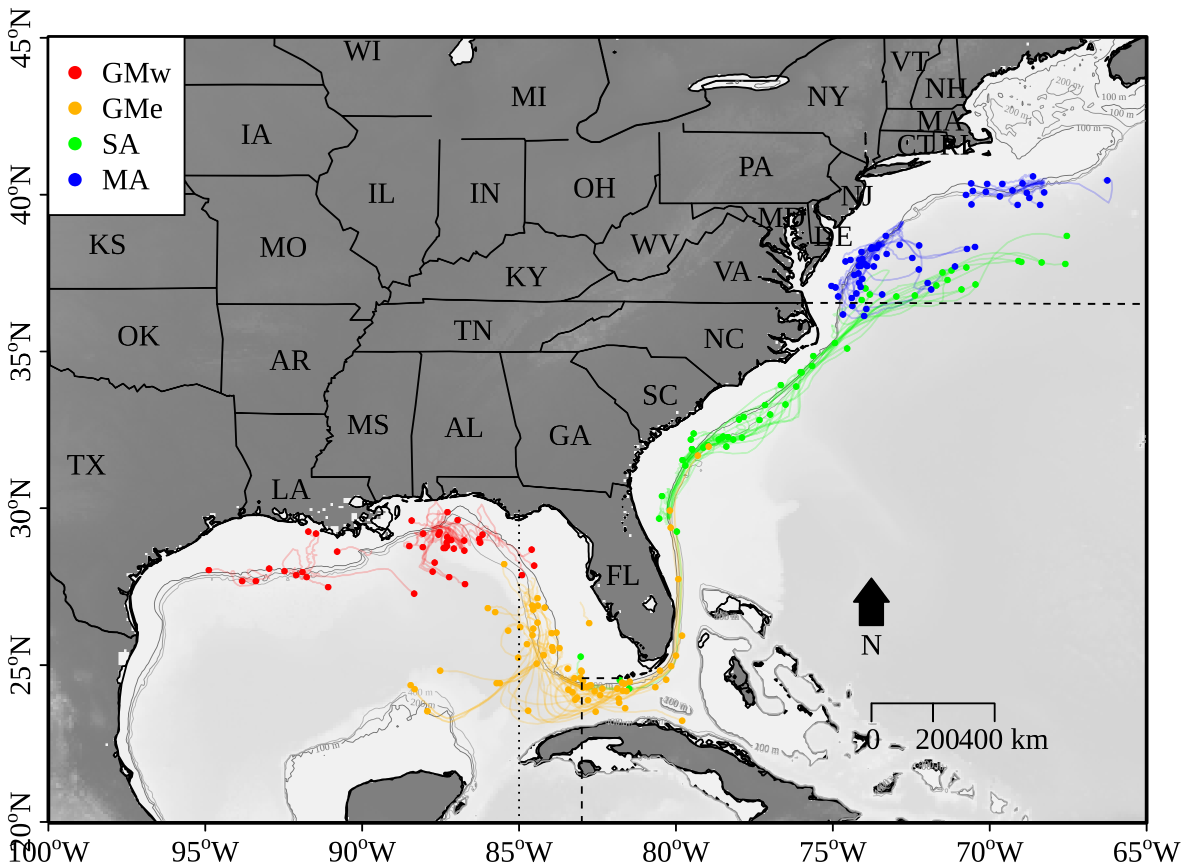

FIG. 4 Locations of individual drogue (surface water) drifters 1-week (t_1) after they were first observed in blueline tilefish habitat. Points and drifter tracks are color coded to indicate the council region where the t_0 point was located (GM = Gulf of Mexico, SA = South Atlantic, MA = Mid-Atlantic). Dashed lines indicate council boundaries. A dotted vertical line at 83W in the Gulf of Mexico marks the boundary between the western and eastern Gulf of Mexico (GMw and GMe) as described in the main text. Note that long straight line segments in drifter tracks usually indicate missing data between the ends of the segment, and do not usually represent the actual path of movement.

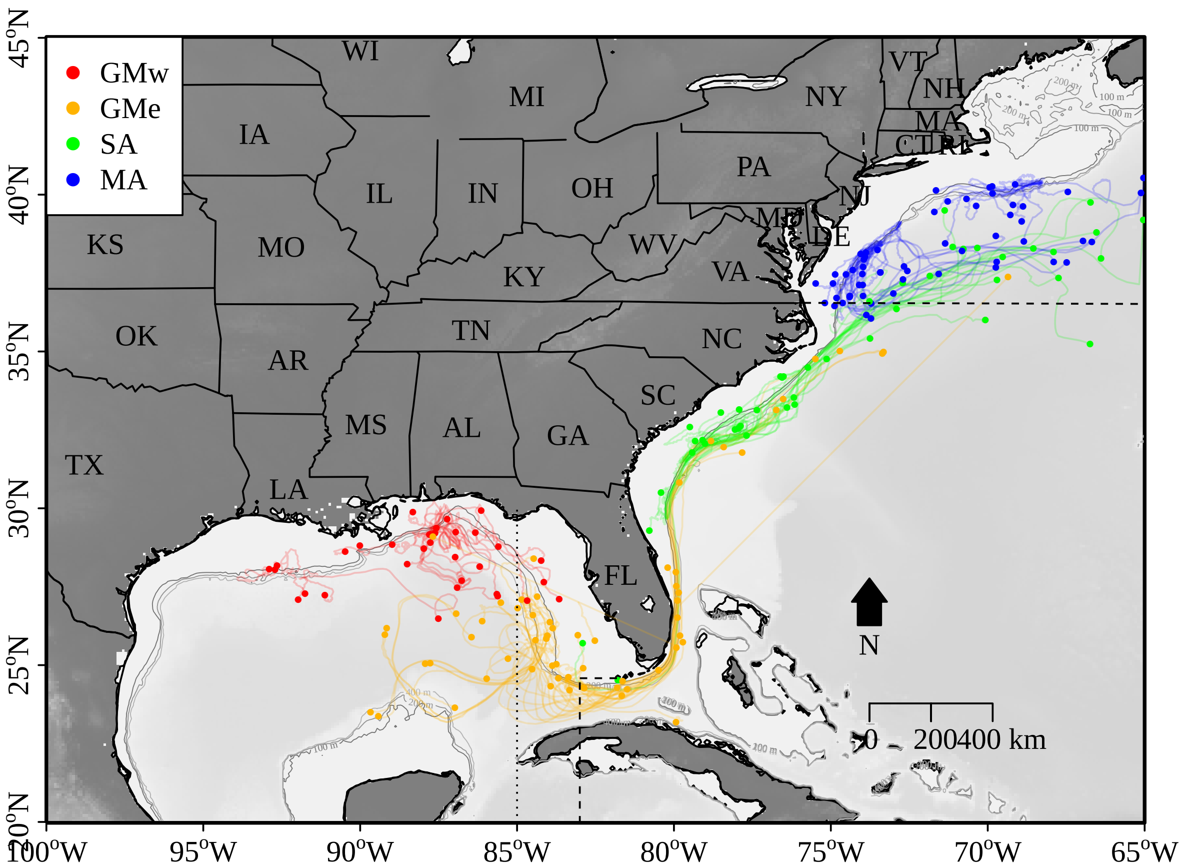

Fig. 5 Locations of individual drogue (surface water) drifters 2-weeks (t_2) after they were first observed in blueline tilefish habitat. Points and drifter tracks are color coded to indicate the council region where the t_0 point was located (GM = Gulf of Mexico, SA = South Atlantic, MA = Mid-Atlantic). Dashed lines indicate council boundaries. A dotted vertical line at 83W in the Gulf of Mexico marks the boundary between the western and eastern Gulf of Mexico (GMw and GMe) as described in the main text. Note that long straight line segments in drifter tracks usually indicate missing data between the ends of the segment, and do not usually represent the actual path of movement.

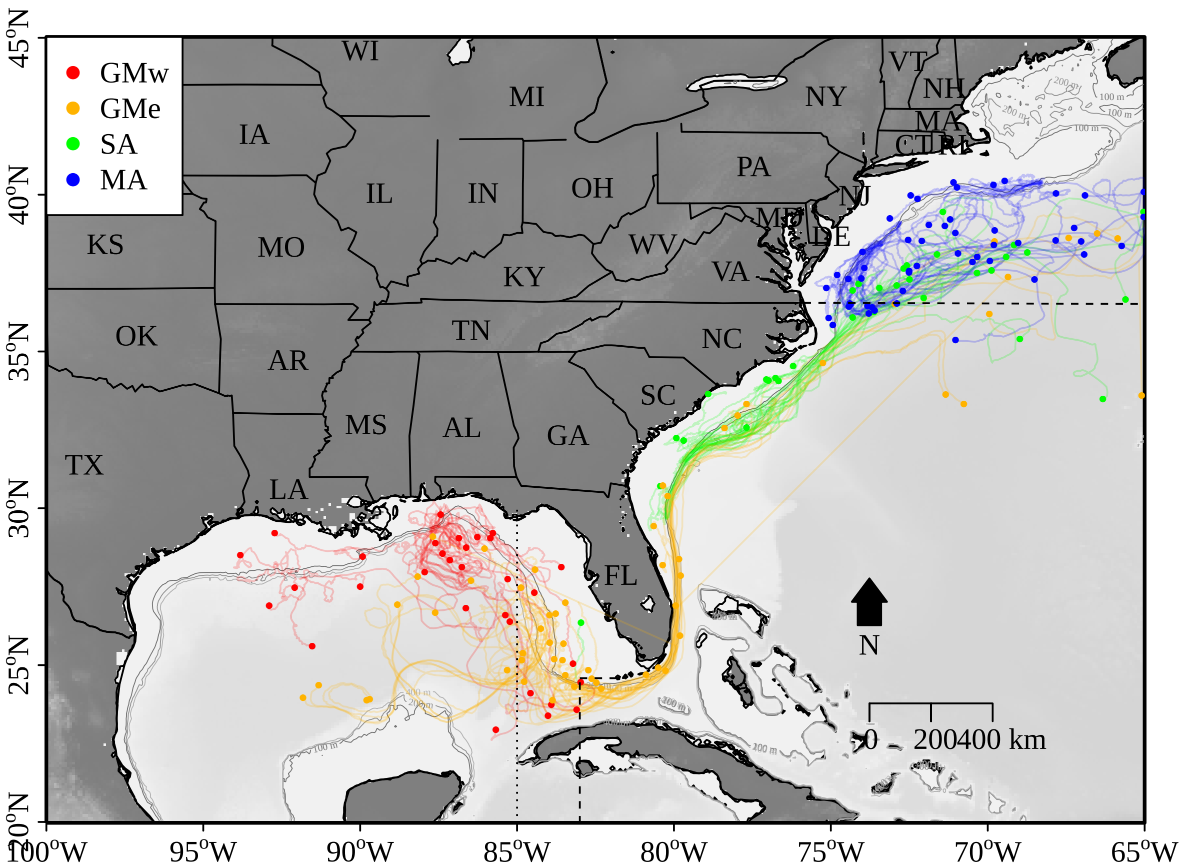

Fig. 6 Locations of individual drogue (surface water) drifters 4-weeks (t_4) after they were first observed in blueline tilefish habitat. Points and drifter tracks are color coded to indicate the council region where the t_0 point was located (GM = Gulf of Mexico, SA = South Atlantic, MA = Mid-Atlantic). Dashed lines indicate council boundaries. A dotted vertical line at 83W in the Gulf of Mexico marks the boundary between the western and eastern Gulf of Mexico (GMw and GMe) as described in the main text. Note that long straight line segments in drifter tracks usually indicate missing data between the ends of the segment, and do not usually represent the actual path of movement.

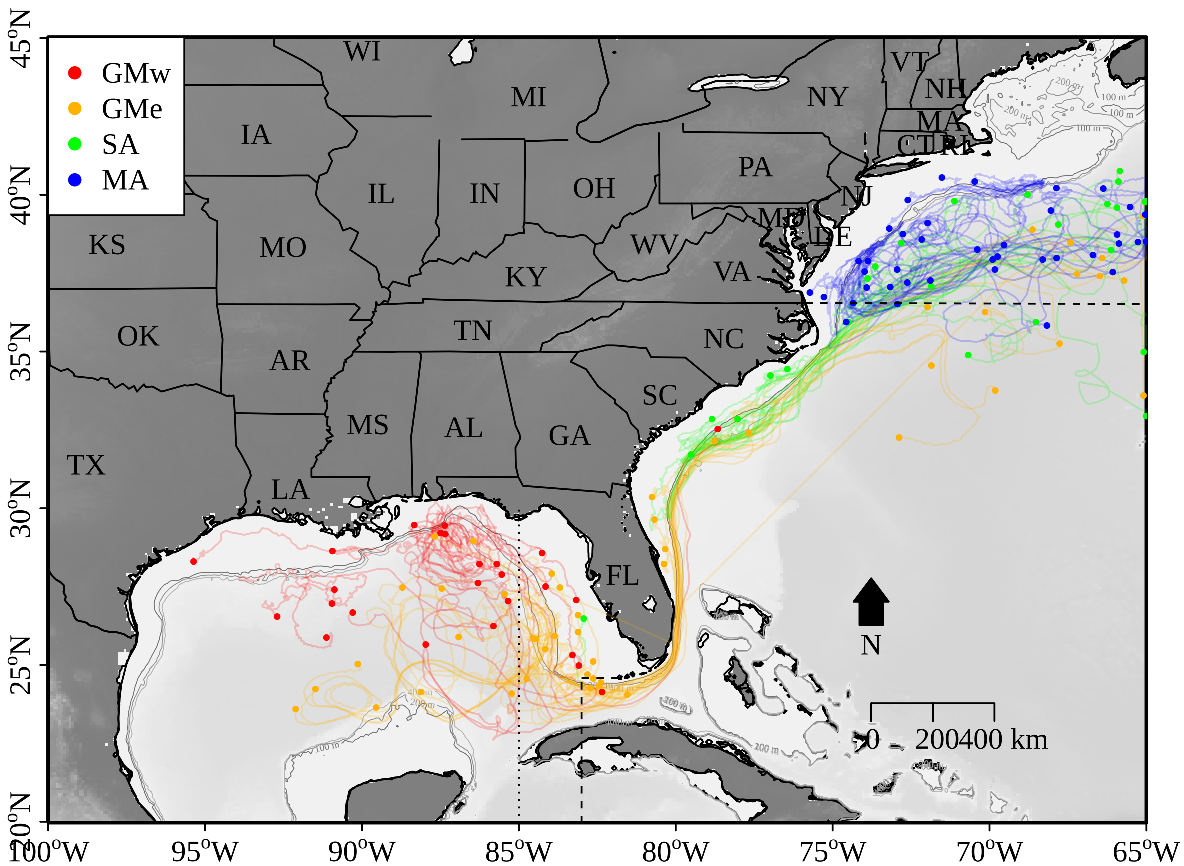

FIG. 7 Locations of individual drogue (surface water) drifters 6-weeks (t_6) after they were first observed in blueline tilefish habitat. Points and drifter tracks are color coded to indicate the council region where the t_0 point was located (GM = Gulf of Mexico, SA = South Atlantic, MA = Mid-Atlantic). Dashed lines indicate council boundaries. A dotted vertical line at 83W in the Gulf of Mexico marks the boundary between the western and eastern Gulf of Mexico (GMw and GMe) as described in the main text. Note that long straight line segments in drifter tracks usually indicate missing data between the ends of the segment, and do not usually represent the actual path of movement.

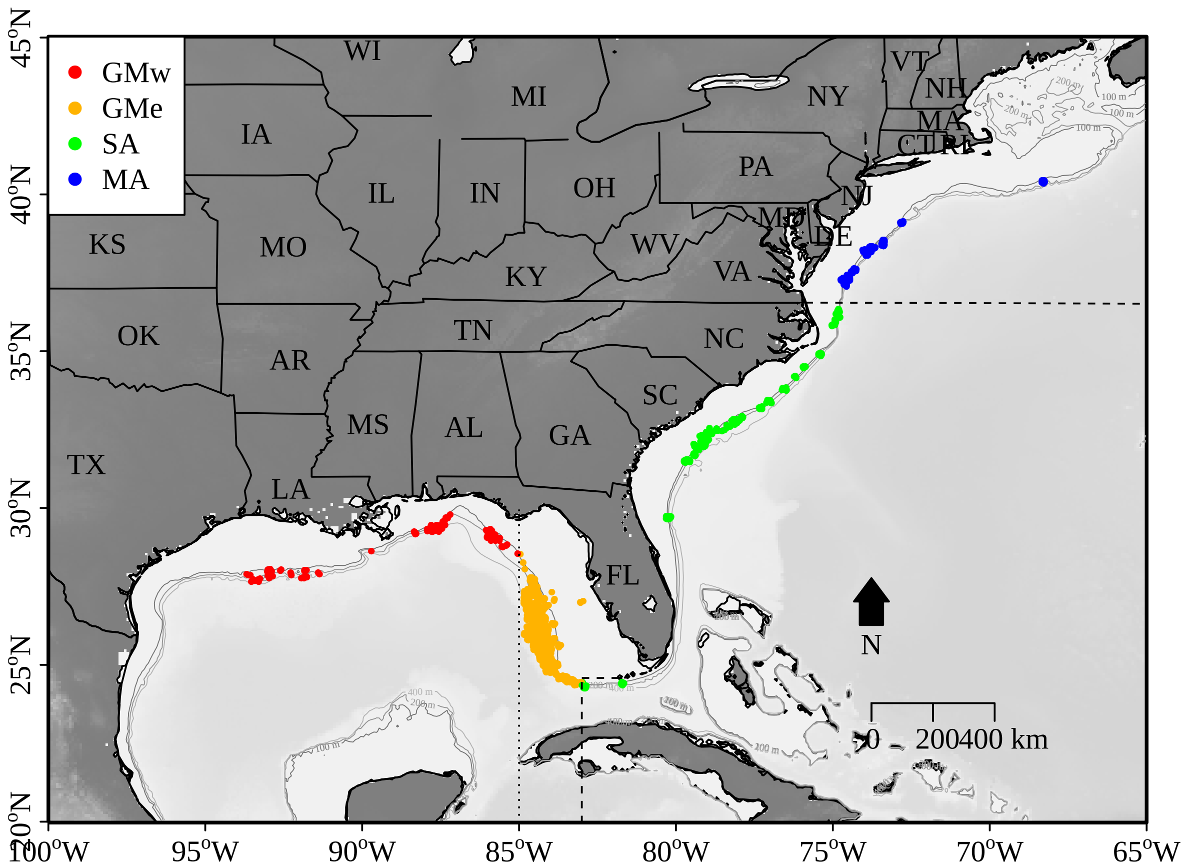

Fig. 8 Locations of resampled-drogue (surface water) drifters at multiple time zero values (t_0). Since drifters pass through multiple blueline tilefish habitat cells, this version of the analysis calculates a new t_0 value each time a drogue track enters a new habitat cell. This resampling approach avoids the problem of having too many t_0 zero points being located "upstream" and provides a more complete picture of how blueline tilefish eggs and larvae are likely to to drift. Points are color coded to indicate the council region where the t_0 point was located (GM = Gulf of Mexico, SA = South Atlantic, MA = Mid-Atlantic). Dashed lines indicate council boundaries. A dotted vertical line at 83W in the Gulf of Mexico marks the boundary between the western and eastern Gulf of Mexico (GMw and GMe) as described in the main text. Note that long straight line segments in drifter tracks usually indicate missing data between the ends of the segment, and do not usually represent the actual path of movement.

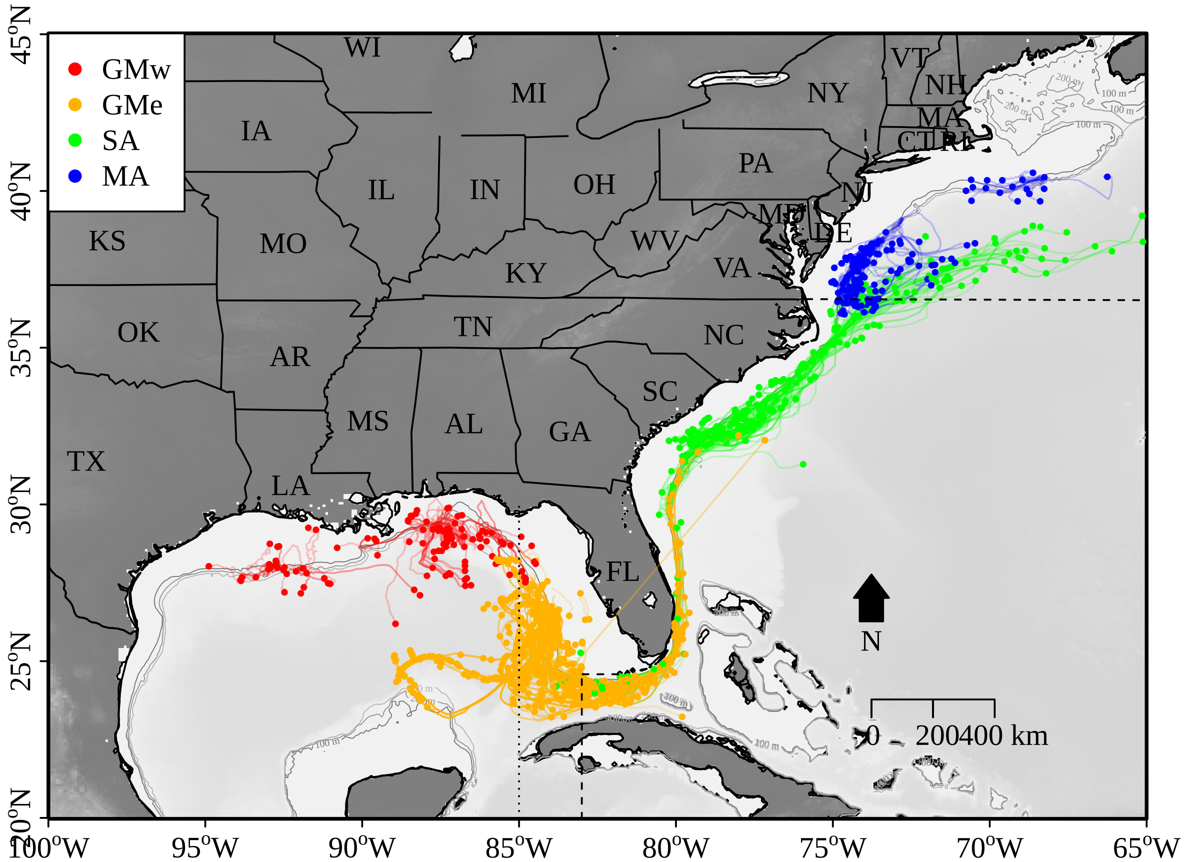

FIG. 9 Locations of resampled-drogue (surface water) drifters 1-week (t_1) after they were first observed in each blueline tilefish habitat square (0.1X0.1 degree). Points and drifter tracks are color coded to indicate the council region where the t_0 point was located (GM = Gulf of Mexico, SA = South Atlantic, MA = Mid-Atlantic). Dashed lines indicate council boundaries. A dotted vertical line at 83W in the Gulf of Mexico marks the boundary between the western and eastern Gulf of Mexico (GMw and GMe) as described in the main text. Note that long straight line segments in drifter tracks usually indicate missing data between the ends of the segment, and do not usually represent the actual path of movement.

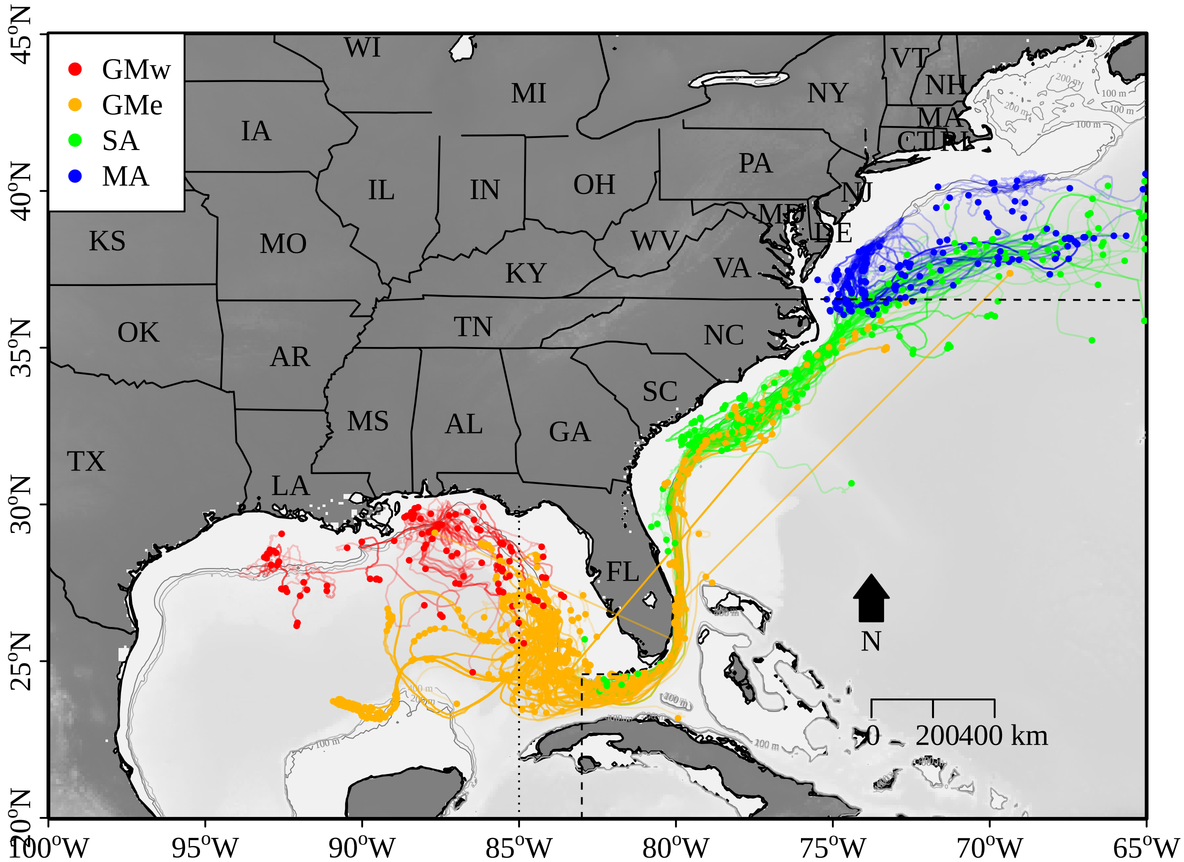

FIG. 10 Locations of resampled-drogue (surface water) drifters 2-weeks (t_2) after they were observed in each blueline tilefish habitat square (0.1X0.1 degree). Points and drifter tracks are color coded to indicate the council region where the t_0 point was located (GM = Gulf of Mexico, SA = South Atlantic, MA = Mid-Atlantic). Dashed lines indicate council boundaries. A dotted vertical line at 83W in the Gulf of Mexico marks the boundary between the western and eastern Gulf of Mexico (GMw and GMe) as described in the main text. Note that long straight line segments in drifter tracks usually indicate missing data between the ends of the segment, and do not usually represent the actual path of movement.

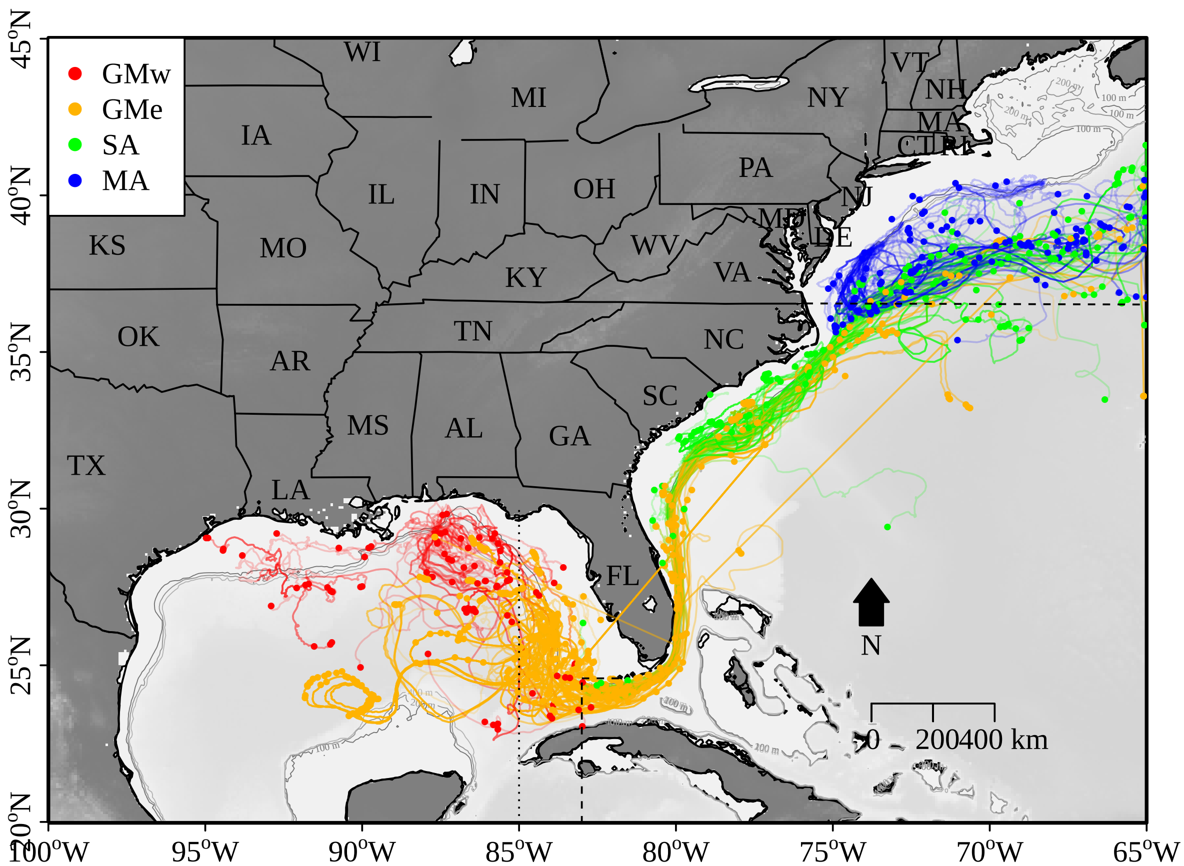

Fig. 11 Locations of resampled-drogue (surface water) drifters 4-weeks (t_4) after they were observed in each blueline tilefish habitat square (0.1X0.1 degree). Points and drifter tracks are color coded to indicate the council region where the t_0 point was located (GM = Gulf of Mexico, SA = South Atlantic, MA = Mid-Atlantic). Dashed lines indicate council boundaries. A dotted vertical line at 83W in the Gulf of Mexico marks the boundary between the western and eastern Gulf of Mexico (GMw and GMe) as described in the main text. Note that long straight line segments in drifter tracks usually indicate missing data between the ends of the segment, and do not usually represent the actual path of movement.

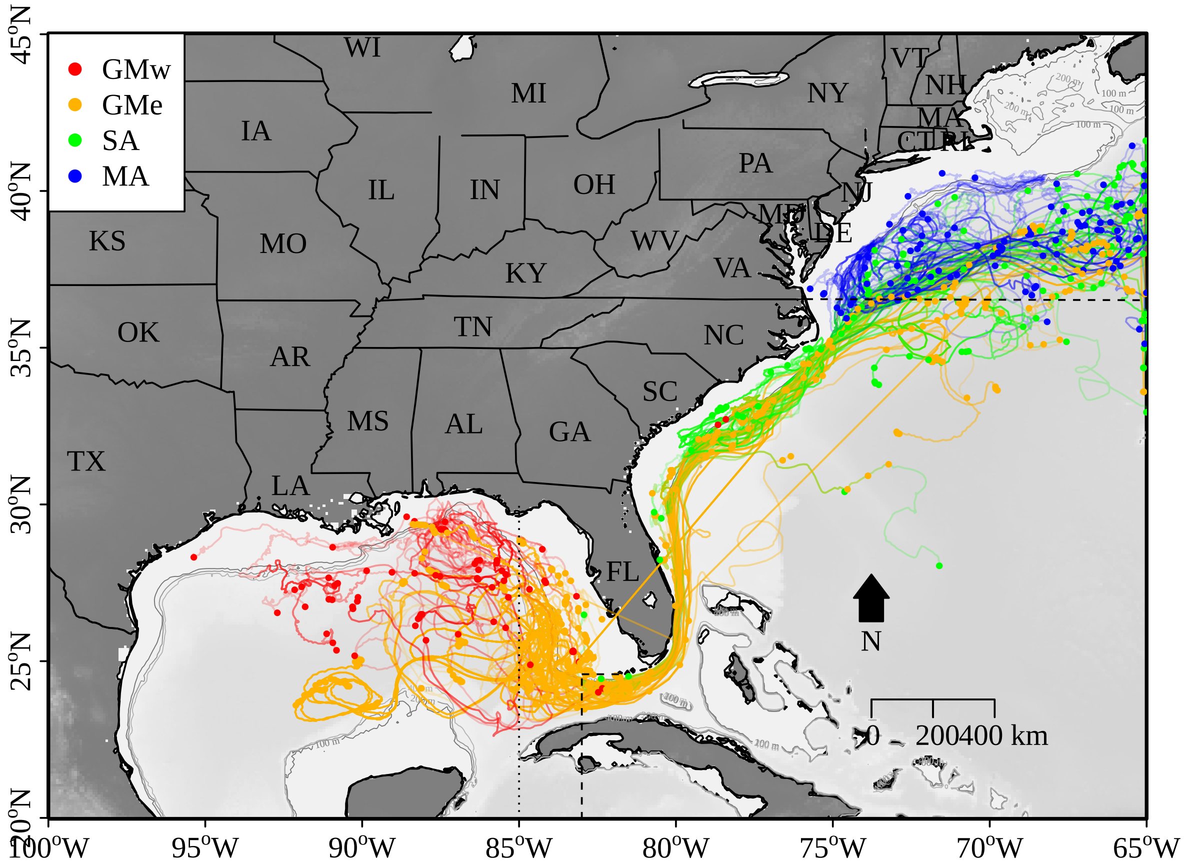

Fig. 12 Locations of resampled-drogue (surface water) drifters 6-weeks (t_6) after they were observed in each blueline tilefish habitat square (0.1X0.1 degree). Points and drifter tracks are color coded to indicate the council region where the t_0 point was located (GM = Gulf of Mexico, SA = South Atlantic, MA = Mid-Atlantic). Dashed lines indicate council boundaries. A dotted vertical line at 83W in the Gulf of Mexico marks the boundary between the western and eastern Gulf of Mexico (GMw and GMe) as described in the main text. Note that long straight line segments in drifter tracks usually indicate missing data between the ends of the segment, and do not usually represent the actual path of movement.