

DO WESTERN ATLANTIC BLUEFIN TUNA SPAWN OUTSIDE OF THE GULF OF MEXICO? RESULTS FROM A LARVAL SURVEY IN THE ATLANTIC OCEAN IN 2013

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*In 2013, a larval survey was conducted north and east of the Bahamas aboard the NOAA Ship NANCY FOSTER. Sampling areas were selected based on larval habitat model predictions, and daily satellite analysis of surface temperature and ocean color. Samples were collected at 97 stations, and 18 larval BFT (*Thunnus thynnus*) were found at 9 stations. Six of these stations came from oceanographically complex regions characterized by cyclonic and anticyclonic gyres. Larvae ranged in size from 3.22mm to 7.58 mm, corresponding to approximately 5-12 days in age. Analysis of satellite derived surface currents and CTD data suggest that these larvae were spawned and retained in this area. Larval habitat models show areas of high predicted abundance extending east to 65° W, but the actual extent of spawning in this area remains unknown.*

Key words

Habitat, Spawning Grounds, Spawning Migrations, Fishery Oceanography

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Introduction

Atlantic Bluefin Tuna (*Thunnus thynnus*: Linnaeus 1758) is a highly migratory fish found (and fished) throughout the North Atlantic and adjacent seas, ranging from the equator to the north of Norway. Bluefin tuna reach a size up to 900 kg, and undertake extensive migrations between the cold waters of the North Atlantic Ocean and the warm waters of their spawning grounds in the Gulf of Mexico and Mediterranean Sea (Mather et al., 1995, Fromentin and Powers 2005). Stock management of this species is complex as the adults may undertake transatlantic migrations and are not easily separated into an eastern and western stock (Scott et al., 1993, Rooker et al., 2007, Galuardi et al., 2010). The spawning migration to the Gulf of Mexico and Mediterranean was first determined by conventional tagging, and has been confirmed by numerous studies using electronic tags (Block et al., 2005). These studies support spawning site fidelity in both regions, though tagging and larval collection results suggest there may be reproductive activity in other regions (Muhling et al., 2010, Galuardi et al., 2010, Richards 1969).

Spawning of the western stock is currently assumed to take place in late April to early June in the Gulf of Mexico (Richards 1976) at temperatures above 23°C. Spawning activity is primarily focused in the north-central Gulf of Mexico, however larval bluefin have also been reported from the Straits of Florida (Richards and Potthoff 1980, Brothers et al., 1983), south-west Gulf of Mexico (Olivera Limas et al., 1988), and along the east coast of the US as far north as the Carolinas (McGowan and Richards 1989). Results from the latter collections were attributed to advection from the Gulf of Mexico by the Gulf Stream. These results appeared to have been confirmed by recent electronic tagging studies (Block et al., 2005, Teo et al., 2007). However, work by Muhling et al., (2010) using habitat models, suggested suitable spawning habitat may exist in areas adjacent to the Gulf of Mexico, and in particular the Yucatan coast north of Cozumel, Mexico. Samples collected from that region in 2009-2010 were found to have bluefin larvae in the western Caribbean and southern Gulf of Mexico, though in small numbers (Muhling et al., 2011).

Tracks from electronically tagged adult bluefin (BFT) from the north-west North Atlantic foraging grounds presented by Lutcavage et al., (2012) suggest that not all sexually mature fish return to the known spawning grounds in the Gulf of Mexico each year. These results indicated a sizable adult presence in the area north of the Bahamas during the spawning season. Applying the existing larval BFT habitat model to this area indicated the possibility of extensive favorable larval bluefin habitat north and east of the Bahamas (Fig. 1).

The presence of larval bluefin outside the traditional spawning grounds, combined with the tracks from electronically tagged fish that do not appear to follow historic migration tracks, suggests the possibility of alternative spawning grounds for some portion of the western bluefin spawning stock. Rooker et al. (2007) proposed three hypotheses for bluefin spawning behavior, to explain the presence of mature adults outside spawning grounds during spawning season: (1) spawning occurs in regions outside the Gulf of Mexico and Mediterranean Sea, (2) a fraction of the presumed mature adults are not reproductively mature, or (3) bluefin are not obligate annual spawners. Lutcavage et al., (2012) argued that adult bluefin spawn annually, and may spawn at different times and areas whenever conditions are appropriate. Given the historical and electronic tagging results the Southeast Fisheries Science Center (SEFSC) decided to conduct a larval bluefin tuna survey in 2013 in areas not previously explored to the north and east of the Bahamas.

Methods.

Samples were collected at 97 stations by the NOAA ship NANCY FOSTER (Fig. 2) during the period May 2-22, 2013. Stations were selected using larval bluefin habitat models and real-time satellite sea surface temperature and ocean color imagery (Muhling et al., 2010, 2012). Stations were located from the Florida Keys (24°.30' N) to 30° N latitude. Samples were collected across the Gulf Stream though the majority of samples were collected east and north of the Bahamas. Stations were selected in order to sample across a wide array of mesoscale oceanographic features. Surface temperature was monitored using a Seabird flow through system, CTDs, and daily satellite analyses, and the ship was positioned accordingly. Plankton collections were made using an S-10 net (1 x 2 meters 0.505mm mesh) towed from the surface to 10 meters in an undulating fashion for 10 minutes. Surface neuston tows (0.95 mm mesh on a 1 x 2 m frame) were made at selected locations, and a Multiple Opening and Closing Net Environmental Sensing System (MOCNESS) was used to collect vertical distribution data for larval fish and zooplankton.

MOCNESS samples were taken in 10-meter increments from 50 meters to the surface. All collections were sorted and identified at the Southeast Fisheries Science Center in Miami. Seven World Ocean Circulation Experiment (WOCE) satellite tracked drifter buoys were deployed and tracked throughout the cruise. CTD data was collected from the surface to 300 meters. Larval habitat models were computed on a weekly basis providing predicted locations of suitable habitat.

Results and Discussion

Eighteen *Thunnus thynnus* were found at 9 stations (Table 1), primarily to the north east of the Bahamas (Fig. 2a). Specimens ranged in size from 3.22 mm to 7.58 mm, corresponding to approximately 5-12 days in age (Malca et al., 2014). One was collected within the Northwest Providence Channel, and one in the Northeast Providence Channel, and one in the Gulf Stream. Analysis of the satellite images and particle backtracking suggest these fish were spawned in the Gulf of Mexico or Florida Straits. The remaining larvae were collected north and east of the Bahamas, in an oceanographically complex region characterized by cyclonic and anti-cyclonic gyres (Figure 3). In this area, the Gulf Stream forms the western boundary, with warm Caribbean water to the south, and cooler Atlantic water in the northeast. A series of gyres are evident in the sea surface temperature (SST) within the narrow band of water between the warmer Caribbean waters to the south and southwest, and the cooler waters of the Atlantic to the north. SST was uniform across the area except in the region of a cyclonic eddy just north of the Bahamas ($\sim 27^{\circ} .5$ N, $77^{\circ} .5$ W), and to the northeast where cooler Atlantic water is intruding in the surface expression. The water to the south and east of the Bahamas was characterized by deep thermoclines (20° C >200 meters) similar to those found in the Loop Current or Gulf Stream. The depth of the 20° isotherm was below 200 meters in this region, and BFT larvae are not normally found in waters with warm deep thermoclines.

Warm filaments can be seen extending east and south from the Gulf Stream, mixing with the offshore waters (Figure 2b). These filaments extend to the south from 31.5° N to 29° N where they become entrained in a series of cyclonic and anticyclonic gyres. The complex interaction and mixing of eddy features hinders our ability to accurately track water masses in the northern region of our study area, and two stations that contained bluefin that were possibly transported south with these filaments. However, we were able to backtrack the water masses where the bluefin larvae were found to confidently identify the origin. The area immediately south was characterized by a series of cyclonic gyres where cooler Atlantic water is mixing with the warm Caribbean water from the south. It is in this area that the majority of the larval bluefin were collected. The water to the south and east of the Bahamas was characterized by deep thermoclines (20° C >200 meters) similar to those found in the Loop Current or Gulf Stream (Figure 3). In the Gulf of Mexico the depth of the 20° isotherm is an indicator used to define the edge of the Loop current and anticyclonic gyres. Typically bluefin larvae in the Gulf are found in areas where this isotherm is <100 m in depth. The samples were collected in the area where this isotherm shallows to near 100 meters. This is similar to depths of the 20° isotherm found in the eastern Gulf of Mexico near the Loop Current, but deeper than is typical for the western Gulf.

To further understand the near surface water currents, 5 WOCE satellite drifters were deployed in this area. Two drifters deployed near the northern stations moved to the north over a period of a week and rejoined the Gulf Stream moving north. Those deployed south of the northern transect line were caught up in various recirculating features and remained in the area, suggesting that the currents in this area act to retain eggs and/or larvae spawned there.

The hypothesis that bluefin spawn near the Bahamas was first proposed by Rivas (1954) when he found that “bluefin appear in the middle of May in large numbers on the shallow edge of the Great Bahama bank in the vicinity of Riding Rocks and Orange Cay.” Rivas proposed that these fish were returning to northern feeding grounds from the Gulf of Mexico, and that some portion of unspent fish may be spawning in the Bahamas. He estimated that to be no greater than 6% of the spawning stock.

Bluefin larvae have been collected in the Straits of Florida and east of Miami (Richards and Pottoff 1980, Brothers et al., 1983), and Berrien et al., (1978) reported them from off Cape Hatteras. To test the hypothesis that bluefin were spawning in the Gulf Stream, the NOAA National Marine Fisheries Service conducted an extensive larval survey cruise in May 1985, sampling across the Gulf Stream from 27° - 37° N, along the shelf edge from Palm Beach Florida to Cape Fear, North Carolina, and offshore as far as the Blake Plateau. These stations were primarily sampled across the Gulf Stream, though some samples were taken north of the Bahamas out to 77.5° W. McGowan and Richards (1989) examined samples collected from this survey, finding a total of 14 bluefin larvae, with most collected within or near the Gulf Stream. Four stations north of the Bahamas also contained bluefin larvae. The authors concluded

that the majority of these fish were spawned either within the Gulf of Mexico, or the Florida Straits, and advected northward by the Gulf Stream. They also note that the current circulation east and north of the Bahamas is complicated, and could act to retain larvae as does the western Gulf of Mexico. This survey was limited in the area of the Bahamas and did not extend eastward beyond 78° W.

McGowan and Richards (1989) reported only 14 bluefin larvae from this survey, but as they note, in 1984 and 1986 the average catch in the Gulf of Mexico was less than 24 total larvae at 10 positive stations from 60 cm bongo tows. During 2013, we collected 18 larval bluefin in the Bahamas region, while in the same year, less than 350 larvae were collected in the Gulf of Mexico (5.1%). However the geographical area sampled in the Atlantic was much smaller than the area covered in the standard Gulf of Mexico survey. The Atlantic Ocean east of the Bahamas is poorly known in regards to larval distribution and abundance, and the size of the potential spawning habitat is not clear.

Caution is needed when applying a habitat models developed from data in the Gulf of Mexico to other regions. However this model has been successful in predicting the occurrence of larvae in the western Caribbean and now in the Atlantic. Figure 1 shows the predicted occurrence across the Gulf of Mexico and the Atlantic. The highest predicted favorable habitat in the Atlantic was well east of our survey area, running from approximately 75°W to 65° W or the eastward boundary of our analysis. We were not able to sample that area due to research vessel limitations, instead concentrating our efforts in a smaller geographic area.

Figure 4 shows larval bluefin collections from the 2013 cruise overlaid on a surface temperature climatology from NOAA Pathfinder satellite data. Three of the stations border the 24°C isotherm area near the intruding colder Atlantic waters. This frontal habitat and series of gyres continue east as far as 70° W, another 500 km. While it is unknown if bluefin do in fact spawn over an extended area in the Atlantic Ocean, habitat models and oceanographic conditions suggest the conditions may be favorable during spring.

Historically, adult bluefin have been found along this frontal system out to 65° W. Figure 5 shows historical catches in the region plotted over a surface temperature climatology. Bluefin are present over a broad geographic region between approximately 25° -35° N. There has been historically little effort further east of 65° and it is not clear if this boundary represents lack of effort or a species geographic boundary. Catches in the Bahamas region were typically smaller fish (200-400 lbs), although larger specimens were present as well. However, catch records for the period of April-June do not show this extended distribution. There was low effort east of 70°W during this time period. The weights of the fish taken in this period were from a mixture of sizes between 200 and 800 lbs (Figure 5b, d). The presence of the larger fish may represent adults migrating out of the Gulf, or it may be fish that are resident in this region during spawning season. Recent work by Lutcavage et al., (2012) and Knapp et al., (2012) suggest that western bluefin's age at maturity more closely resembles that of the eastern stock, with maturity occurring as young as age 5. The fish present in this region, though smaller than in the Gulf of Mexico, may be mature fish capable of spawning (Lutcavage et al., 2012).

Spawning grounds of the western BFT has puzzled researchers from the beginning. Richards (1976) summarized known spawning activity for bluefin that included not only the Gulf of Mexico and the Mediterranean but larvae found in the eastern tropical Atlantic as well. These latter samples are particularly interesting as they were collected in February, March, and August, all three outside the normal spawning season for either of the primary spawning grounds. In surveys conducted with INAPESCA, we found BFT larvae along the northern Yucatan coast in April of 2009, and 2010. None were found in April of 2011 despite an extensive survey throughout the western Caribbean. Peak spawning in the northern Gulf of Mexico is in May, so it is possible that spawning in this region was delayed in 2011, but it is also possible that spawning in this area is intermittent. Despite the many years of satellite tagging, no bluefin have been recorded as moving into the western Caribbean (pers comm Barbara Block).

Lutcavage (2012) proposed 4 hypotheses for bluefin spawning:

1. Large, sexually mature fish in good condition spawn annually, as predicted by life history models.
2. In the Gulf of Mexico, contingents of large bluefin spawn not only in springtime and in known areas but may also spawn in winter in the southern Gulf and adjacent seas, when conditions are appropriate.
3. Contingents of large bluefin also spawn in the Atlantic.
4. Spawning patterns of bluefin exhibit size dependence, similar to patterns observed in the Mediterranean. While the largest fish spawn in the Gulf of Mexico, smaller fish may spawn elsewhere.

The 2nd hypothesis proposes quite a different model than is currently accepted in regards to the timing of bluefin spawning. While we have no evidence of bluefin spawning before April in the northern Gulf of Mexico despite extensive sampling over 30 years, the extent of spawning activity in the southern and southwestern Gulf remains a question. Limited sampling by NOAA found bluefin larvae in the south-west Gulf of Mexico in April 2009, but not in 2010. NOAA has sampled the northern Caribbean throughout the Windward Islands in both winter and spring, but no bluefin larvae were found. However, as noted above, Richards (1976) found bluefin larvae in the central tropical Atlantic in the winter months on the EQUALANT survey.

The work presented here tends to support the third hypothesis; that contingents of mature bluefin also spawn in the Atlantic. However, given the limited extent of our data, this question must remain open. It is not clear if the larvae we collected represent late spawning of bluefin migrating to feeding grounds, or fish that never went into the Gulf of Mexico. Only a more extensive survey can answer that question.

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Table 1. Bluefin tuna larvae collected during the 2013 Bahamas cruise.

Station	Gear	Date Collected	Longitude	Latitude	Length (SL, mm)
015	S-10	5-May-13	-77.342	25.767	4.59
045	S-10	9-May-13	-77.995	26.303	6.65
053	NN (505)	15-May-13	-79.183	27.657	4.63
060	S-10	16-May-13	-76.801	27.998	4.82
062	S-10	16-May-13	-76.000	27.992	4.48
062	S-10	16-May-13	-76.000	27.992	7.38
067	MOC-0	17-May-13	-75.992	28.994	6.64
067	S-10	17-May-13	-75.992	28.994	3.54
067	S-10	17-May-13	-75.992	28.994	6.47
067	S-10	17-May-13	-75.992	28.994	7.58
067	S-10	17-May-13	-75.992	28.994	6.86
070	S-10	18-May-13	-76.521	29.508	7.58
083	S-10	20-May-13	-77.514	29.748	4.72
083	S-10	20-May-13	-77.514	29.748	4.01
083	S-10	20-May-13	-77.514	29.748	3.69
083	S-10	20-May-13	-77.514	29.748	3.95
083	S-10	20-May-13	-77.514	29.748	3.22
087	S-10	20-May-13	-77.983	28.493	3.44

Figure

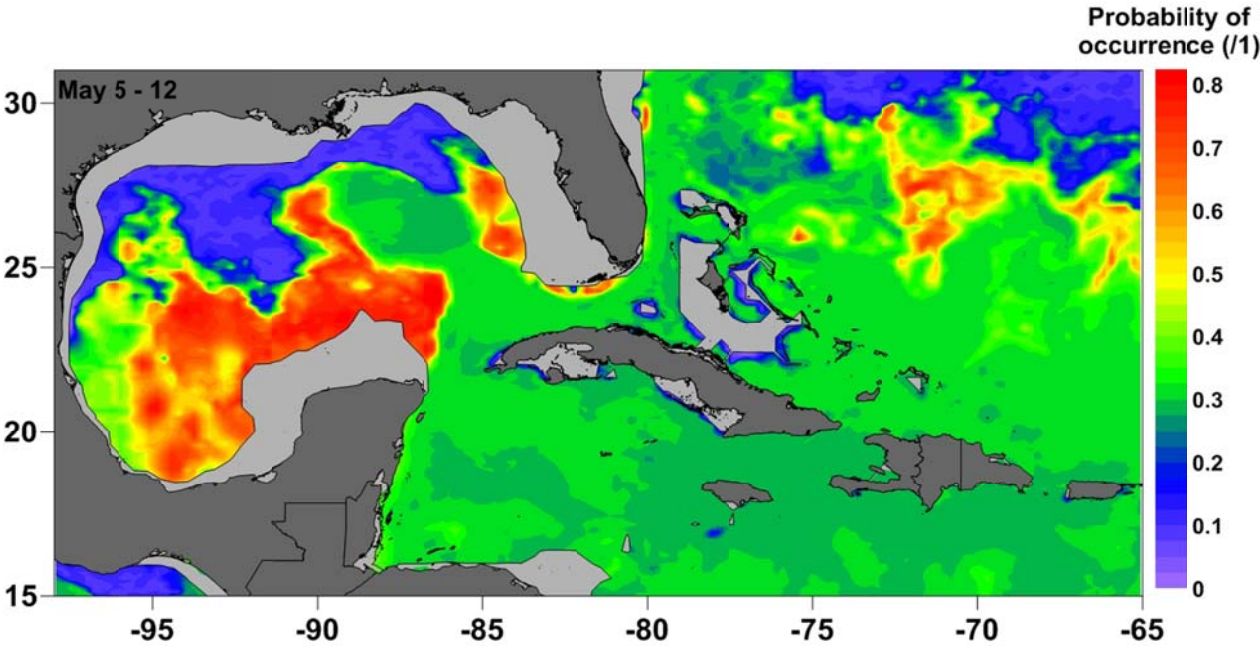
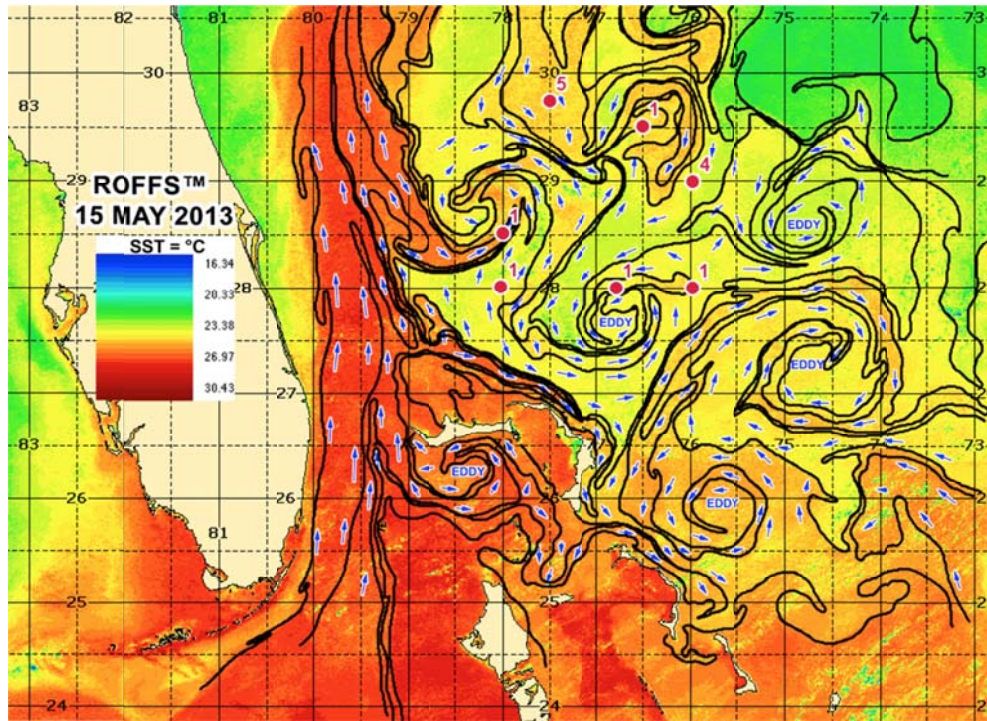


Figure 1: Probability of occurrence of larval bluefin tuna in the Gulf of Mexico and the Atlantic Ocean east of the Bahamas from an artificial neural network habitat model for May 5-12, 2013.

A



B

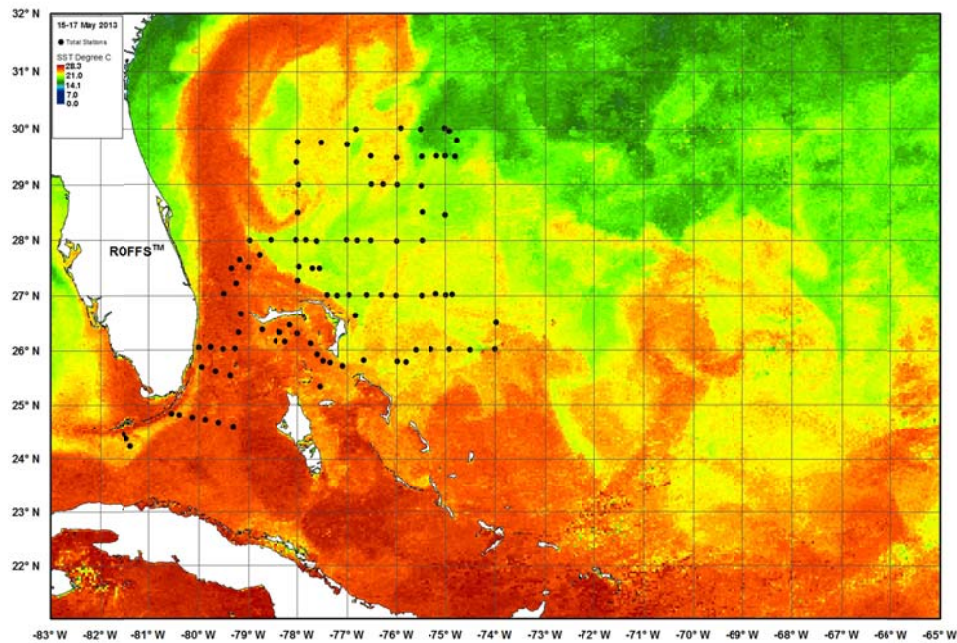


Figure 2A: Bluefin catches from the 2013 Bahamas cruise are plotted in red (●). Contours show sea surface temperature (°C) and blue arrows indicate vectors for surface flow derived from time series analysis. Figure 2B: Stations sampled during the Bahamas survey (●). Contours show sea surface temperature °C.

Figure 3: Depth of the 20°C isotherm from CTD casts. Red indicates a shallow thermocline, and blue a deep (>200m) thermocline. Stations sampled are indicated in black (+), larval bluefin catches are plotted in magenta (●).

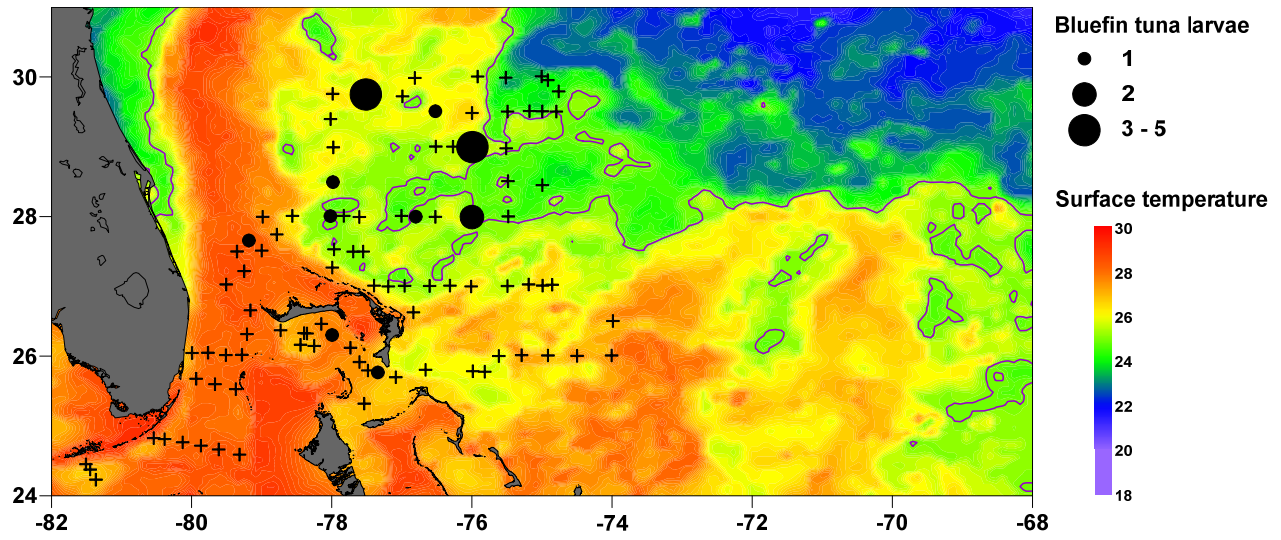
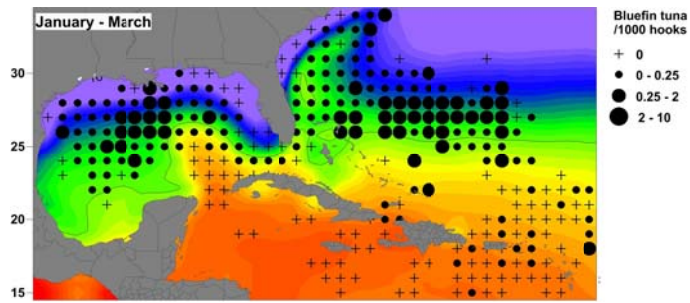
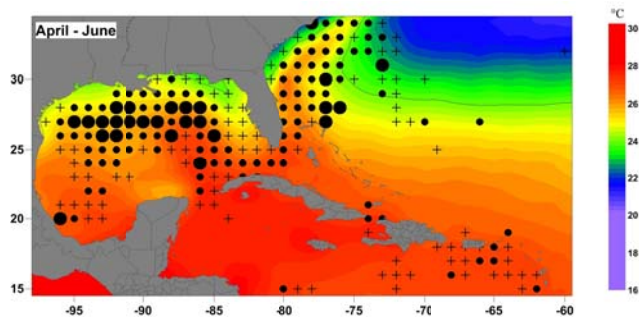


Figure 4: Larval bluefin tuna from the 2013 cruise overlaid on a climatology of surface temperature (°C) from NOAA Pathfinder. The 24°C isotherm is outlined. Stations sampled are indicated in black (+), larval bluefin catches are plotted in black (●).

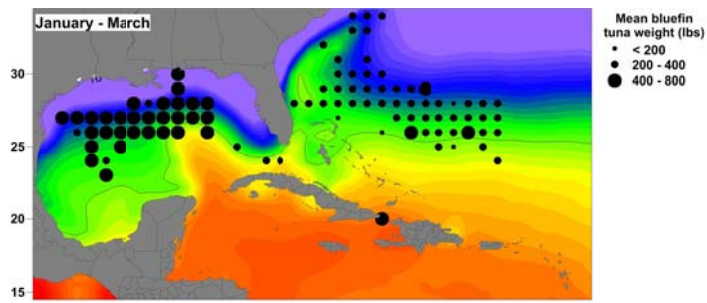
A



B



C



D

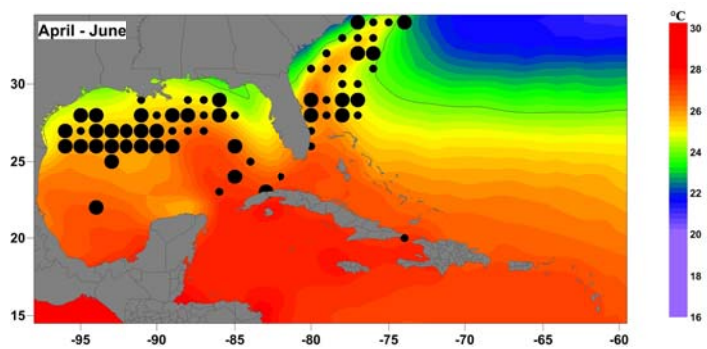


Figure 1 A, Historical bluefin catches for January -March, B, Historical catch for April-June. C is mean BFT weight for historical catches January-March, and D, mean BFT weight for historical catches from April-June. Surface temperature climatology is shown ($^{\circ}\text{C}$).