FINAL REPORT
MONKFISH RSA 2009-2011

Report title: Influence of climate on the distribution and catch rates of monkfish, *Lophius americanus*
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1. Abstract

The monkfish, *Lophius americanus* V., is an important commercial species in the Northwest Atlantic Ocean. The influence of climate on monkfish distribution and catch rates was investigated using VEMCO™ Minilog temperature and depth data loggers. Data loggers were distributed to four commercial gillnet fishermen from Cape Cod, MA south to Chincoteague, VA to record bottom temperature and depth as well as catch rates and length information for monkfish over time. In general, bottom temperatures were warmest during summer and autumn and coolest during winter and spring with little to no relation to lunar cycle at all sampling locations. Relationships between monkfish catch numbers and bottom temperatures and depths were difficult to elucidate. The majority of samples were taken from southern New England, and these were generally larger than samples from the southern sampling locations. Average total length (TL) of monkfish was 74 cm.

2. Statement of Problem:

The American monkfish or goosefish (*Lophius americanus* V.) is a fast growing, benthic species belonging to the family Lophiidae (Steimle et al., 1999). It is found in the northwest Atlantic Ocean from the Grand Banks and northern Gulf of St. Lawrence, Canada to the east coast of Florida (Steimle et al., 1999). Although the species ranges from Canada to Florida, it is most commonly found north of Cape Hatteras, North Carolina in shallow coastal waters to over 800 m (Armstrong et al., 1992).

Once considered a commercially unimportant species in the United States, *L. americanus* has become one of the highest valued finfish species in the northeast. Historically, *L. americanus* was often taken as a bycatch species in the groundfish and scallop fisheries (Armstrong et al. 1992). The popularity of monkfish as a food fish began to grow following a decline of traditional groundfish species in the 1970s and 1980s (Armstrong et al. 1992). Since then, the demand for monkfish has increased dramatically and the species may face overfishing in certain parts of its range. However, some aspects of monkfish biology and life history are not well known. One such aspect is the effect of thermal conditions on the distribution and abundance of monkfish within their geographic range. Currently, little information exists about the influence of changing sea temperatures on the movement and behavior of monkfish. Previous findings suggest that sea water temperature shifts may have an effect on seasonal onshore-offshore movements and influence inshore spawning migrations. Sea water temperature changes could

potentially affect the distribution and abundance of adults and juveniles, the timing and locations for spawning, the successful development of larvae, and may also help regulate the movement and availability of important prey species. Acquiring knowledge about the influence of thermal conditions on monkfish behavior is important because it would offer us a better understanding of the biology and life history and provide information to aid in the management of the fishery in the northwest Atlantic. Further, improving the present knowledge of thermal influences may provide a basis for assessing the effects of climate change on monkfish movements and behavior in the future

Project Objectives

The overall objective of this study was to investigate the influence of water temperature on monkfish distribution and behavior. These specific objectives of the project were continued from our 2008 project, and performed utilizing commercial gillnet Minilog data collection:

Objective 1: *Define monkfish thermal habitat*

Objective 2: *Investigate whether there have been latitudinal shifts in monkfish distribution over time that can be correlated with temperature*

Objective 3: *Investigate whether migration (as evidence by increased catch rates in gillnets) is correlated with temperature, lunar cycle, currents, or weather patterns*

Objective 4: *Determine whether the seasonal movement of reproductively active monkfish can be correlated with temperature*

3. Methods

Sampling locations

Sampling for monkfish by commercial gillnet fishermen took place at various sites throughout the Northwest Atlantic from Cape Cod, MA south to Chincoteague, VA (Table 1; Figure 1). Data sampling and collection occurred during the winter/spring and summer/autumn monkfish fishing seasons depending on location. In areas north of the New Jersey coast, sampling generally occurred from April to July and October to February. Sampling in areas off the coast of Maryland and Virginia generally occurred from April/May to June and November to February.

Sampling locations were considered fixed sites though on rare occasions, conflicts with other fishing gear or nuisance species (e.g. isopod “sea-lice”) or low catches forced fishermen to move their nets to new locations. Since it was not possible to insure that sampling gear would remain in the exact location of deployment, locations were considered fixed unless changes in position were identifiable through the data.

Sample collection
Bottom temperature (˚C) and depth (m) was recorded at each sampling site and during each gillnet deployment. Temperature and depth (pressure) loggers, VEMCO TDR 8-bit Minilog (temperature range: -4-20˚C, 0.1˚C resolution, ±0.2˚C accuracy; Depth range: 204 m, 1.2 m resolution; VEMCO Division, AMIRIX Systems Inc., 2100 Horseshoe Lake Drive, Halifax, N.S. Canada B3S 0B9; http://www.vemco.com) were distributed to four gillnet fishermen who attached them to the outer bottom edge of one panel of each gillnet with cable wire ties; one logger was utilized per net. The data loggers recorded temperature and depth information hourly during the time period that gillnets were deployed; average gillnet soak time was ~2-4 days (48-96 hrs). During sampling, each fisherman was asked to record data regarding the date and time of net deployment and retrieval, location (latitude and longitude), number of fish, total weight of catch, depth, and presence or absence of residual currents and their direction.

Data evaluation
Temperature, depth, and catch data (rough measure of CPUE = # fish caught/24 hour period) in numbers collected at each sampling location were examined separately. Relationships among these variables were explored graphically. Time-series plots of daily average bottom temperature and depth at sampling sites were constructed to examine general trends. Spikes in the data (jumps in temperature and depth reading) associated with the haul back of the fishing gear were removed prior to examining the data.

Monkfish total length measurements taken at selected sampling sites were examined graphically for patterns by plotting mean, minimum, and maximum values for each time-series.

Relationships between monkfish catch and lunar cycle or moon phase information (obtained on-line: http://aa.usno.navy.mil/data/docs/MoonPhase.php) were also explored graphically to examine whether lunar cycle had an influence on catch rates.

4. Results and Conclusions

Data evaluation
Examples of time-series plots of bottom temperature (°C) and depth (m) are presented in Figure 2 and Figure 3 where data were collected during the spring and summer by John Stolgitis off the coast of southern New England and Roger Wooleyan off the coast of Ocean City, MD. In both cases, temperatures showed an increasing trend throughout the late spring and into the summer months. Temperature and depth patterns indicated no strong relationship between the two variables. A general cooling trend is shown over time with the warmest temperatures occurring during the autumn months.

Monkfish catch (# of fish/haul) in the month of May by Chris Hickman does not show a discernable trend with lunar phase (Figure 3). Additional graphical representation of new and full lunar phases (Figure 5) with temperature and catch time series for fishing of Point Judith, RI did not indicate discernable relationships among the variables either.

There appears to be a slight indication of higher catch rates with temperatures below 8°C, which persisted through May in Spring 2009 (Figure 5-a). During winter 2009-2010 (Figure 5-c) catch rates fluctuated over time in the presence of a general cooling trend and without an apparent correlation to lunar phase. This suggests that other factors may be affecting catch rates. During the winter of 2010-2011 (Figure 5-e) catch rates decline as the winter progresses and bottom temperature drops. A decline in depth of fishing is also seen over this time period (Figure 5-f) but is minor in comparison.

Of total length (TL) measurements taken for monkfish sampled among locations, 74 cm was the average. Fish sampled by Roger Wooleyan in Washington Canyon during January to April 2011were generally smaller, averaging 68 cm TL (Figure 6). Monkfish sampled by the *F/V Wooly Bully* between February and March 2010 (Figure 6-a) were larger than those sampled between January and April 2011 in Washington Canyon (Figure 6-b). The majority of samples were taken in southern New England, and these averaged 77 cm TL. Monkfish total lengths neither varied substantially between fishing seasons nor within years (Figure 7, a-d).

Conclusions

Collection of bottom temperature and depth data by monkfish gillnetters was successful using the Minilog data loggers. Regardless of location, patterns for temperature showed warming trends during late spring to early autumn and cooling trends during late autumn to early spring. Relationships between depth, temperature, lunar cycle, and monkfish catch were difficult to discern for all sampling locations. Due to the size selectivity of gillnets used by the fishermen, monkfish caught were generally larger than 40 cm TL and averaged 74 cm.

<u>5. Project Management:</u> list individuals and/or organizations actually performing the work and how it was done.

The major collaborators on this project were from UMES, NEFSC, and the fishing industry.

1. **University of Maryland Eastern Shore**
   Minilog data loggers were distributed and temperature, depth, and monkfish catch information was collected and processed by Dr. Johnson, Mr. Daniel Cullen, and Mr. Evan Lindsay
2. **Northeast Fisheries Science Center**
   Fishery independent research vessel bottom trawl survey data were collected and provided by NEFSC. All data were analyzed by Dr. Johnson, Mr. Daniel Cullen and Mr. Evan Lindsay in collaboration with Drs. Richards and McBride from NEFSC.
3. **Monkfish gillnetters**
   Data and sample collection by gillnetters occurred at three sites along the coast of New England and the Mid-Atlantic region. These industry collaborators were Chris Hickman (*F/V Bout Time*) John Stolgitis (*F/V Martha Porter*) and Roger Wooleyan (*F/V Wooly Bully*).

6. Financial Report

A total of $54,177.38 was received from sale of monkfish by gillnetters participating in the RSA (see Table 2). A total of $56,284 was spent during this funding period. Additional funds ($8841) from (2008/2009) were used to offset expenses.

RESEARCH BUDGET			
GRANTEE:	Project Title: Influence of climate on the distribution and catch rates of monkfish, *Lophius americanus*		
A. SALARIES AND WAGES			
1 SENIOR PERSONNEL		Total Time (Mo	Expenditures
a. Principal Investigator:	Andrea Johnson	3	
b. Graduate Student:	Daniel Cullen	12	
	Evan Lindsay	12	
c. Undergraduate Students (2):			$31,541
Total Salaries and Wages			$31,541
B. PERMANENT EQUIPMENT			
C. EXPENDABLE SUPPLIES AND EQUIPMENT			$10,578
D. TRAVEL			$14,165
E. PUBLICATIONS AND DOCUMENTATION COSTS			
F. OTHER COSTS			
TOTAL DIRECT COSTS			$56,284

7. Evaluation

A. Describe the extent to which the project goals and objectives were attained. This description should address the following:

1. Were the goals and objectives attained? How? If not, why?
2. Were modifications made to the goals and objectives? If so, explain.

Objectives 1 and 2: Results from these two objectives have been completed in 2010 (see Appendix 1).

Objective 3: Evidence of an influence of lunar cycle and bottom temperature on monkfish migration was not indicated by catch rates. Relationships between these variables were unclear. Additional data collection is required to uncover possible relationships since additional variables may have contributed to the observed patterns in monkfish catch rates.

Objective 4: The investigation of whether a seasonal movement of reproductively active monkfish is related to temperature is underway. Gonad tissue samples have been collected and processed for histology. The reproductive state of sampled fish is currently being assessed. Additional time is needed to analyze whether a relationship exists between reproductive state and ocean temperature and whether this can be linked to seasonal movements.

B. If significant problems developed which resulted in less than satisfactory or negative results, they should be discussed.

Significant problems did not develop despite the inability to fully attain all the objectives of the study. One problem that did arise for the gillnet fishermen involved conflicts with other fishing gear where gillnets with attached data probes were dragged away by trawlers. In these instances, the data probes were not recovered and the data were lost. A second problem encountered was the expiration of batteries during the deployment of some data loggers. In these instances, an absence of data ranging in duration from days to weeks resulted. While battery life can be estimated with reference to data probe deployment history and data log frequency, this cannot be defined. The currently used data probe model (TDR 8-bit) is the most up-to-date logger with temperature-depth capacity offered by VEMCO. Unfortunately, this model neither provides information on reserve battery life, nor the capability of battery recharge/exchange. However, data probe LED light blink pattern frequency alters when a battery reaches reserve level, but this was not observed during deployment.

2. Dissemination of project results:
Explain, in detail, how the project's results have been, and will be disseminated.

This research provided partial fulfillment of the requirements for a Master of Science degree for Mr. Daniel Cullen (graduated-Spring 2010).A manuscript of the results of this study is being prepared by Mr. Cullen and will be submitted for publication to the ICES Journal of Marine Science.

The results have been presented at the following scientific conferences below:

1. "Temperature and Depth Associations of Monkfish (*Lophius americanus*)" American Fisheries Society 139th Annual Meeting, Nashville, Tennessee (August 30 to September 3, 2009). Oral presentation by Daniel Cullen (UMES M.S. student)
2. "Temperature and Depth Associations of Monkfish (*Lophius americanus*)" NOAA 5th Annual Education and Science Forum, Howard University, Washington D.C. (November 12 to 14, 2009). Oral presentation by Daniel Cullen (UMES M.S. student)

Results will be presented at the following:

1. "Fecundity estimation of American goosefish (*Lophius americanus*) in the western North Atlantic Ocean" American Fisheries Society 141st Annual Meeting, Seattle, Washington (Sept. 4-8, 2011). Poster presentation by Evan Lindsay (UMES M.S. student) and Courtnee DePass (UMES B.S. student)

8. References

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Table 1. Location, position, and times of data collection for monkfish gillnetters.

Monkfish Gillnetters	Location	Position	Months of Data Collection	Sample Collection
Brian Roche	Cape Cod, MA; F/V Lady Irene	Lat: 42° 00' 00" N Lon: 69° 15' 00" W	None	None
John Stolgitis	Pt. Judith, RI; F/V Martha Porter	Lat: 40° 56' 41" N Lon: 71° 45' 16" W	October to February & April to August	Length Composition
Chris Hickman	Chincoteague, VA; F/V Bout Time	Lat: 37° 56' 00" N Lon: 74° 58' 00" W	December to February & May	Length Composition
Roger Wooleyan	Ocean City, MD; F/V Wooly Bully	Lat: 38° 03' 21" N Lon: 74° 49' 56" W	November to February & April to May	Length Composition Gonad Tissue Samples

Table 2. Monkfish landings information collected from May 2009 to April 2011.

DAS	VTR	F/V	Landing Date	Port Landed	Whole wt.	Amt. Sold ($)	Research Funds ($)
0.625	11451204	Martha Porter	5/30/2009	Point Judith, RI	5125	$7,060.15	$1,069
0.625	11451205	Martha Porter	6/1/2009	Point Judith, RI	4140	$5,856.00	$899
0.625	11451206	Martha Porter	6/3/2009	Point Judith, RI	3840	$5,228.00	$784
0.625	11451207	Martha Porter	6/7/2009	Point Judith, RI	2700	$3,870.30	$582
0.625	11451208	Martha Porter	6/8/2009	Point Judith, RI	1430	$1,921.68	$289
0.625	11451209	Martha Porter	6/10/2009	Point Judith, RI	2300	$3,295.80	$494
0.625	11451210	Martha Porter	6/14/2009	Point Judith, RI	4020	$5,375.95	$807
0.625	11451211	Martha Porter	6/15/2009	Point Judith, RI	2085	$2,978.60	$449
0.625	11451212	Martha Porter	6/17/2009	Point Judith, RI	2535	$3,434.00	$514
0.64	11451213	Martha Porter	6/20/2009	Point Judith, RI	1850	$2,575.25	$386
0.625	11451214	Martha Porter	6/24/2009	Point Judith, RI	3200	$4,281.00	$603
0.625	11451215	Martha Porter	6/26/2009	Point Judith, RI	1225	$1,604.00	$240
0.625	11451216	Martha Porter	6/28/2009	Point Judith, RI	3630	$4,778.30	$717
0.625	11451217	Martha Porter	6/30/2009	Point Judith, RI	1830	$2,358.50	$354
0.625	11451218	Martha Porter	7/1/2009	Point Judith, RI	3000	$3,826.50	$574
0.625	11451219	Martha Porter	7/4/2009	Point Judith, RI	1660	$2,143.50	$322
0.625	11451220	Martha Porter	7/5/2009	Point Judith, RI	2130	$2,775.00	$416
0.625	11451221	Martha Porter	7/7/2009	Point Judith, RI	1380	$1,795.00	$269
0.625	11451222	Martha Porter	7/10/2009	Point Judith, RI	1570	$2,109.00	$316
0.625	11451223	Martha Porter	7/14/2009	Point Judith, RI	3600	$4,588.30	$688
0.625	11451224	Martha Porter	7/15/2009	Point Judith, RI	1820	$2,371.15	$360
0.625	11451225	Martha Porter	7/19/2009	Point Judith, RI	1860	$2,440.60	$369
0.625	11451226	Martha Porter	7/20/2009	Point Judith, RI	1300	$1,701.50	$261
0.63	11451229	Martha Porter	7/23/2009	Point Judith, RI	1270	$1,447.50	$220
0.625	11451227	Martha Porter	7/28/2009	Point Judith, RI	1610	$2,115.26	$330
0.625	11451231	Martha Porter	7/31/2009	Point Judith, RI	850	$1,090.90	$160.00
0.625	11451232	Martha Porter	8/3/2009	Point Judith, RI	0	$236.40	$30.00
0.625	11451230	Martha Porter	8/4/2009	Point Judith, RI	455	$582.25	$80.00
0.625	11451237	Martha Porter	10/26/2009	Point Judith, RI	80	$135.00	$26
0.625	11451238	Martha Porter	10/27/2009	Point Judith, RI	850	$1,782.00	$274
0.625	11451242	Martha Porter	11/5/2009	Point Judith, RI	1339.8	$3,700.24	$555.00
0.625	Gear Set	Martha Porter	4/12/2010	Point Judith, RI	40		
0.625	11518966	Martha Porter	5/7/2010	Point Judith, RI	3,251	$4,280.00	$642.00
0.625	11518967	Martha Porter	5/11/2010	Point Judith, RI	3,199	$4,218.25	$633.00
0.625	11518971	Martha Porter	5/16/2010	Point Judith, RI	3,549	$4,537.80	$430.00
0.625	11518972	Martha Porter	5/17/2010	Point Judith, RI	1,606	$2,916.05	$620.00
0.625	11518973	Martha Porter	5/21/2010	Point Judith, RI	4,723	$6,182.00	$927.00
0.625	11518973	Martha Porter	5/23/2010	Point Judith, RI	3,449	$4,581.00	$688.00
0.625	11518976	Martha Porter	5/28/2010	Point Judith, RI	332	$4,890.00	$733.00

0.625	11518977	Martha Porter	5/30/2010	Point Judith, RI	0	$4,765.60	$714.00
0.625	11518978	Martha Porter	5/31/2010	Point Judith, RI	3,015	$4,421.60	$663.00
0.625	11518980	Martha Porter	6/4/2010	Point Judith, RI	2,784	$3,882.00	$582.00
0.625	11518981	Martha Porter	6/7/2010	Point Judith, RI	3,208	$4,143.00	$621.00
0.625	11518982	Martha Porter	6/8/2010	Point Judith, RI	2,433	$3,420.00	$514.00
0.625	11518983	Martha Porter	6/11/2010	Point Judith, RI	2,599	$3,427.00	$510.00
0.625	11518986	Martha Porter	6/16/2010	Point Judith, RI	2,690	$4,050.00	$605.00
0.625	11518988	Martha Porter	6/19/2010	Point Judith, RI	1,499	$2,013.00	$302.00
0.625	11518989	Martha Porter	6/21/2010	Point Judith, RI	2,842	$3,629.00	$544.00
0.625	11518991	Martha Porter	6/23/2010	Point Judith, RI	1,993	$2,495.00	$374.00
0.625	11518992	Martha Porter	6/29/2010	Point Judith, RI	1,893	$2,394.00	$360.00
0.625	11518996	Martha Porter	7/3/2010	Point Judith, RI	1,379	$1,729.00	$260.00
0.625	11518997	Martha Porter	7/5/2010	Point Judith, RI	1,646	$2,025.00	$303.00
0.625	11518998	Martha Porter	7/7/2010	Point Judith, RI	1,046	$1,363.00	$204.00
0.625	11519099	Martha Porter	7/10/2010	Point Judith, RI	1,070	$1,454.00	$220.00
0.625	11519000	Martha Porter	7/13/2010	Point Judith, RI	1,200	$1,522.00	$228.00
0.625	11668101	Martha Porter	7/15/2010	Point Judith, RI	1,313	$1,659.00	$250.00
0.625	11668102	Martha Porter	7/18/2010	Point Judith, RI	1,383	$1,712.00	$257.00
1.28	11668103	Martha Porter	7/20/2010	Point Judith, RI	708	$894.00	$135.00
2.23	11668104	Martha Porter	7/27/2010	Point Judith, RI	557	$692.00	$105.00
0.625	11668123	Martha Porter	10/29/2010	Point Judith, RI	1,726	$2,933.00	$440.00
1.302	11668126	Martha Porter	11/7/10	Point Judith, RI	0	$2,211.00	$330.00
1.326	11668127	Martha Porter	11/14/10	Point Judith, RI	25	$1,850.60	$280.00
1.573	11668142	Martha Porter	1/1/11	Point Judith, RI	275	$1,094.60	$168.00
1.441	11668143	Martha Porter	1/3/11	Point Judith, RI	460	$942.95	$142.00
1.389	11668144	Martha Porter	1/7/11	Point Judith, RI	300	$1,075.00	$165.00
0.625	11668149	Martha Porter	4/25/11	Point Judith, RI	355	$1,022.70	$155.00
47.436						**$78,473.05**	**$27,542**
0.45	10422341	Wooley Bully	1/19/2010	Ocean City, MD	1804.0	$2,986.85	$448.02
1.03	10422342	Wooley Bully	1/28/2010	Ocean City, MD	365.0	$1,085.94	$250.00
0.71	10422343	Wooley Bully	2/4/2010	Ocean City, MD	684.8	$1,098.25	$250.00
1.08	10422344	Wooley Bully	3/1/2010	Ocean City, MD	2043.0	$3,398.50	$509.77
1.01	10422345	Wooley Bully	3/7/2010	Ocean City, MD	1188.0	$2,032.50	$304.67
1.2	10422347	Wooley Bully	3/21/2010	Ocean City, MD	2024.0	$2,882.20	$432.94
1.25	10422348	Wooley Bully	3/26/2010	Ocean City, MD	3065.0	$4,315.25	$647.28
1.25	10422349	Wooley Bully	4/2/2010	Ocean City, MD	3258.8	$4,033.20	$604.98
	11514824	Wooley Bully	5/8/2010	Ocean City, MD	2940	$2,897.00	$434.00
1.01	11514825	Wooley Bully	5/12/2010	Ocean City, MD	3050	$3,991.00	$598.65
1.01	11514828	Wooley Bully	5/17/2010	Ocean City, MD	2450	$3,944.00	$591.00
0.625	11514830	Wooley Bully	5/20/2010	Ocean City, MD	1500	$1,917.00	$287.55
	11514872	Wooley Bully	12/04/10	Ocean City, MD	2,259	$4,804.05	$720.60
0.763	11514876	Wooley Bully	01/25/11	Ocean City, MD	5,155	$9,262.25	$1,389.33

1.312	11514878	Wooley Bully	01/29/11	Ocean City, MD	4,576	$8,227.10	$1,233.97
0.625	11514881	Wooley Bully	2/1/2011	Ocean City, MD	3,000	$11,270.00	$1,690.05
1.002	11514882	Wooley Bully	2/4/2011	Ocean City, MD	3,200	$6,810.30	$1,027.44
1.174	11514884	Wooley Bully	2/12/2011	Ocean City, MD	3,041	$5,385.40	$818.98
1.135	11514886	Wooley Bully	2/17/2011	Ocean City, MD	2,420	$4,210.60	$635.58
1.383	11514891	Wooley Bully	3/26/2011	Ocean City, MD	4,250	$6,626.70	$994.00
1.226	11514892	Wooley Bully	3/30/2011	Ocean City, MD	2,827	$4,209.65	$631.36
2.842	11514893	Wooley Bully	4/9/2011	Ocean City, MD	3,036	$4,914.20	$737.22
1.306	11514894	Wooley Bully	4/11/2011	Ocean City, MD	2,814	$4,388.60	$657.98
23.393						**$104,690.54**	**$15,895**
1.46	11254984	Gulf Voyager	1/6/2010	New Bedford, MA	199.2	2586.30	443.42
1.61	11254985	Gulf Voyager	1/11/2010	New Bedford, MA	1540.0	4054.30	527.06
2.13	11254986	Gulf Voyager	1/15/2010	New Bedford, MA	647.4	8519.34	1,107.51
1.84	11254987	Gulf Voyager	1/22/2010	New Bedford, MA	4542.0	10363.90	1,554.31
1.61	11254988	Gulf Voyager	1/28/2010	New Bedford, MA	3784.0	9601.35	1,381.18
1.6	11254989	Gulf Voyager	2/6/2010	New Bedford, MA	5037.2	7119.59	925.55
1.66	11254990	Gulf Voyager	2/14/2010	New Bedford, MA	6822.6	11499.25	1,494.90
1.55	11254991	Gulf Voyager	2/23/2010	New Bedford, MA	5024.0	6597.70	857.70
2.36	11254992	Gulf Voyager	3/9/2010	New Bedford, MA	7548.8	11993.25	1,559.12
15.82						**72334.98**	**9850.76**
1.642		Reginas Pride	3/21/2011	New Bedford, MA	3216	$5,928.00	$889.26
88.291						**622334.87**	**$54,177.36**

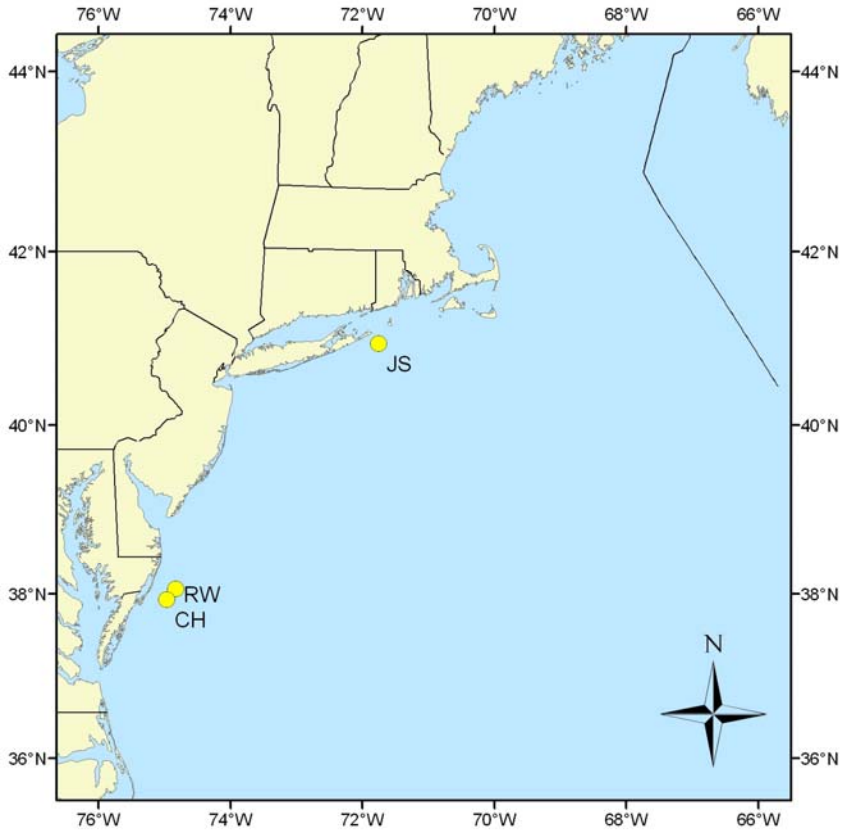
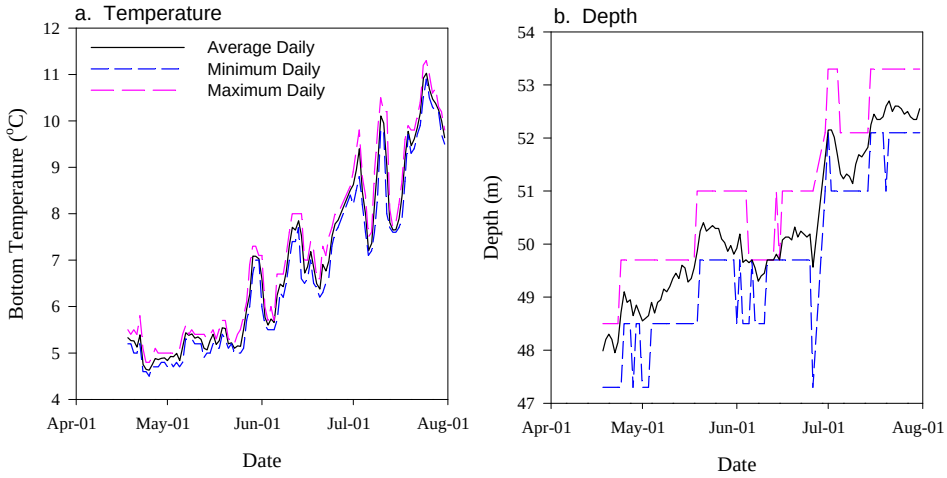


Figure 1. Sampling locations for monkfish gillnetters from May 2009 to April 2011 (JS = John Stolgitis, RW = Roger Wooleyan, CH = Chris Hickman).



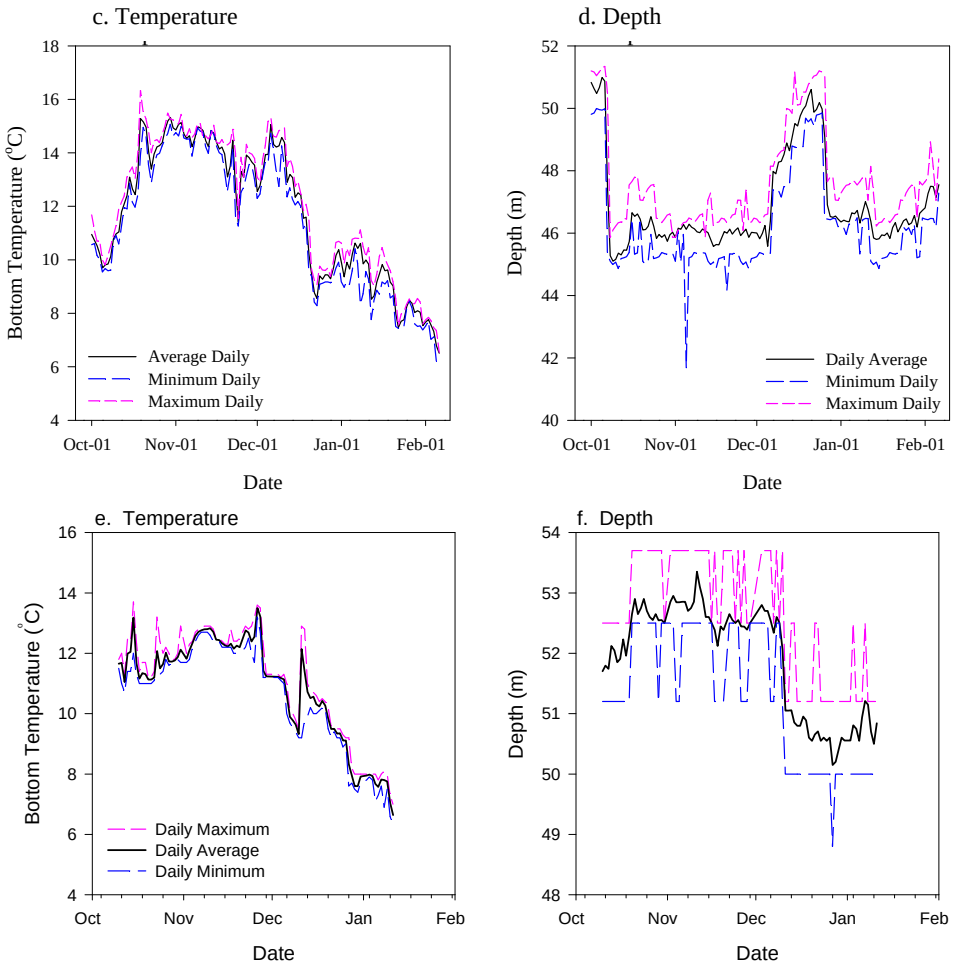
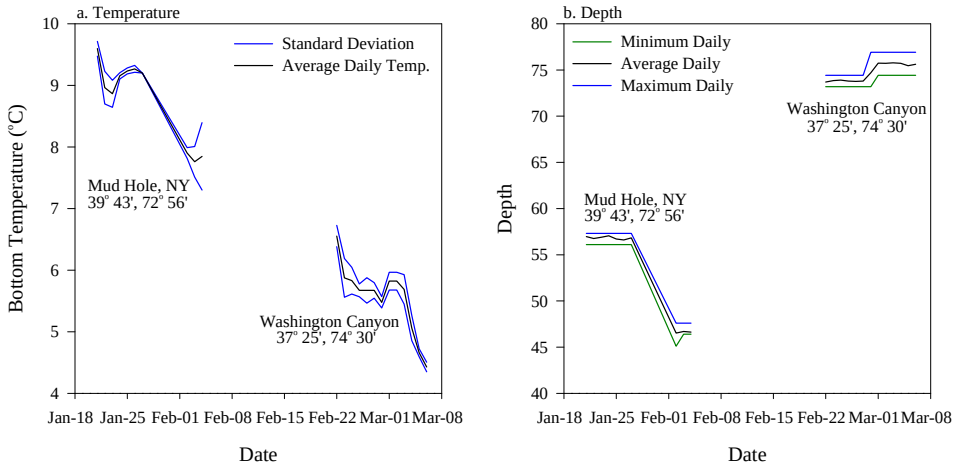


Figure 2. Bottom temperature and depth (m) time-series collected from (a-b) April to August 2009, (c-d) October 2009 to February 2010 and (e-f) October 2010 to February 2011off Pt. Judith, RI.



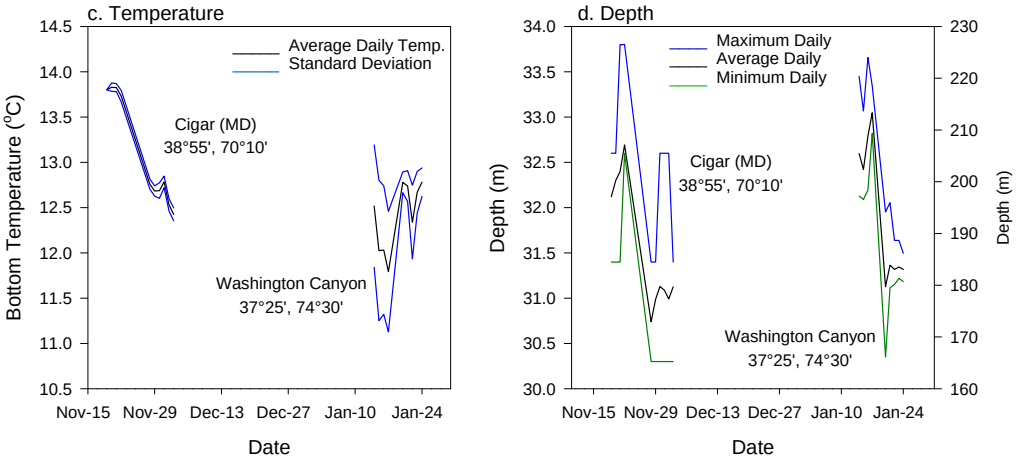
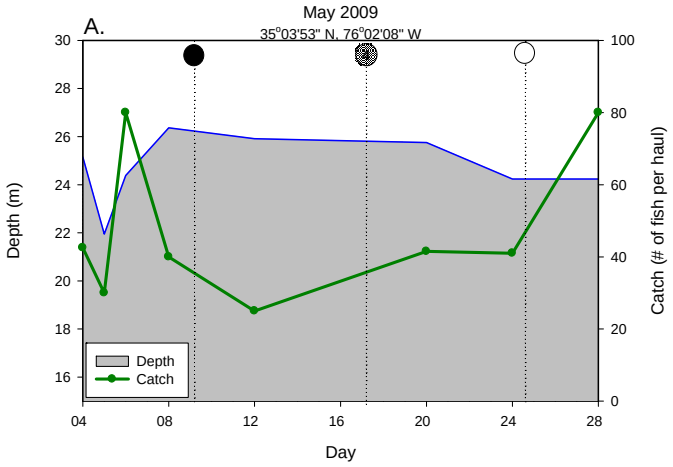


Figure 3. Bottom temperature (˚C) and depth (m) time series for three locations (Mud Hole, NY; Cigar, MD; Washington Canyon) sampled by the F/V Wooly Bully from (a-b) January to March 2010 and (c-d) November 2010 to February 2011.



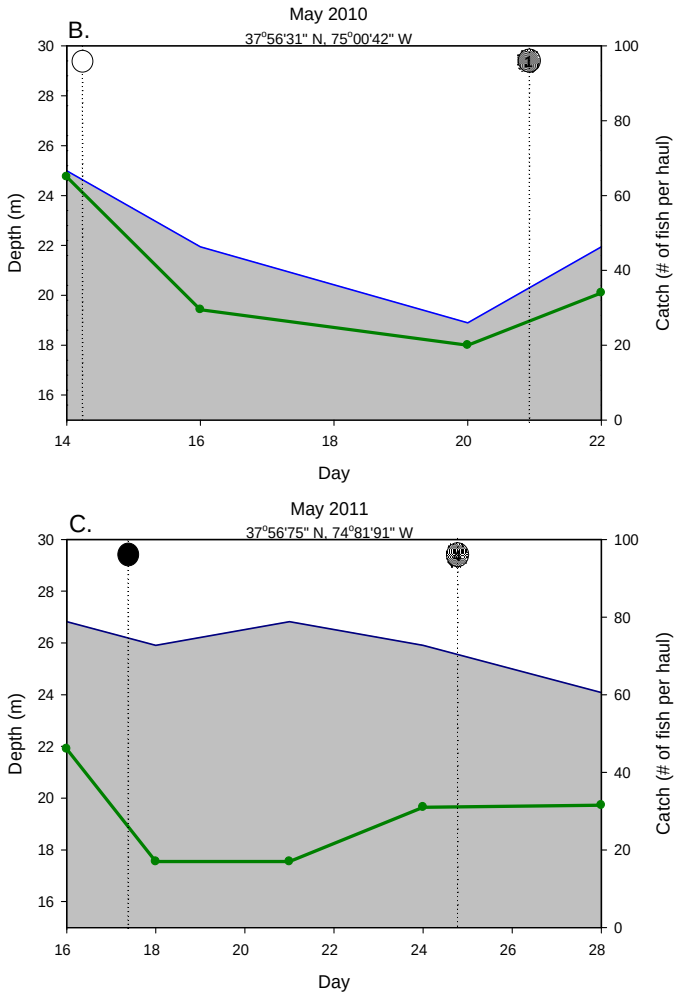
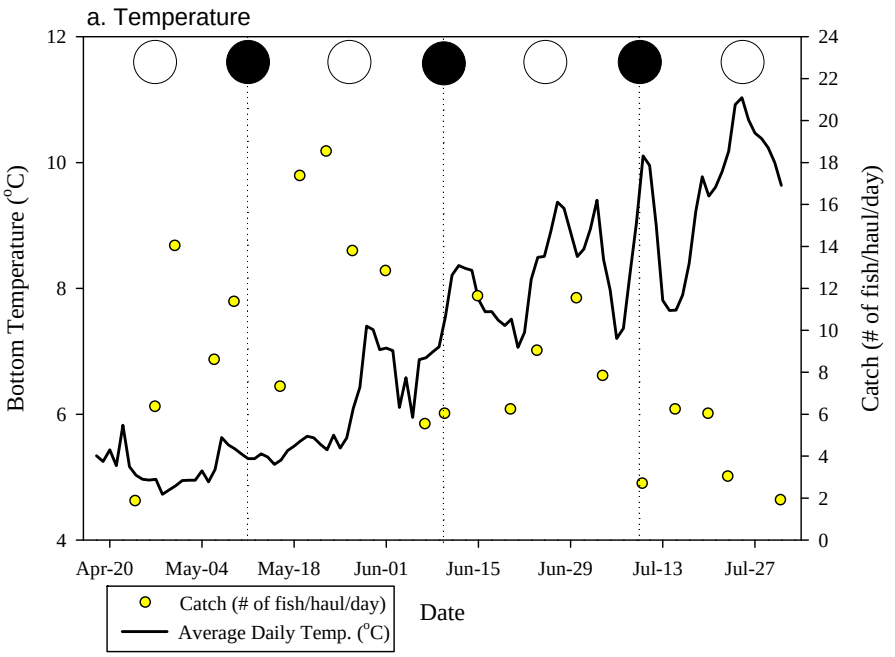
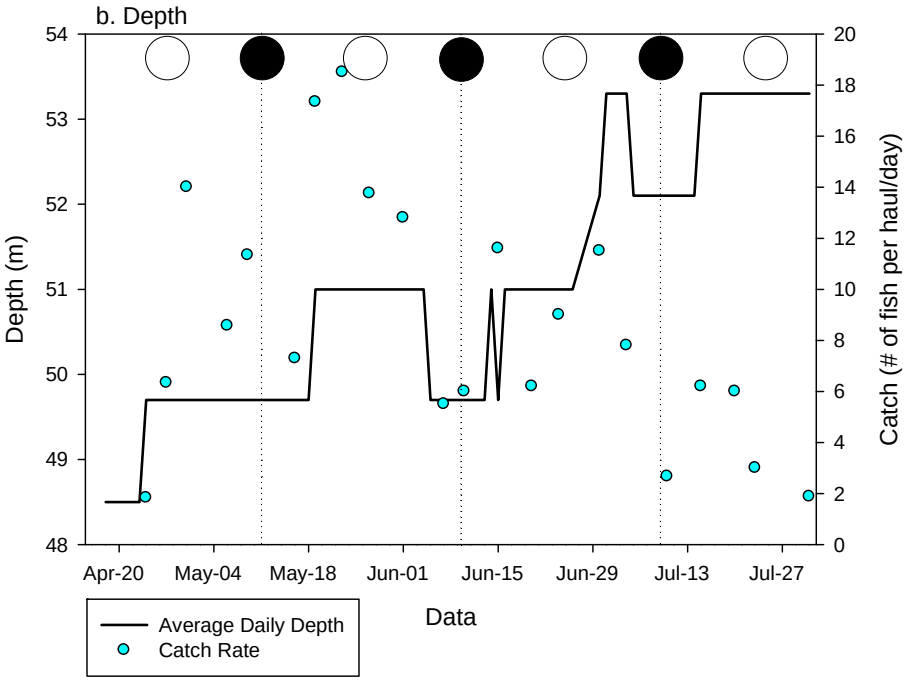
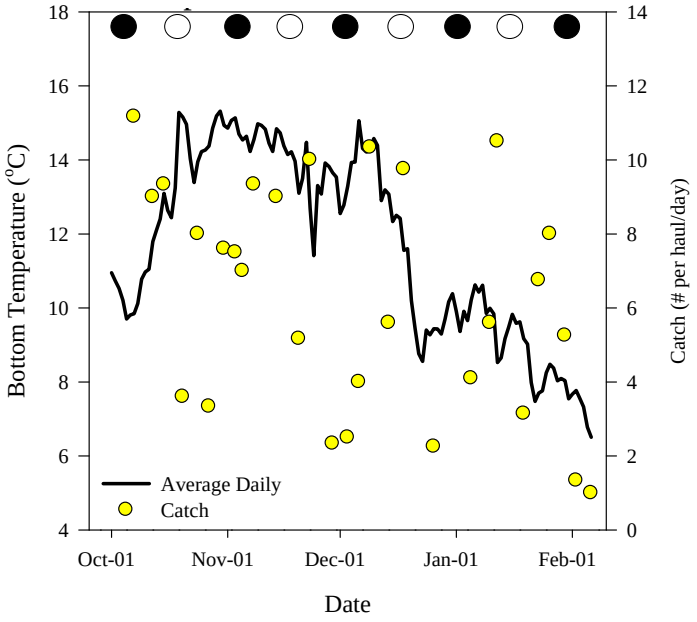


Figure 4. Comparison of depth fished and catch during the month of May in years A) 2009, B) 2010 and C) 2011 by Chris Hickman off the coast of Chincoteague, VA. Lunar phases, New (○), First Quarter (sphere, grey-1), Full (●), and Last Quarter (sphere, grey-4) present during the month of May are displayed.

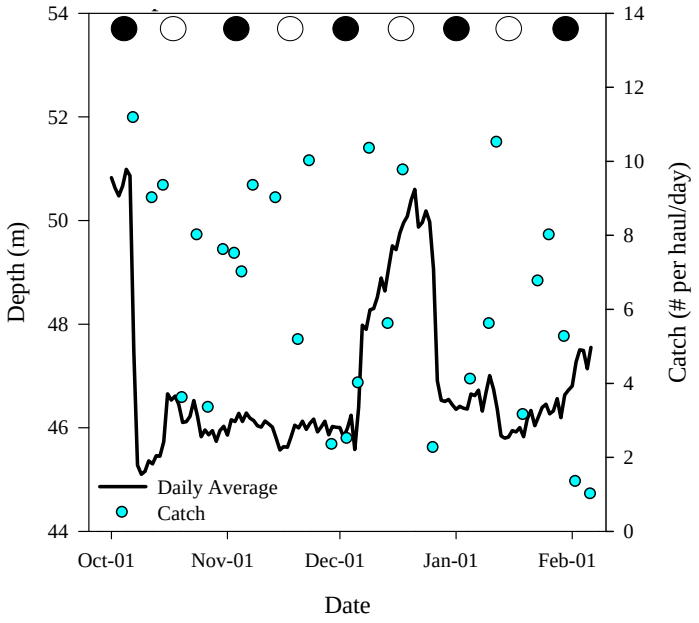

a. Temperature
Bottom Temperature (°C)
Catch (# of fish/haul/day)
12
10
8
6
4
24
22
20
18
16
14
12
10
8
6
4
2
0
Apr-20
May-04
May-18
Jun-01
Jun-15
Jun-29
Jul-13
Jul-27
Date
Catch (# of fish/haul/day)
Average Daily Temp. (°C)


b. Depth
Depth (m)
Catch (# of fish per haul/day)
54
53
52
51
50
49
48
20
18
16
14
12
10
8
6
4
2
0
Apr-20
May-04
May-18
Jun-01
Jun-15
Jun-29
Jul-13
Jul-27
Data
Average Daily Depth
Catch Rate

c. Temperature



d. Depth



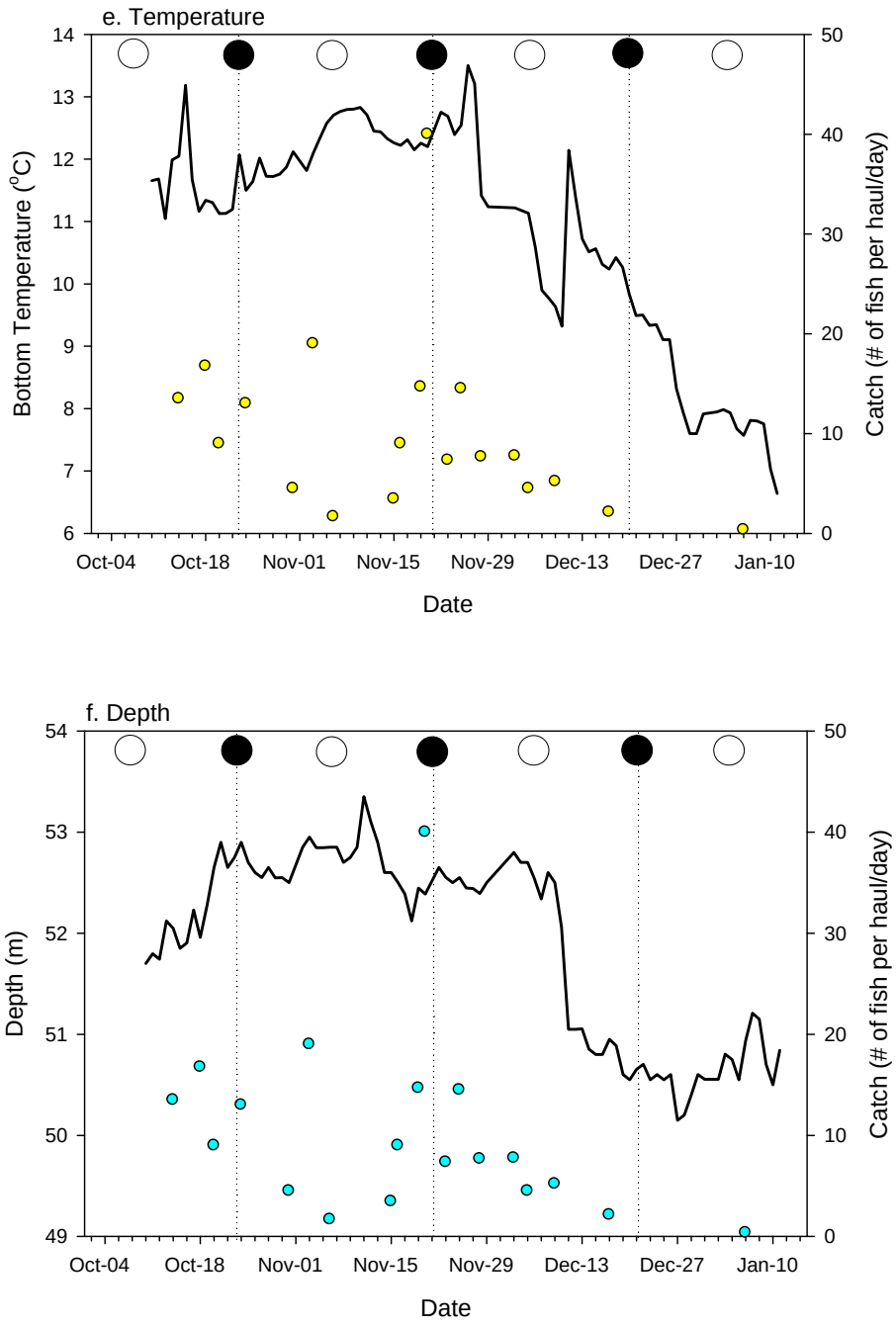


Figure 5. Comparison of bottom temperature and depth with monkfish catch sampled from a-b) April to August 2009, c-d) October 2009 to February 2010 and e-f) October 2010 to January 2011 off the coast of Pt. Judith, RI. Full (●) and new (○) lunar phases present during each month are displayed.

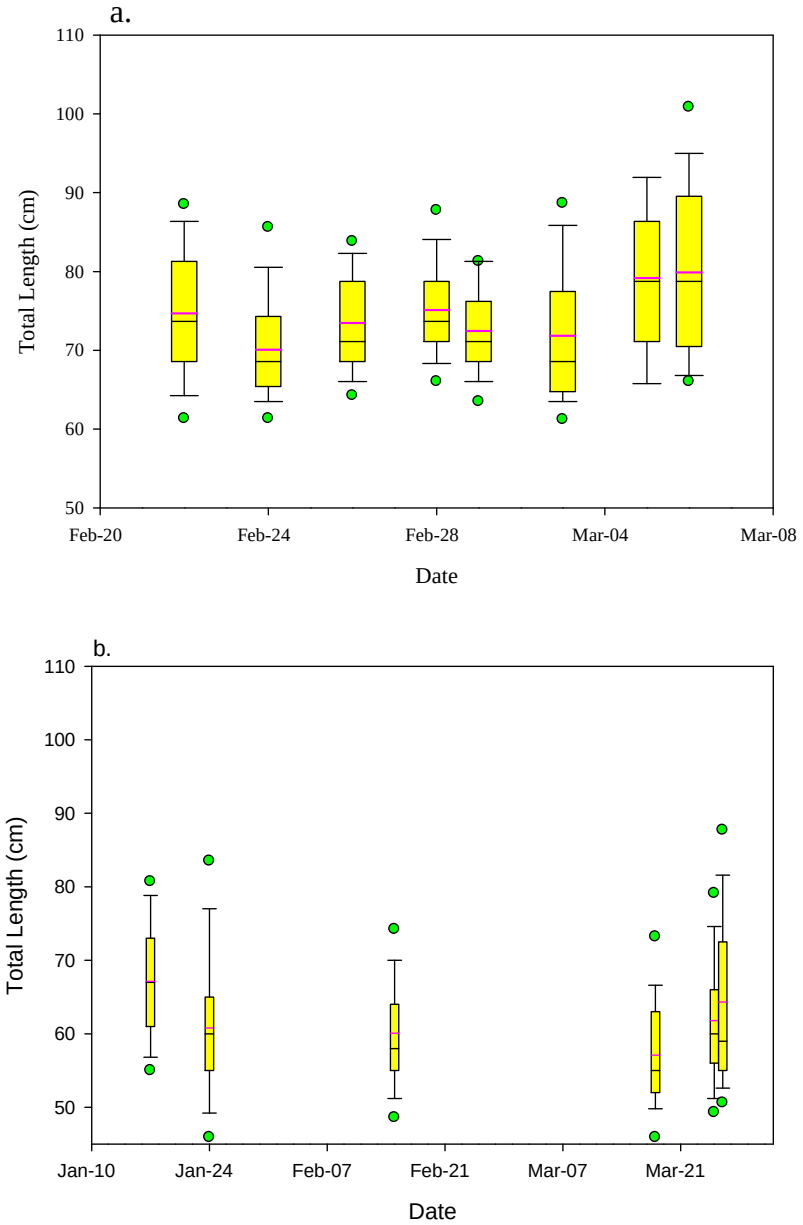
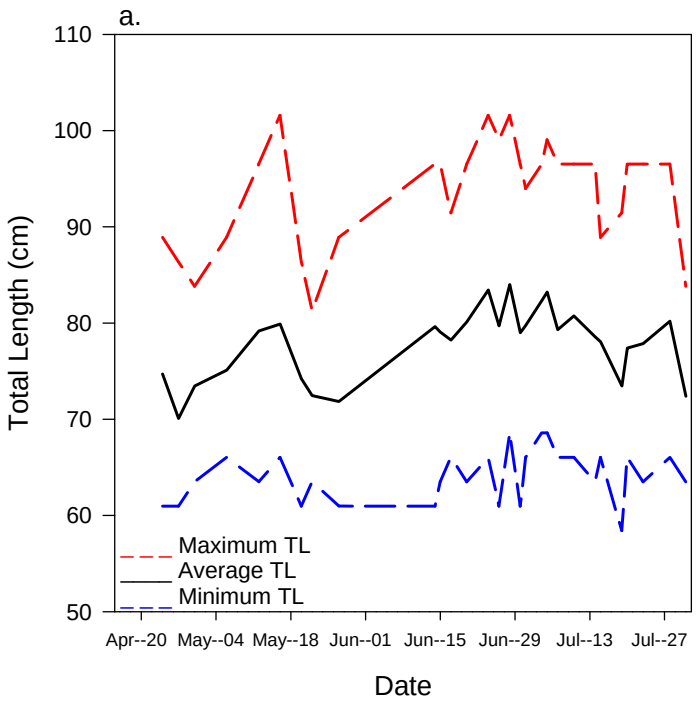
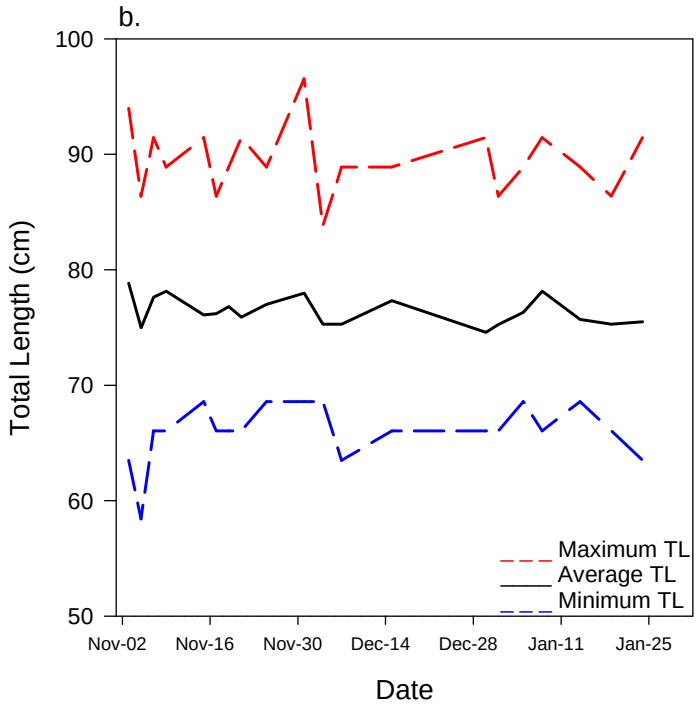
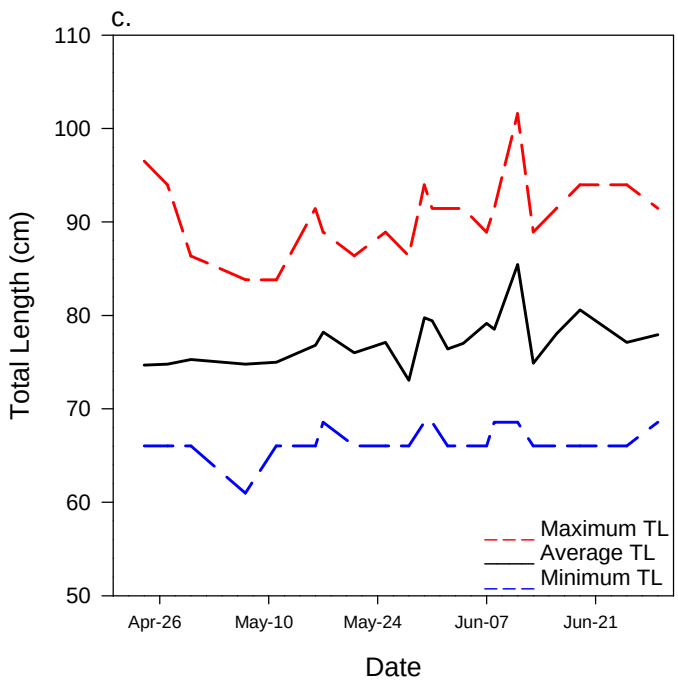


Figure 6. Box plots of total length for monkfish caught at Washington Canyon by the F/V Wooley Bully from a) February to March 2010 and b) January to April 2011. Boxes represent the 25th and 75th percentiles, whisker bars represent the 10th and 90th percentiles, solid black line represents the 50th percentile (median), solid pink line indicates the mean, and green circles represent 95% confidence intervals.


a.
110
100
90
80
70
60
50
Total Length (cm)
Maximum TL
Average TL
Minimum TL
Apr--20
May--04
May--18
Jun--01
Jun--15
Jun--29
Jul--13
Jul--27
Date


b.
100
90
80
70
60
50
Total Length (cm)
Maximum TL
Average TL
Minimum TL
Nov-02
Nov-16
Nov-30
Dec-14
Dec-28
Jan-11
Jan-25
Date



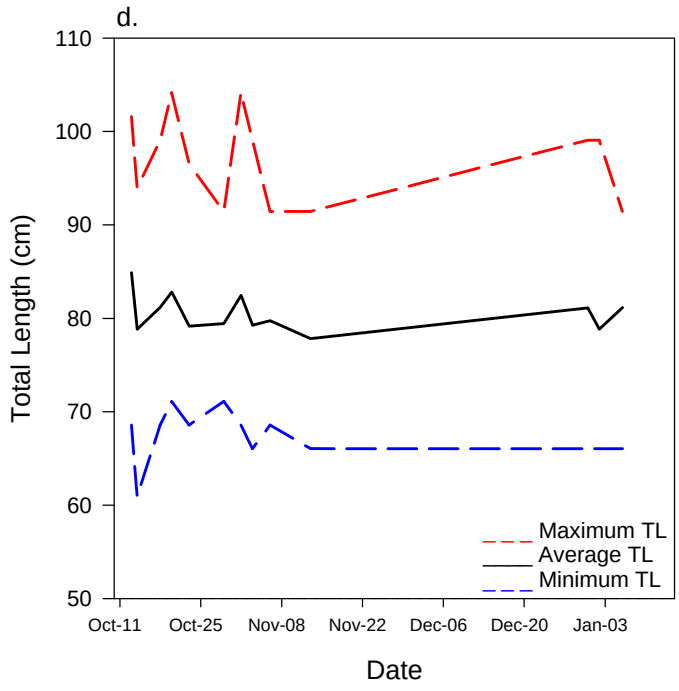


Figure 7. Mean, maximum, and minimum total lengths (cm) for monkfish sampled from a) April to August 2009 b) November 2009 to February 2010 c) April to July 2010 d) October 2010 to January 2011 off the coast of Pt. Judith.

APPENDIX 1

Currently, little information exists about the influence of changing sea water temperatures on the movement and behavior of monkfish. Previous findings suggest that sea water temperature shifts may have an effect on seasonal onshore-offshore movements and influence inshore spawning migrations. Sea water temperature changes could potentially affect the distribution and abundance of adults and juveniles, the timing and locations for spawning, the successful development of larvae, and may also help regulate the movement and availability of important prey species. Acquiring knowledge about the influence of thermal conditions on monkfish behavior is important because it would offer us a better understanding of the biology and life history and provide information to aid in the management of the fishery in the northwest Atlantic. Further, improving the present knowledge of thermal influences may provide a basis for assessing the effects of climate change on monkfish movements and behavior in the future.

Project Objectives

The overall objective of this study is to provide information on the biology of monkfish that can be used to enhance the management of this species.

Objective 1: *Determine seasonal habitat associations for monkfish with bottom temperature and depth over time*
Objective 2*: Evaluate thermal habitat availability for monkfish based on seasonal habitat associations*
Objective 3: *Determine if shifts in average centers of occurrence (abundance-weighted latitude, longitude, depth, and catch-temperature) for monkfish have occurred in response to changes in bottom temperature*

Trawl Survey Data – Fishery independent research vessel bottom trawl surveys conducted annually by NOAA NEFSC during autumn (1968 - 2007) and spring (1968 - 2008) were used for analyses. Surveys use a stratified random sampling design (Figure 1) with strata defined by latitude and bathymetry. Survey locations include a series of 350 stations that range from the Gulf of Maine south to Cape Hatteras, North Carolina. Sampling at each station includes weighing and enumerating each species as well as recording data on length, age, maturity, and diet composition. Further, information on sea surface temperatures, bottom temperatures, and bottom depths is also recorded.

NEFSC data for autumn and spring groundfish surveys were partitioned into five distinct geographic shelf regions defined by survey strata. Both inshore and offshore strata were combined along with information regarding physical and ecological ecosystem properties (Townsend et al., 2006; Fogarty et al., 2008) when delineating the regions. The five regions were the Southern Mid-Atlantic Bight (SMAB; offshore strata 61 – 76; inshore strata: 15 – 44), Northern Mid-Atlantic Bight (NMAB; offshore strata: 1 – 12; inshore strata: 1 – 14, 45 – 55), Georges Bank (GB; offshore strata 13 – 23, 25), Gulf of Maine (GOM; offshore strata: 24, 26 – 30, 36 – 40; inshore strata: 56 – 90), and the Scotian Shelf (SS; offshore strata: 31 – 35; Figure 2).

Habitat Associations

For each region, cumulative distribution functions (CDFs) were calculated to describe the association between monkfish distribution and bottom temperature and depth. CDFs were determined for the observed distributions for bottom temperature and depth. Monkfish were associated with these distributions by weighting the CDFs by fish abundance (number of fish caught per survey tow). Additionally, the strength of the association was examined statistically using a non-parametric method developed by Perry and Smith (1994); a Kolmogorov-Smirnov type statistic was used to determine the maximum vertical difference between un-weighted and abundance-weighted CDFs.

In general, habitat associations for monkfish with regard to bottom temperature and depth were variable by latitude and season. Monkfish caught in the GOM during autumn and spring surveys were associated with temperatures ranging from 5.0 – 11.1˚C and 3.5 – 8.7˚C, respectively, while 95% of sampling stations included temperatures from 4.7 – 11.3˚C and 2.7 – 8.7˚C, respectively. Similarly, 95% of the depth distributions occupied by monkfish during autumn and spring were from 40 – 292 m and 75 – 336 m, respectively, while those for sampling stations ranged from 26 – 317 m and 20 – 315 m, respectively. Compared to the bottom temperature and depth distributions of the stations, monkfish in the GOM occupied warmer temperatures and deeper depths during autumn and spring (Figure 3a – 3b). Monkfish were significantly associated with bottom temperature during spring and depth during both autumn and spring ($P < 0.05$). In the SMAB, 95% of monkfish caught during autumn and spring surveys were significantly associated ($P < 0.05$) with temperatures of 7.4 – 16.0˚C and 5.6 – 15.5, respectively, while 95% of stations sampled included temperatures ranging from 7.5 – 24.3˚C and 3.3 – 13.7˚C. Similarly, 95% significant depth distributions for monkfish caught in the SMAB for all seasons ranged from 18 – 326 m while 95% of sampled depths at stations varied from 12 – 134 m. Compared to the bottom temperature and depth distributions of the stations, monkfish occupied cooler temperatures and deeper depths in autumn and warmer temperatures and even deeper depths in spring (Figure 4a – Figure4b). In the SMAB, monkfish distributions appear to shift toward deeper areas to occupy optimal temperatures. Habitat selection with regard to temperature and depth may be more important for *L. americanus* in lower portions of its range where seasonal environmental conditions are more variable.

Available Thermal Habitat

Cumulative distribution functions were used to examine changes in available thermal habitat for monkfish by identifying the distribution of the central 95% of all abundance-weighted or occupied temperatures from habitat associations. This was done using five-year average portions of shelf area (stratified area; squared nautical miles; nmi^2) where bottom temperature values were equal to, above, or below the preferred range of temperatures (˚C) for monkfish. For each region, a time series of seasonally preferred bottom temperatures was determined for autumn (1968-2007) and spring (1968-2008) prior to identifying the portions of shelf area within, above or below that range. Portions of area were identified by multiplying the area of strata within a survey region by the percent of temperatures within, above or below the preferred range over time (e.g. SMAB

= 17,133 nmi^2 * 67% within range = 11,507.5 nmi^2).

The central 95% of occupied bottom temperatures for autumn and spring surveys are presented in Figure 5a – 5b. In general, area of habitat within the seasonally preferred temperature ranges for monkfish varied by season and latitude with the greatest changes occurring during autumn in the southern portions of the survey region. For example, area within the favored autumn (5.0-11.1˚C) and spring (3.5-8.7˚C) temperature ranges in the GOM decreased from 20,897 nmi^2 in 1972 to 18,073 nmi^2 in 1997 and 19,986 nmi^2 in 1972 to 17,208 nmi^2 in 1997, respectively (Figure 5c). Compared to the GOM, area within the favored autumn (7.4-16˚C) temperature range in the SMAB decreased from 11,507 nmi^2 to 4,204 nmi^2 from 1972 to 2007 while habitat area with temperatures above 16.0˚C increased from 5,078 nmi^2 to 12,813 nmi^2 (Figure 5d). For the spring trawl survey, area of preferred temperatures (5.6-15.5˚C) fluctuated with marked decreases from 15,019 nmi^2 to 13,136 nmi^2 from 1977 to 1982 and 15,114 nmi^2 to 12,438 nmi^2 from 2002 to 2007 and increases from 13,500 nmi^2 to 14,570 nmi^2 from 1987 to 1992 and 12,467 nmi^2 to 15,114 nmi^2 from 1997 to 2002 (Figure 5d).

Declines in available thermal habitat during autumn suggest that monkfish may have face losses of habitat, especially in lower latitude regions (GB, NMAB, SMAB). Losses in habitat may lead to shifts in distribution to deeper waters or more northern latitudes where thermal conditions are more favorable.

Distribution Shifts

The influence of water temperature on monkfish distribution was also investigated by examining relationships among environmental variables using general linear models. To do this, yearly shelf-wide (continental shelf from western Scotian Shelf south to Cape Hatteras) abundance-weighted mean latitude (˚N y^{-1}), longitude (˚W y^{-1}), stratified catch-temperature (˚C y^{-1}), and stratified depth (m y^{-1}) were calculated for autumn and spring. Multiple linear regressions were used to relate mean abundance-weighted response variables to $\log_e$-abundance and same year and 5-year running average bottom temperature (independent variables).

The results for multiple regressions are summarized in Table 1. During spring, monkfish showed a significant ($P < 0.05$) positive relationship between 5-year average bottom temperature and mean catch-temperature, mean latitude, and mean depth of occurrence. The significant relationship between catch-temperature and 5-year average bottom temperature suggests that monkfish are compensating for changes in temperature by shifting their average latitude by 0.58 (˚N y^{-1}) and depth by 14.14 (m y^{-1}). These results suggest that monkfish may shift their distribution northward to higher latitudes and to deeper depths in response to climate warming.

Table 1. Summary of multiple regression analyses for the NEFSC autumn and spring inshore and offshore trawl surveys with yearly-average and 5-year average bottom temperature (BT˚C) and $\log_e$-abundance (Abund) as independent variables and the mean abundance-weighted factors (latitude, longitude, depth, catch-temperature) as dependent variables. Slopes and *P*-values ("*" denotes *P*-value <0.05) are listed for independent variables; multiple r^2 is given for each regression.

Latitude (˚N y^{-1})	r^2	BT (˚C)	*P*-value	Abund	*P*-value
Autumn	0.185	-0.02	0.736	-6.52	0.023*
Spring	0.118	0.16	0.124	-3.48	0.081
Longitude (˚W y^{-1})					
Autumn	0.360	0.06	0.358	8.62	0.001*
Spring	0.106	-0.01	0.868	4.39	0.050
Depth (m y^{-1})					
Autumn	0.217	-0.80	0.752	-241.99	0.008*
Spring	0.106	3.67	0.193	-97.52	0.080
Catch (˚C y^{-1})					
Autumn	0.696	0.78	0.0001*	12.53	0.003*
Spring	0.960	0.91	0.0001*	0.42	0.419
Latitude (˚N y^{-1})	r^2	5-Year BT	*P*-value	Abund	*P*-value
Autumn	0.159	0.06	0.535	-6.49	0.019*
Spring	0.235	0.58	0.007*	-3.82	0.039*
Longitude (˚W y^{-1})					
Autumn	0.433	-0.09	0.383	11.70	0.0001*
Spring	0.141	-0.30	0.225	4.65	0.033*
Depth (m y^{-1})					
Autumn	0.213	1.13	0.794	-254.51	0.003*
Spring	0.194	14.14	0.021*	-100.32	0.056
Catch (˚C y^{-1})					
Autumn	0.405	0.52	0.023*	19.05	0.001*
Spring	0.351	0.78	0.0009*	2.47	0.245

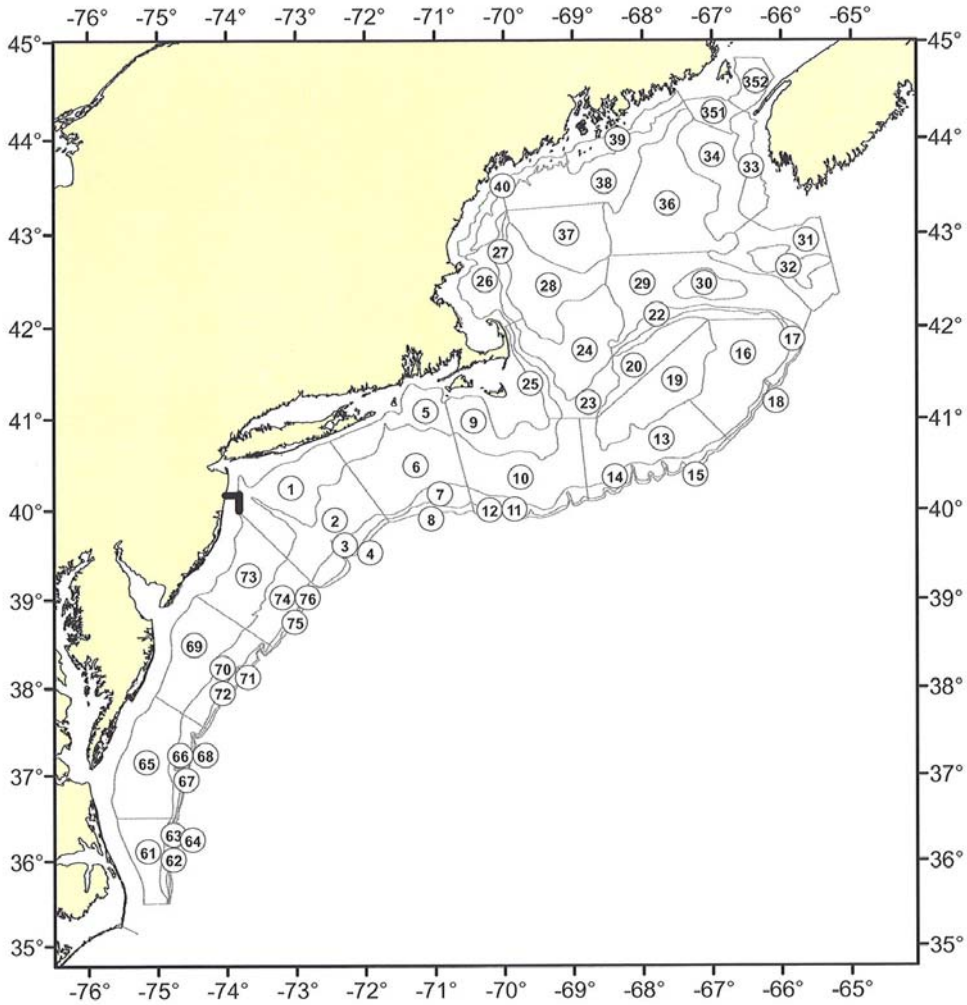


Figure 1. Map of NEFSC strata sampled during annual offshore (27-365 m) bottom trawl surveys. Courtesy of NOAA Northeast Fisheries Science Center.

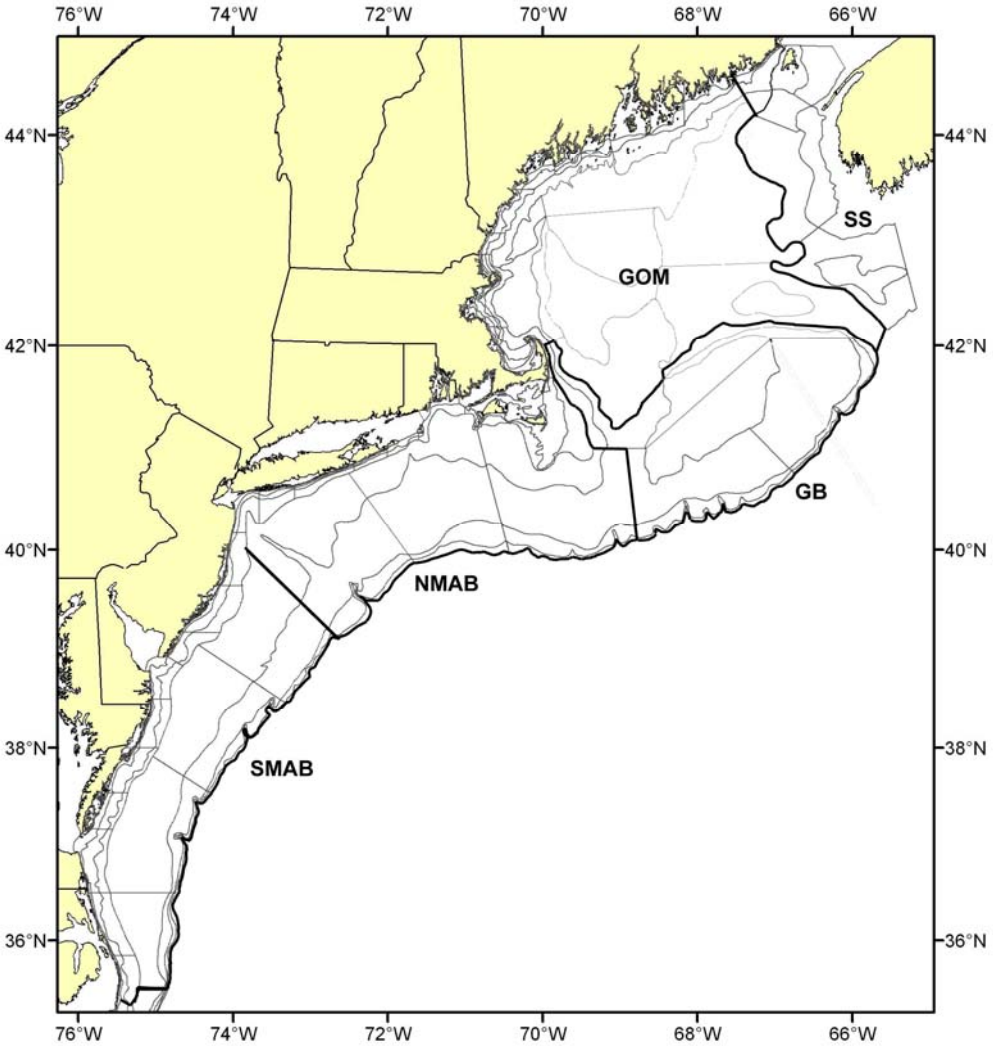


Figure 2. Map showing the five regions sampled during NEFSC annual autumn and spring bottom trawl surveys defined by survey strata.

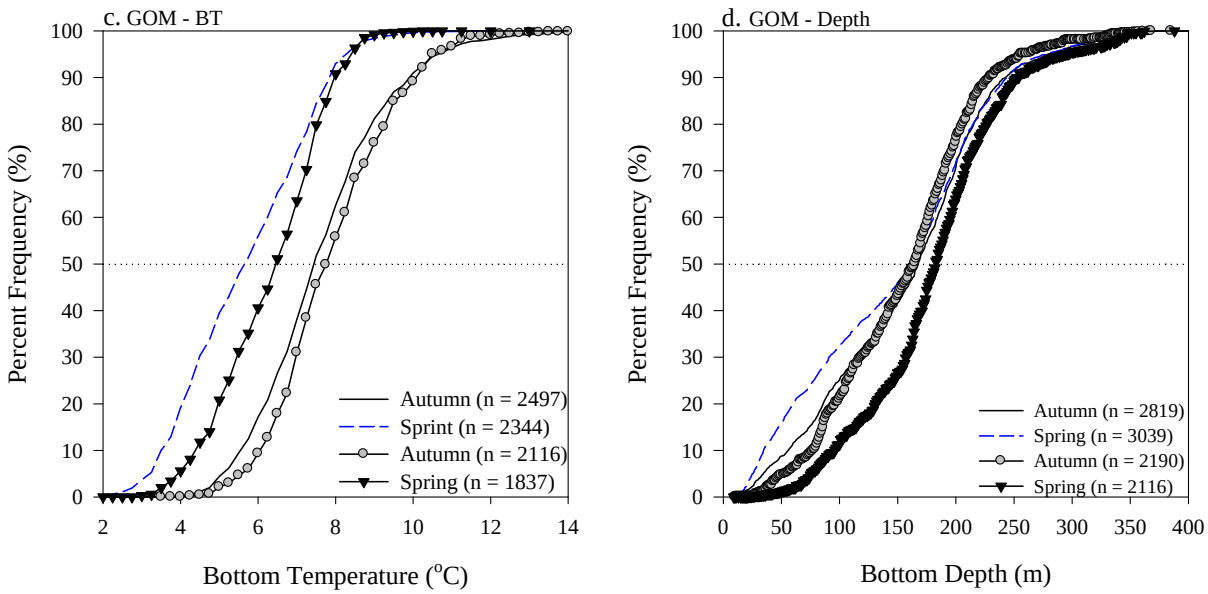


Figure 3. Cumulative distribution functions of bottom temperature (˚C) and depth (m) for the GOM region. Solid lines represent the distribution of the sampled temperatures and depths, while the lines with symbols show the distribution of abundance-weighted (number of fish caught per survey tow) temperatures and depths (n = sample size).

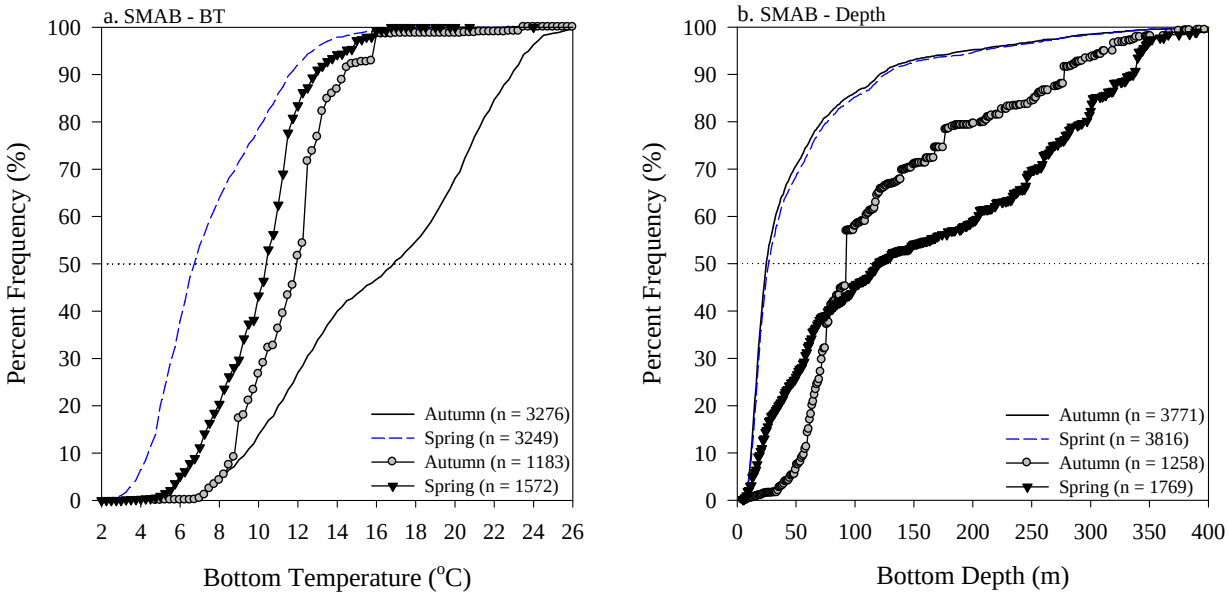


Figure 4. Cumulative distribution functions of bottom temperature (˚C) and depth (m) for the SMAB region. Solid lines represent the distribution of the sampled temperatures and depths, while the lines with symbols show the distribution of abundance-weighted

(number of fish caught per survey tow) temperatures and depths (n = sample size).

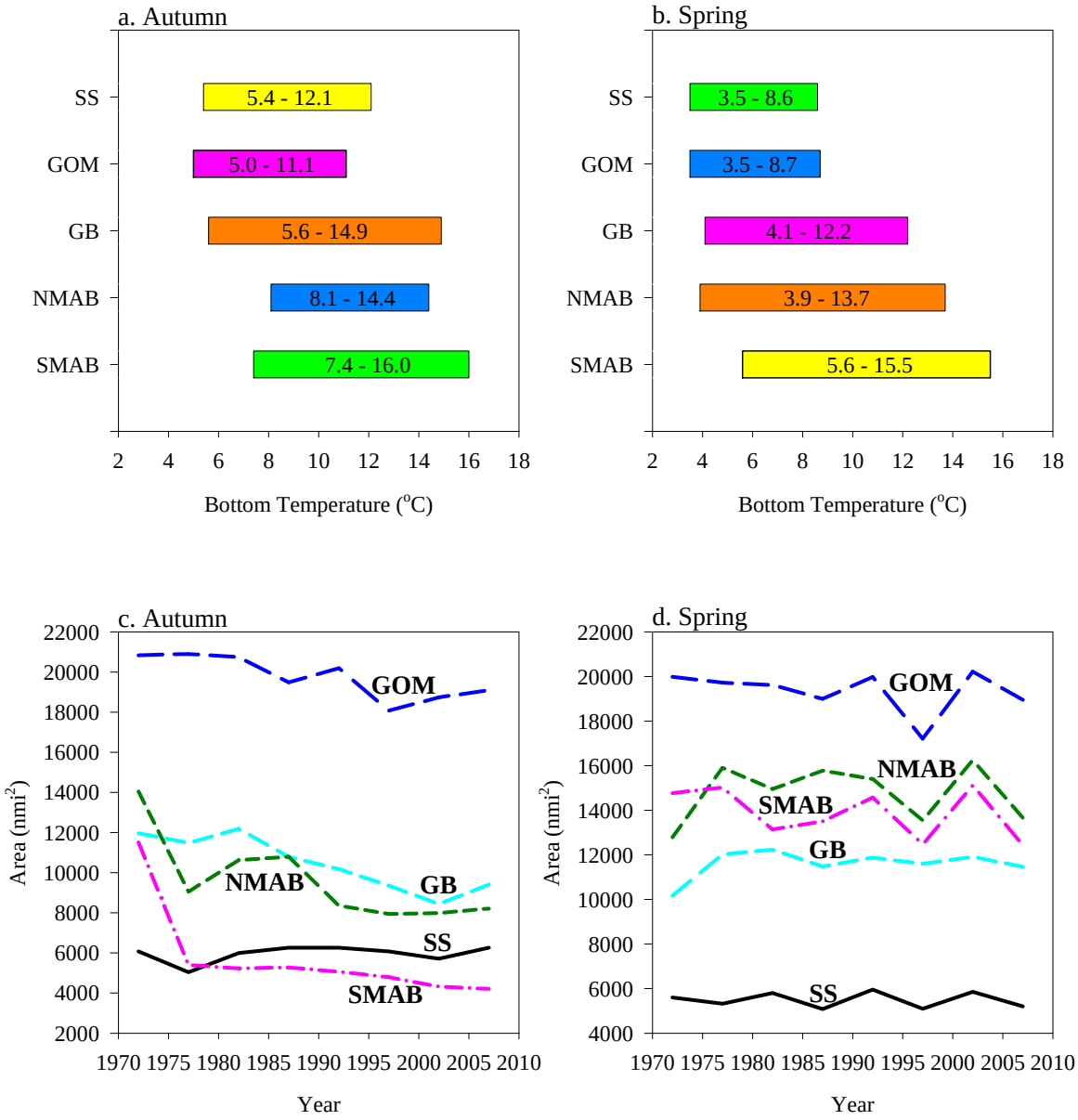


Figure 5. Occupied bottom temperatures and area of available thermal habitat for autumn (plot a, c) and spring (plot b, d) surveys.

Andrea Johnson
Digitally signed by Andrea Johnson
DN: cn=Andrea Johnson, o=UMES, ou=Department of natural Sciences, email=akjohnson@umes.edu, c=US
Date: 2011.07.29 12:39:58 -04'00'