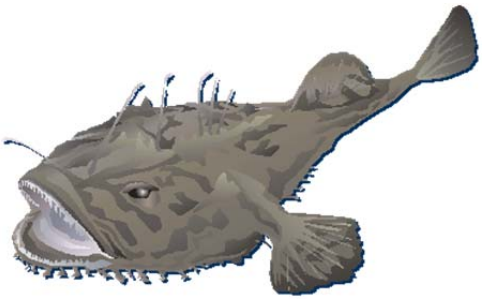

Final Report

2008 Monkfish Research Set Aside Program

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Movements, Growth, and Habitat Use of Monkfish, *Lophius americanus*, based on Archival Tagging and Otolith Elemental Analyses.

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A. EXECUTIVE SUMMARY

In the eastern US, monkfish (*Lophius americanus*) are managed as separate northern (Gulf of Maine and northern Georges Bank) and southern (southern Georges Bank and Mid-Atlantic Bight) stocks. However, the degree to which these stocks intermingle, or even whether or not they represent separate stocks, is unknown. We investigated patterns in monkfish movement and habitat usage using data storage tags. We tagged 187 monkfish with Starr Oddi centi tags, and were able to recover 5 tagged fish. Growth rates of the male monkfish were much lower than the female fish that was recaptured, perhaps suggesting why female monkfish are capable of growing much larger than males. Recapture rates were substantially lower than conventional tagging efforts, suggesting that scientists should account for this potential limitation when planning DST tagging studies with monkfish. We also inject our fish with oxytetracycline (OTC), which could explain why tag recover rates have been low given that recaptured fish injected with OTC have had necrotic tissue around the injection site. Two of the three fish that were recaptured retained their DST tag, and the archival tag results indicated that at least one of these monkfish stayed in shallow water (i.e., < 50m) throughout the winter.

We anticipate combining these results with our previous (Sherwood et al. 2009) and ongoing monkfish tagging studies, and will hopefully receive additional recaptures that will allow us to address the amount of connectivity between the two management areas, the degree of migration that occurs along the coast in the Southern Management Area, and the degree to which the offshore and inshore fisheries are fishing the same population of monkfish. We also intend to use both otolith microchemistry and the results from our DST tags to examine migratory behavior more thoroughly when we have additional recaptured fish. Finally, we are hopeful that

we can develop a non-invasive method to groundtruth the age of monkfish using markers similar to OTC and otolith microchemistry.

B. BACKGROUND AND OBJECTIVES

The monkfish (or goosefish, *Lophius americanus*) has been the highest valued finfish in the northeastern U.S. since the mid-1990s following the decline of traditional groundfish species and the rapid development of the monkfish fishery. However, monkfish biology is relatively poorly known, primarily because relatively few are caught in Northeast Fisheries Science Center resource surveys. Synoptic industry-based monkfish trawl surveys conducted in 2001 and 2004 have helped elucidate the biology of monkfish; however, important gaps remain (NEFSC 2002, 2005).

One of the fundamental unknowns is the amount of exchange between monkfish management regions (north and south of Georges Bank). During the 1990s, population assessments were based on a working hypothesis that two monkfish stocks existed, north and south of Georges Bank. The hypothesis was based primarily on differences in recruitment patterns and growth rates between the two areas (NEFSC 1997). However, more recent evidence suggests a single panmictic population. Genetic studies (Chikarmane et al. 2000) found no genetic divergence between the regions, and results of the cooperative monkfish surveys (NEFSC 2002, 2005) showed no differences in growth or maturation rates between the areas (Richards et al. 2007). Monkfish continue to be managed separately in the two regions primarily because of differences in the way that the fisheries are prosecuted. However, lack of information on exchange rates between the northern and southern management regions hinders effective management.

We hypothesized that there may be net movement from the southern to the northern management region. This is based primarily on patterns in sex ratios observed during the cooperative surveys, and agrees with fishermen's observations. In the southern region, sex ratios (F:M) shift from

~50:50 in fish less than 40 cm to approximately 20:80 in fish ~60 cm in length. Ageing studies indicate that the change in sex ratios is not due to a cessation of growth in males (NEFSC 2002, 2005). A similar pattern in sex-ratios-at-length is not seen in the northern management region, where F:M sex ratios gradually increase in fish greater than about 45 cm (~4 yr) (Figure 1). The spatial distribution of sex ratios also suggests the possibility of a gender-dependent migration (Figure 2). All monkfish over 70 cm (~ 7 yr) from both areas are female, most likely because of shorter longevity of males (there is no evidence of sequential hermaphroditism in monkfish). We hypothesize that maturing females (L_{50}=46 cm, NEFSC 2002) from the southern region move out of the sampling/fishery region (<225 fa), perhaps into deeper waters, before returning inshore to spawn. Some of these mature females may move northward into the Gulf of Maine and/or into Canadian waters. Monkfish have been caught from waters as deep as 900 m (500 fa) (NEFSC 2002), and their maximum depth distribution is not known. In experimental deepwater fishing, monkfish CPUE peaked at around 700 m (380 fa), and declined in waters deeper than 730 m (400 fa) (Balcom 1997). The maximum depth sampled in the study was 2,150 m (1175 fa).

Every aspect of the monkfish population assessment is impacted by underlying assumptions about stock structure and mixing among management areas, and potential bias due to false assumptions could have serious consequences. For example, if there is net movement from south to north that is unaccounted for, mortality will be overestimated in the southern management region and underestimated in the northern management region. Similarly, it may appear that monkfish stock status is satisfactory in the north, but not in the south, when in fact the reverse could be true. Understanding exchange between regions and possible movement into Canadian waters is critical to evaluating stock status. An archival tagging study will address the critical

issue of exchange among areas, and will illuminate other important questions about monkfish biology as well. The study will address two key recommendations of the NEFSC Stock Assessment Review Committee (conduct tagging studies to evaluate adult movements and conduct validation studies for ageing methods (NEFSC 2002, 2005).

Data storage (or archival) tags have been used successfully in a variety of marine fish species, ranging from large pelagics such as bluefin tuna (e.g. Itoh et al. 2003), to smaller demersal fish such as cod (e.g. Godo and Michalsen 2000), salmon (e.g. Friedland et al. 2001), yellowtail flounder (Cadrin and Westwood 2004) and others. Effects of internal implantation of devices appear to be minimal (Cote et al. 1999; Lower et al. 2005; Righton et al. 2006, Richards et al. 2011), although the impact undoubtedly varies among species. Survival, growth rates and swimming performance of Atlantic cod (*Gadus morhua*) were unaffected by internally- or externally-attached DSTs (Righton et al. 2006; Cote et al. 1999); however, external attachment led to wounds and tissue necrosis at the attachment site (Righton et al. 2006).

Monkfish have been considered poor candidates for tagging because they have no scales and a large unprotected abdomen, which makes them susceptible to injury and infection resulting from capture and tagging. Because of this, there has been little tagging of monkfish in the northwest Atlantic to date. However, over 2,300 *Lophius americanus* have been tagged in the western Gulf of Maine and southern New England during summer and fall of 2007 with a return rate of 3.2% (Sherwood et al. 2009). Thirteen externally DST-tagged monkfish were released over Georges Bank in 2003, one of which was recaptured after 192 days (Rountree et al. 2006). A congener (*Lophius piscatorius*) has been tagged successfully in the northeast Atlantic using conventional tags with return rates ranging from 4.5% to 14.4% (Laurenson et al. 2005; Landa et al. 2001;

L.H. Ofstad, Faroese Fisheries Laboratory, personal communication). These results indicate that monkfish can survive the capture and tagging process and that tagging studies hold promise for elucidating monkfish movement patterns.

We have developed DST tagging methods for monkfish with funding from a 2005 NEC Project Development Award (Richards et al. 2011). We investigated options for tag placement (internal, external, location), developed surgical procedures, and tested tag retention and survival of tagged monkfish. The DSTs were Star-Oddi DST centi-TD loggers (Figure 3), which are relatively large and heavy (15 mm (diameter) x 46 mm (length), 19 g in air), and thus could be considered a 'worst case' burden from tagging. Our surgical technique used a 1.5-cm incision lateral to the mid-dorsal aspect of the tail (Figures 4 and 5) which is closed using a purse-string suture. This tag location was chosen because there is an abundance of loose skin to accommodate the tag, and interference with internal organs and behavior (e.g. burrowing by using the pectoral fins, Laurenson et al. 2004) should be minimal. Tags in this location are likely to be detected by fishermen during processing (personal communication from several monkfish fishermen), and if not detected at sea, the tag will be retained in the dressed product (tails or gutted whole monkfish). We decided not to attempt external attachment of tags because of the scaleless skin of monkfish and potential for entanglement with algae and gear (Rikardsen and Thorstad 2006). The tags we tested had a streamer for external visibility (Figure 3), but we concluded that the streamer led to increased tag loss by 6 months, so that DST tags should be completely enclosed and an externally visible tag (i.e., t-bar) should be used elsewhere as an external mark. Tagged fish did not experience a significantly different mortality rate than control fish (Richards et al. 2011).

DSTs are available with a range of data collection capabilities, including time, temperature, pressure (depth), conductivity, and location, and with battery lives up to 5 years or more. We chose tags that collect time, temperature and pressure to infer location rather than attempt to estimate it directly. Geolocating tags depend on measurements of light intensity, and are relatively imprecise (error in the range of 1° of latitude (140 km) (Welch and Evenson 1999; Westerberg et al. 1999a; Itoh et al. 2003). In addition, the light sensors require a larger tag and reduce battery life, making the tags more difficult to use on smaller species. An alternative is to infer position by comparing observed variables (e.g. temperature, depth, tidal timing and amplitude) with oceanographic observations from satellite data, in-situ sampling, and/or oceanographic models (e.g. Arnold and Holford 1995; Metcalfe and Arnold 1997; Westerberg et al. 1999b; Friedland et al. 2001). This approach has been successfully used since the mid-1990s, and will be adapted for use with the monkfish DST data.

Project Objectives

The objectives of the project were to investigate large-scale movements of monkfish (including deepwater excursions) and to compare inferences about movements and habitat use from archival tags and otolith microconstituents analysis (Campana 2005). We hypothesize net movement of monkfish from south to north, with a possible deepwater excursion by maturing females from the southern area. Additional objectives of the archival tagging are to learn more about monkfish behavior, including off-bottom excursions (Hislop et al. 2000; Rountree 2006) that may be related to transport on ocean currents and/or spawning behavior; activity rhythms in relation to tidal cycles; and habitat (depth-temperature) associations. Our goal was to retrieve the entire fish along with the data storage tag (DST) to allow us to determine age, gender, and reproductive

state as well as learn more about growth of monkfish. This approach also allowed us to extract the otoliths for analysis of elemental composition (Campana 2005).

C. METHODS

Archival tags were used in this study because we suspected that monkfish move outside the range of fishing and survey activity during part of their life history, thus conventional tags could not provide the kind of information we need. We used tags that record time, pressure (depth) and temperature. We had originally planned to release tags in 3 areas: Cape Hatteras (near the southern extent of monkfish distribution), Hudson Canyon, and in the western Gulf of Maine. However, the monkfish fishery was extremely poor in the fall of 2008, which resulted in a project shortfall. Given that we generated only ~60% of the budgeted funds for this project, we released tags in the western Gulf of Maine and off of southern New England in order to reduce programmatic costs. However, we were able to obtain additional funding from the Northeast Consortium to bolster our tagging efforts, which we used to release an additional 90 tags.

We completed 6 day-trips between January 2009 and April 2010 and released 187 data storage tagged (DST) monkfish in the Gulf of Maine and southern New England (Table 1). We targeted monkfish in the 40-60 cm (total length) size range, which is the length range where sex ratios are skewed in the southern region (NEFSC 2002). Monkfish were captured by commercial fishermen using 25-30 cm stretch gillnets set for a relatively short (i.e., ~2-3 days) soak-time. Star-Oddi Centi DST tags were used because they have an extended battery life (3-5 years), and a depth capability of up to ~2000 m.

DST tags were inserted subcutaneously on the dorsal portion of the tail muscle directly posterior of the pectoral fin using methods developed by Richards et al. (2011). A small incision in the skin was created prior to inserting the tag, and this incision was then sewed shut with two to three Ethilon black 18" PS-1 cutting sutures from eSutures.com. Monkfish then received two conventional pink Hallprint t-bar tags located dorsally along the tail inserted to interlock between spine bones. These tags contain GMRI's tagging phone number, a unique number to help identify the fish, GMRI's general tagging website address (www.gmri.org/tagging), and a note stating '$500 REWARD FOR RETURN OF WHOLE FISH.' Tags were inserted with an Avery Denison Mark 3 tagging gun. We then injected 75 mg/kg of oxytetracycline (OTC) in muscle tissue in the tail region in order to create a fluorescent stain on the otolith, vertebrae, and the fin spines for use in ageing the fish. This ageing work is being conducted as part of another ongoing monkfish RSA project aimed at validating monkfish ageing methods and growth rates. Fish were also measured (total length) prior to receiving DST tags, conventional tags, and an OTC injection. The length of the surgery procedure, fish condition, release time, and the release location (latitude and longitude) were noted for each tagged monkfish.

Sagittal otoliths were collected from all recaptured monkfish with archival tags in order to conduct laser ablation inductively coupled plasma mass-spectroscopy analyses to compare with the movement behavior inferred from the DST results. However, project budgetary shortfalls precluded us from completing these analyses. Sagittal otoliths were saved to be processed with other recaptured fish in the future using funds that have since been obtained from the 2010 and 2011 monkfish RSA programs to conduct additional tagging effort.

D. OUTREACH

We have launched a vigorous outreach program to alert US and Canadian fishermen and port authorities of our tagging activities. For instance, a postcard (Figure 1) was sent to all monkfish permit holders in the spring of 2008 to encourage participation from as many fishermen as possible. Additionally, posters have been hung along fishing wharfs throughout much of the monkfish's range in the U.S. and provided to port agents (Figure 2). An advertisement was published in Commercial Fisheries News in November 2008 (Figure 3). An announcement about the large reward was included on the back page of the final Cod Tagging Program mailing, which was sent to ~2500 fishermen in New England in 2009. An article was published by Janice Plante in Commercial Fisheries News in late January 2010 detailing our ongoing tagging projects (http://www.nefsc.noaa.gov/read/popdy/monkfish/Survey2009/Tagging%20Study/pdf%20files/Monkfish_Tagging_CFN%202_10.pdf). The article was featured on the inside cover, and covered 4 pages tackling several facets of our tagging program. We attempted to disseminate this article as broadly as possible throughout the fishing community. An announcement about the project was sent to the Monkfish Defense Fund and a press release was issued by the Northeast Fisheries Science Center in early 2010 (http://www.nefsc.noaa.gov/press_release/2010/SciSpot/SS1002/index.html). This project was also covered by Live Science: http://www.livescience.com/8942-data-tags-shine-light-mysterious-monkfish.html. Finally, both NMFS (http://www.nefsc.noaa.gov/read/popdy/monkfish/Survey2009/taggingstudy.htm) and GMRI (http://www.gmri.org/mini/index.asp?ID=34) have created websites to disseminate information and results from this project.

E. RESULTS

To date, 5 tagged monkfish have been recaptured, indicating a recapture rate of 2.35%. Two were recaptured within 3 days of release on October 21, 2010, in the same area in which they were released, reducing the effective recapture rate to 1.4%. Two that were released on November 11, 2009 were recaptured in June 2010 (a male, 213 days at large) and July 2010 (a female, 248 days at large) (Figure 4). One monkfish tagged on October 24, 2010 was recaptured in late June 2011. Of these, one had shed its DST but retained both t-bar tags. The DST insertion site on all three fish had healed and appeared healthy.

The recaptured fish were dissected to collect food habits, maturity data, samples for age and growth studies, genetics, isotopic analysis of diet, and otolith microconstituents analysis. The growth rates (annualized cm/day) differed between the two fish recaptured after 7-8 months at large, suggesting the possibility of sex-specific differences in growth rates of monkfish of this size range (Figure 5). Specifically, the male monkfish grew much more slowly than the female monkfish.

The record from the DST (female) recovered after 8 months showed that this fish remained in relatively shallow (<35 m) water during its time at large, experienced temperatures ranging from 4-16 ˚C, and made occasional off-bottom excursions, which became more frequent in late May (Figure 6). These data suggest that this individual did not migrate offshore in the winter. The DST data show a strong tidal signal (Figure 7), which will be important for attempting to estimate location from the depth and temperature traces, as well as if the fish remained in southern New England or migrated along the coast.

The oxytetracycline (OTC) injection used to mark the bones for age and growth studies caused a strong tissue reaction in both specimens recovered (Figure 8); therefore, we did not use OTC for the October 2010 releases. Laboratory studies are being conducted by C. Bank at UMass Dartmouth to investigate other possibilities for marking hard parts including lower doses of OTC and different chemical markers.

F. DISCUSSION

The monkfish fishery intensifies in southern New England in spring when fish are thought to immigrate from either further south or offshore. Unfortunately we only have results from one DST tag that was on a fish at-large for over 6 months. This individual did not migrate offshore, and we have yet to determine whether it remained in southern New England over winter or if it migrated further north or south. Both of the fish that were tagged and recaptured in the Southern Management Area were caught to the west of where they were tagged, suggesting that these fish are migrating westward along southern New England. These results agree with our previous conventional tagging work (Sherwood et al. 2009), where there was a general trend of southwest movement for fish throughout the range. We are currently examining the tidal oscillation data that was captured by the DST tag (see Figure 7) to identify how far south this fish may have migrated.

Our extremely limited dataset on fish growth suggests that males grow much more slowly than females. Richards et al. (2007) demonstrated that male monkfish rarely grow to 70 cm, whereas females can grow much larger. Our results suggest that the mechanism for this may be differences in growth rates rather than males achieving maximum size earlier in life than females. We hope to extend this dataset with several additional recaptures to examine whether

male monkfish grow more slowly than female monkfish, as well as how sex-specific growth rates vary throughout its range.

Collectively our results suggest that DST tagging is a viable method to examine the migratory behavior and distribution of monkfish, but recovery rates were low. Given our success in recovering conventional tags using a much lower reward (ranging from a t-shirt to $100) system where we recovered 3.2% of the tagged fish (Sherwood et al. 2009) than in this study (1.4%), it seems unlikely that fishermen would choose not to report a recaptured DST tagged monkfish. Furthermore, we have developed an extensive and multifaceted outreach program in this study, and more fishermen were involved in the program during this study than in Sherwood et al. (2009), so that awareness of the DST tagging program should be better than the earlier conventional study.

Low recapture rates could be a consequence of fishermen not seeing the tags while processing their catch. We have heard anecdotally that some of the tags were difficult to see on recovered fish (Phillip Powell, F/V Foxy Lady, pers. comm.). Yet the only difference between the conventional tags used in the DST program and the earlier tagging study was the color of the t-bar tags (pink in this study vs. yellow and blue), so that it is highly unlikely that this potential issue can explain the difference in recovery rates between the two studies. Still, we are exploring the possibility of using tags on the belly of the fish and/or different color t-bar tags that may be easier for fishermen to see.

It is also possible that inserting DST tags induced higher mortality rates. All three fish that were recaptured did not contain extensive scarring around where the surgery occurred, suggesting that

they can heal from the surgery and that our surgical method works well. To date, we have recaptured three fish that were at large for greater than six months, and two of three retained their tags. Hopefully with future recaptures we will be able to determine tag retention rates. Richards et al. (2011) recommended that archival tags be completely enclosed if implanted subcutaneously due to tag loss in two of four fish held for six months in captivity. They concluded tag loss was likely a consequence of streamer tags that extended through the skin at the surgery location to provide an externally visible tag, explaining why we chose to completely enclose tags in this study and use externally visible t-bar tags elsewhere on the monkfish.

All fish that were at large for several months and injected with 75 mg/kg of OTC contained large patches of necrotic muscle tissue near the point of injection. Thus it is possible that OTC injections induced higher mortality rates in fish at large, yet it is unclear given that recapture rates for fish with OTC injections (2 in 145) differs slightly from (1 in 42). However, the 42 tagged monkfish without OTC injections (tagged on October 24, 2010) have been at large for far less time than those that were injected (tagged in 2009), so that recapture rates are likely skewed against those without injections. Given the necrotic lesion that was found in recaptured fish, we recommend that the doses and injection location (muscle tissue) used in this study for a subset of the tagged fish is not appropriate for monkfish.

Scientists that use DST tags to study monkfish behavior should anticipate lower recapture rates than in conventional tagging studies even when offering high recapture rewards, and consequently should plan accordingly when determining how many fish will need to be tagged. Thankfully we received funding for additional tagging efforts from the Northeast Consortium in 2008 and more recently from both the 2010 and 2011 monkfish RSA programs, explaining why

we were able to tag 187 fish rather than just the proposed 90. In addition, this spring we tagged another 77 monkfish near Block Canyon to test the degree of connectivity between the offshore and onshore fisheries, and have already recaptured two of these fish that migrated inshore.

Our ongoing monkfish tagging studies will hopefully result in additional recaptures that in combination with this study and our previous conventional tagging study (Sherwood et al. 2009) will allow us to address the amount of connectivity between the two management areas, the degree of migration that occurs along the coast in the Southern Management Area, and the degree to which the offshore and inshore fisheries are fishing the same population of monkfish. We also intend to use both otolith microchemistry and the results from our DST tags to examine migratory behavior more thoroughly when we have additional recaptured fish. Finally, we are hopeful that we can develop a non-invasive method to groundtruth the age of monkfish using markers similar to OTC and otolith microchemistry.

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H. TABLES AND FIGURES

Table 1. DST Monkfish tagging efforts conducted in the Gulf of Maine and Southern New England.

Date	Vessel	Tagging Location	Captain	Number Tagged
1/13/2009	Gertrude H	So. New England	Ted Platz	16
7/23/2009	Gertrude H	So. New England	Ted Platz	26
10/16/2009	C.W. Griswold	W. Gulf of Maine	Tim Caldwell	6
10/26/2009	C.W. Griswold	W. Gulf of Maine	Tim Caldwell	43
11/10/2009	Gertrude H	So. New England	Ted Platz	54
10/24/2010	C.W. Griswold	W. Gulf of Maine	Tim Caldwell	42
		Total DSTs released	W. Gulf of Maine	91
			So. New England	96
			Total	**187**

2 Monkfish Tagging Studies:

ONGOING STUDY

~3000 monkfish were tagged and released in fall of 2007 in Northern and Southern Fishery Management Areas to assess movement between the areas.

Please help us by reporting:
Tag Numbers ~ Capture Date ~
Capture Location ~ Fish Length

Reward:
-Monkfish tagging t-shirt (**yellow tags**)
-$100.00 (**High-Reward blue tags**)
-Entry into one of two $500 lotteries

COMING SOON (SUMMER 2008)

Electronic data logger tags will be implanted in 90 monkfish from the Gulf of Maine to Cape Hatteras to examine monkfish movement patterns. These fish will be marked externally with **2 pink tags**.

Please help us by RETURNING THE ENTIRE FISH and reporting:
Capture Location & Date

Reward:
-**$500.00** for **RETURN OF FISH** and data (**pink tags**)

Data Reporting:
Call toll-free: 1-866-447-2111
Email: tagging@gmri.org (subject:monkfish)

For More Information:
Visit: http://www.gmri.org/tagging

Administered By:
Gulf of Maine Research Institute
350 Commercial St.
Portland, ME 04101
207-772-2321

Gulf of Maine Research Institute
Science. Education. Community.

Figure 1. Image of front and back of postcard sent by mail to all monkfish permit holders. Note that this outreach effort overlapped with outreach for a 2007 RSA study to tag monkfish with conventional storage tags.

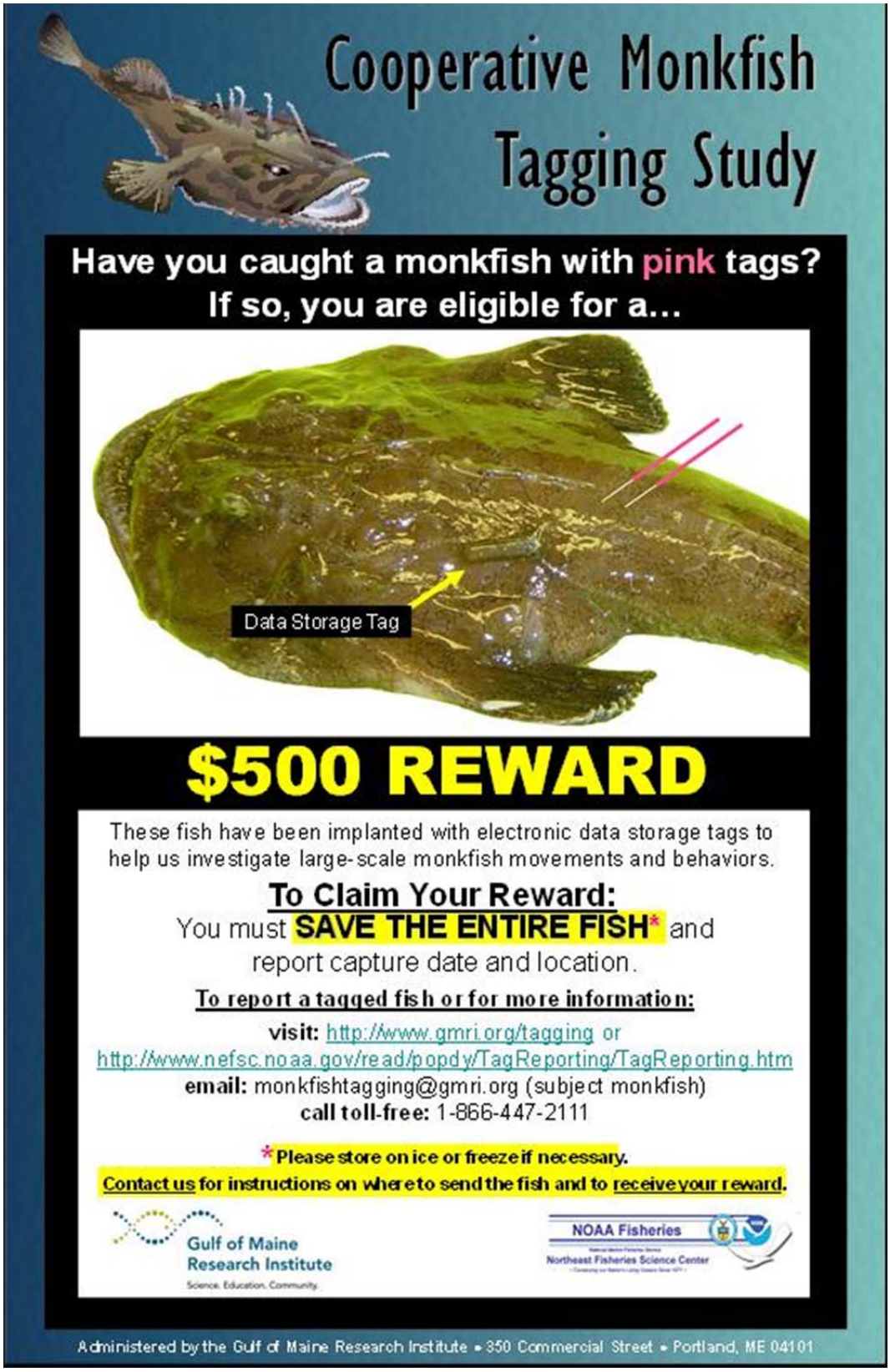

Figure 2. Laminated outreach poster posted at numerous fishing ports in the northeastern U.S.

Figure 3. Copy of add placed in Commercial Fisheries News.

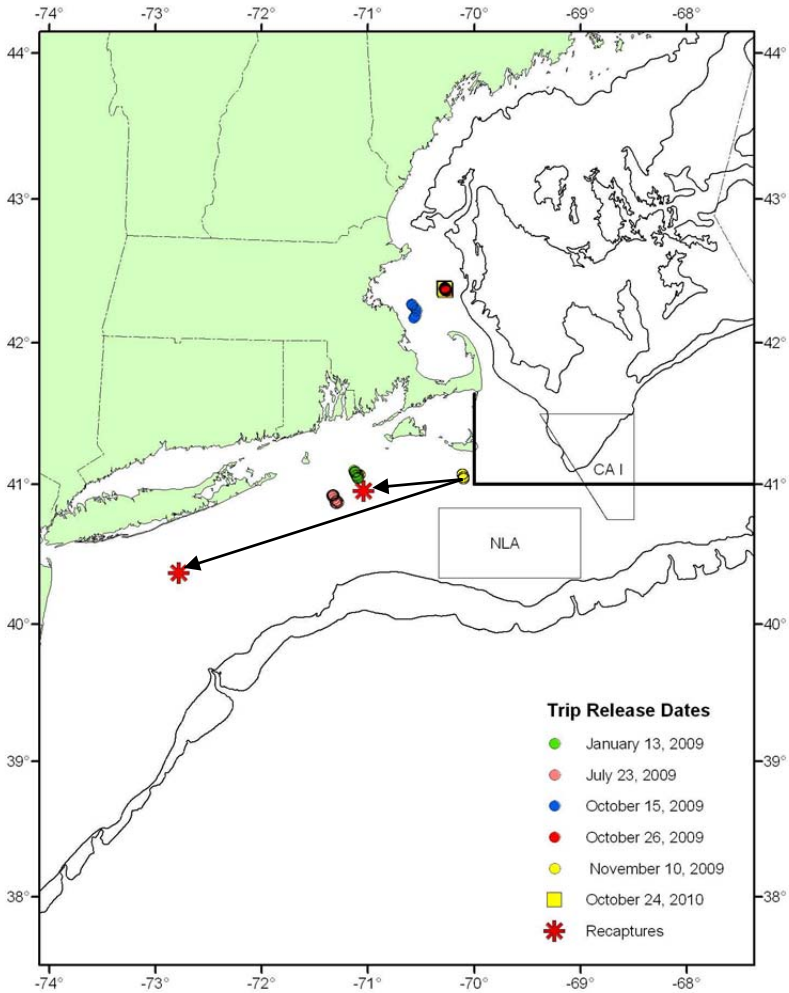

Figure 4. Map showing release of DST-tagged monkfish and recapture locations of two fish that were at large for 7-8 months. The other two recaptures were caught only 3 days after release on October 24, 2010 in the same area as their release. The black line extending south from Cape Cod and east across Georges Bank delineates the Northern and Southern Management Areas of the U.S. monkfish fishery.

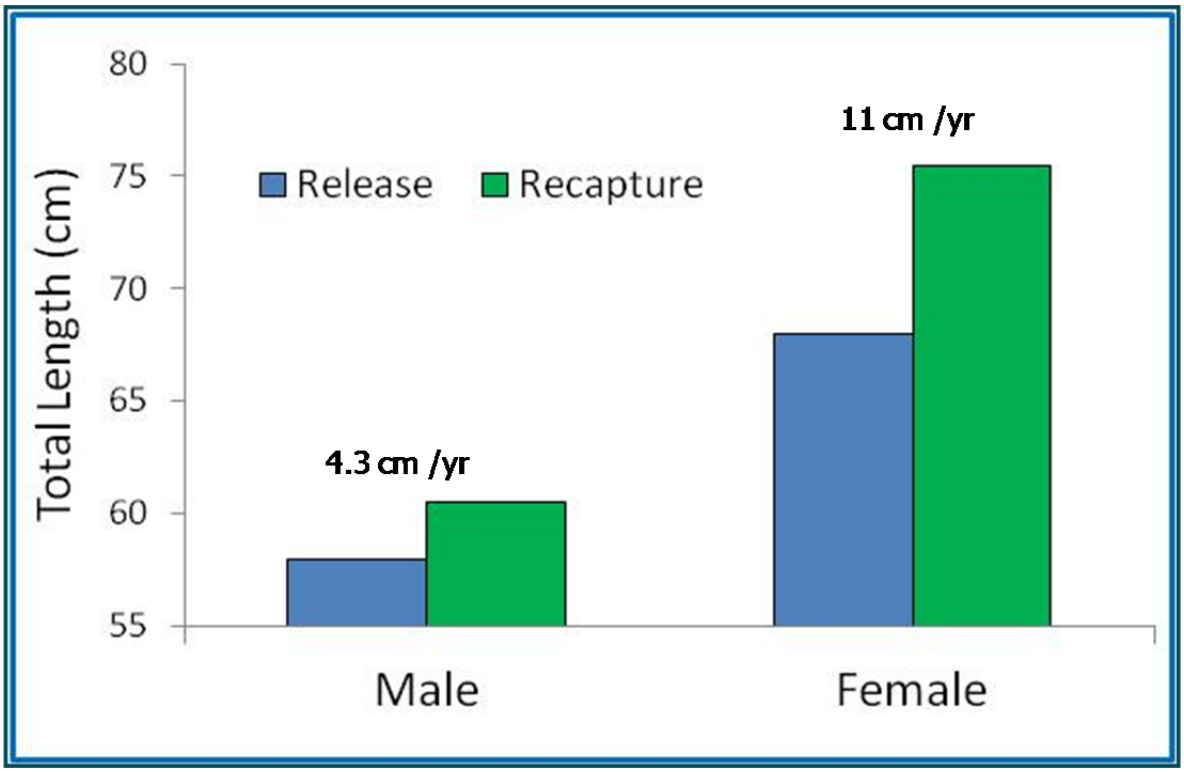

Figure 5. Annualized growth rates of male (n=1) and female (n=1) monkfish recaptured after 7 and 8 months at large.

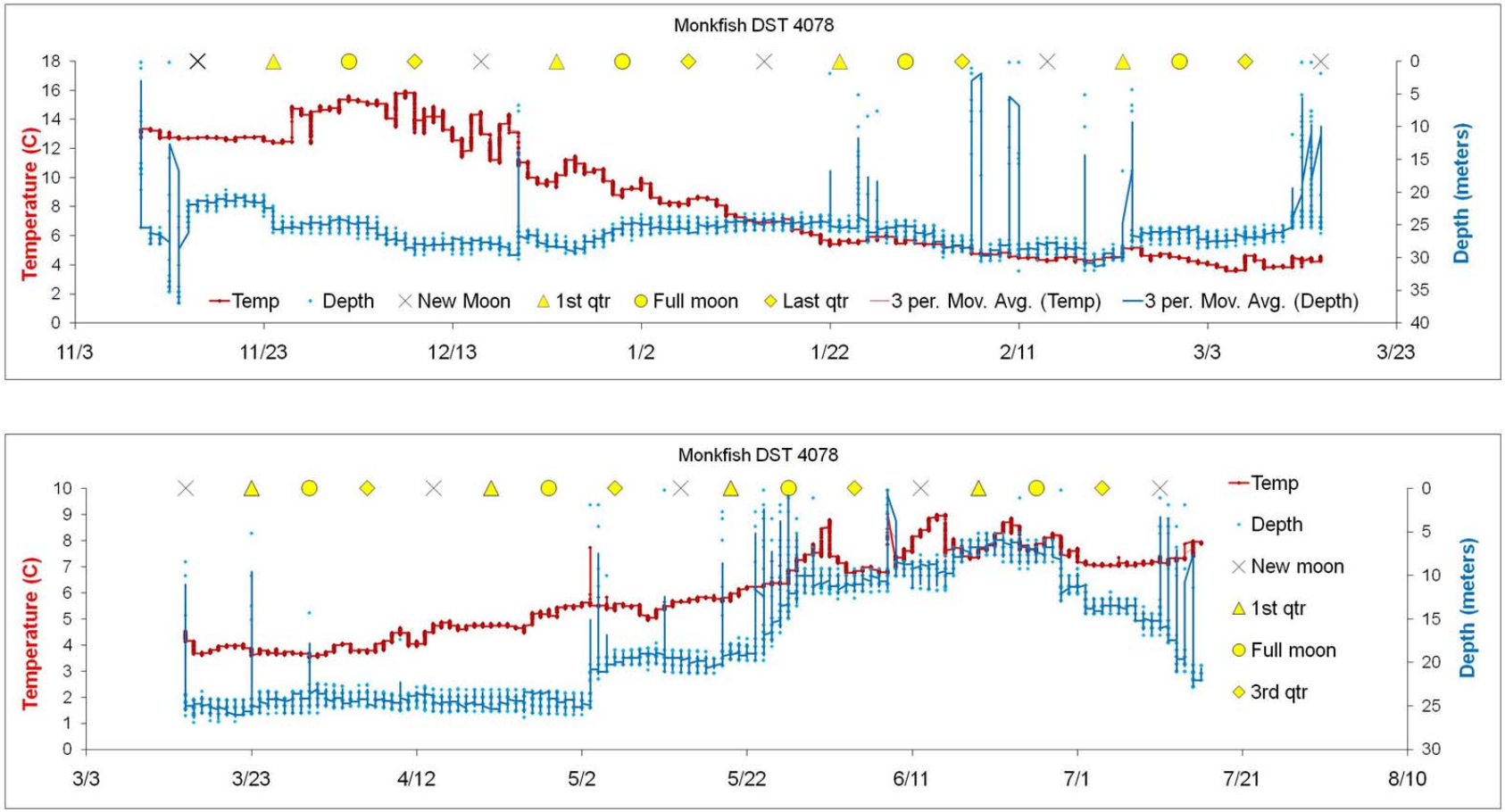

Figure 6. Temperature and depth readings from a DST recovered from a female at large for approximately 8 months, phases of the moon superimposed.

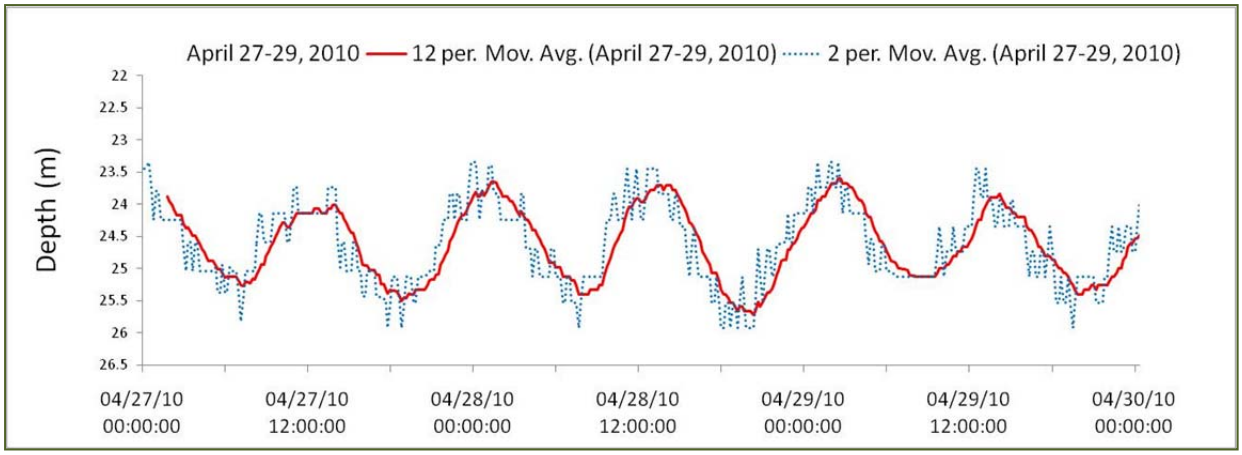

Figure 7. Depth occupied by a recaptured female monkfish during one week in April. The data record reveals the tidal cycle during a time when the fish apparently moved very little.

Figure 8. Recaptured monkfish with necrosis and discoloration of muscle tissue from OTC injection.