NORTHEAST CONSORTIUM
Final Report

Project Title: Archival Tagging Study of Monkfish, *Lophius americanus*

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Abstract

We conducted an archival (DST) tagging study of monkfish *Lophius americanus* to (1) investigate movements of monkfish (including deepwater excursions) among the southern and northern U.S. management regions and Canadian waters and (2) validate aging methods for monkfish. A total of 299 DST-tagged monkfish were released on 9 day-trips between January 2009 and July 2011; 11 fish had been recaptured and returned as of Dec. 1, 2011.

Introduction

The monkfish (or goosefish, *Lophius americanus*) has been the highest valued finfish fishery in the northeastern U.S. since the decline of traditional groundfish species in the mid-1990s and the rapid development of the monkfish fishery. However, monkfish biology has been poorly known, primarily because relatively few were caught in Northeast Fisheries Science Center resource surveys before 2009, when new survey gear was introduced. Synoptic industry-based monkfish trawl surveys conducted in 2001, 2004 and 2009 helped elucidate the biology of monkfish; however, important gaps remain (NEFSC 2002, 2005, 2010).

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 showed no difference in growth or maturation rates between the areas (Richards et al. 2008). Monkfish continue to be managed separately in the two regions primarily because of differences in the way that the fisheries are prosecuted (Haring and Maguire 2008). However, lack of information on exchange rates between the northern and southern management regions hinders effective management.

The monkfish population assessment is strongly 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.

Data storage tags (DSTs, also known as archival tags) have been used successfully in a variety of marine fish species, and have provided fine scale information to improve our understanding of fish behavior and movements. Monkfish distribution likely extends much deeper than areas fished or sampled (reviewed in Richards et al. 2008), thus conventional tagging studies could not reveal the full extent of movements and habitat use. Monkfish have been considered poor candidates for tagging in general because they have no scales and a large unprotected abdomen, characteristics thought to make them susceptible to injury and infection. However, conventional tagging studies with monkfish have been successful (Laurenson et al. 2005; Landa et al. 2001;

Sherwood et al. 2009), and a DST pilot study resulted in one recapture (Rountree et al. 2008), suggesting that DST tagging might be possible. In a preliminary study, DST tagging methods for monkfish were developed with funding from a 2005 NEC Project Development Award (Project NA05NMF4721057). Tagged fish did not experience a significantly different mortality rate than control fish, though both controls and tagged fish were difficult to maintain in the laboratory (Richards et al. 2011).

Project Objectives and Scientific Hypotheses

The primary objectives of this project were (1) to investigate movements of monkfish (including deepwater excursions) among the southern and northern U.S. management regions and Canadian waters, and (2) to validate aging methods for monkfish. Additional objectives were to learn about monkfish behavior, including off-bottom excursions 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. We hypothesize that monkfish move extensively and that there is exchange between fishery management areas and possible deepwater excursions by maturing females from the southern area.

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Methods

The DSTs used in this study were Star-Oddi Centi data storage tags (S-DSTs) (n=149, Figure 1A) and externally-attached Lotek DSTs (L-DSTs) (n=50, Figure 1B). Both tags recorded time, pressure (depth) and temperature. The S-DSTs have an expected battery life of up to 5 years and a depth capability of at least 2000 m. The L-DSTs were made available by the University of Massachusetts School for Marine Science and Technology (SMAST). The L-DSTs were rated to 250 m but battery life was unknown because they were remainders from a previous project. S-DSTs were implanted subcutaneously using methods similar to those described in Richards et al. (2011), and described briefly here. The S-DSTs were implanted on the dorsal portion of the tail, posterior to the dorsal fin. A small incision in the skin was created prior to inserting the tag, and the incision was sewn shut with 2-3 cruciate stitches using Ethilon black 18" PS-1 non-dissolvable cutting sutures from eSutures.com. The L-DSTs were attached externally to the dorsal surface of the tail using two nickel pins inserted through the tail muscle and anchored with a flat tag on the ventral surface of the tail (Figure 1B).

In addition to the DSTs, monkfish received two external Hallprint t-bar tags (Figure 1C), which were inserted posterior to the DST (Figure 2A) using an Avery Denison Mark 3 tagging gun. The tags' inscriptions stated that the entire fish plus the tags must be returned in order to receive a $500 reward. During the first part of the study (n=149 fish), fish were injected intramuscularly with oxytetracycline (OTC, 75 mg/kg, Figure 2B) for growth validation studies. The first two recaptured fish showed necrosis caused by the OTC (Figure 3); therefore, we suspended the injections until a suitable alternative could be identified. Subsequent releases used either no chemical marker (n=105), 50 mg/kg of OTC (n=20), or 25 mg/kg of fluorexon (n=25). Fish length (total length, cm), length of the surgical procedure, fish condition, release time, release location (latitude, longitude) and other ancillary information were noted for each tagged monkfish.

We released a total of 299 DST-tagged monkfish on 9 day-trips between January 2009 and July 2011 (Table 1) using funding from this grant, tags remaining from NEC Project Development Grant NA05NMF4721057, additional funding from the Monkfish Research Set-Aside program (grants to Grabowski, Sherwood and Bank) and Lotek tags donated by SMAST. Monkfish were tagged and released in 3 regions: southern New England (n=131; depths ranging 33-55 m), western Gulf of Maine (n=91; 27-48 m) and Block Canyon (n=77; 165-505 m) (Figure 4).

Fish to be tagged were caught in anchored gillnets (25-30 cm stretched mesh) after soak periods ranging 1-8 days (median 4.5 days). Candidates for tagging were fish that appeared healthy and lively with no serious injuries or skin abrasion. Candidate fish were transferred to holding tanks with running seawater for observation to further evaluate their condition. The tagging procedure was carried out in a tagging box immersed in circulating seawater (Figure 5) to minimize trauma during the operation.

We developed an outreach program to alert fishermen to the tagging study, including web presence (http://www.gmri.org/mini/index.asp?ID=34&p=93, http://www.nefsc.noaa.gov/read/popdy/monkfish/Survey2009/taggingstudy.htm), distribution of posters (Figure 6), outreach to NMFS port agents, advertisements in industry publications, an article in Commercial Fisheries News (Appendix 1), press releases http://www.nefsc.noaa.gov/press_release/2010/SciSpot/SS1002/), and meetings with industry.

Recaptured monkfish were measured, weighed and dissected to determine sex, reproductive state and stomach contents. Samples collected included hard parts (vertebrae, sagittal otoliths and illicia (first dorsal spine or 'fishing pole')) for age and growth studies, and tissue samples for genetics studies, isotopic analysis of diet, and histological studies of fish health and reproduction. Ototliths were archived for future studies of otolith microchemistry to compare with the movement patterns inferred from DST results for each fish.

Data

Information collected under this project include data streams of time, temperature and depth for recaptured DST-tagged monkfish, release and recapture meta-data (location, depth, sea conditions, fishing gear configurations, etc.), biological data including sex, stomach contents, reproductive state, and growth for recaptured monkfish, and growth increments on monkfish vertebrae, otoliths and illicia. In addition, samples were collected for future studies of genetics, histological determination of reproductive state, and otolith microchemistry.

The data for this project have not been submitted to the Northeast Consortium pending publication of results, which is likely to include several papers. Publication is not anticipated for at least a year in anticipation of further tag returns, analysis and completion of thesis work by C. Bank.

Results and Conclusions

Eleven DST-tagged monkfish had been recaptured as of Dec. 1, 2011 (Table 2). Of these 11 fish, one had shed the DST, 3 were recaptured within 9 days of release, and two were returned gutted. All returns came from gillnetters. Time at large ranged 3-248 days. Seventy-eight percent of known-sex fish recaptured were female, ranging 58-77 cm in size at release (median 68 cm). In this size range, expected sex ratios are heavily biased towards females (Richards et al. 2008). All fish were recaptured in the same general region (southern New England, western Gulf of Maine) in which they were released. Most returns came from the southern management region where approximately 2/3 of the tags were released (Figure 7). If fish that were at large less than a month are excluded, only 1 of 8 recaptures (13%) came from the north.

Seven of the returned fish had been tagged subcutaneously with the Star-Oddi tags (5% of released S-DSTs), and 4 had been tagged externally with the L-DSTs (8% of L-DST releases) attached externally. The difference in return rates may be due to greater visibility of the externally attached DST and the large anchor on the ventral surface of the fish (Figures 8A, 8B). However, the attachment and anchor sites of the Lotek DSTs at large for ≥72 days appeared irritated (Figures 9A, 9B). Incisions from internally-implanted tags generally were neatly healed (Figure 9C), but one tag had been shed. T-bar tags sometimes caused irritation at the insertion site (Figure 9D, 9E) and could become entirely fouled with algae (Figure 9F). These observations suggest the need for an obvious but non-injurious mark on the ventral side of the fish.

All fish were recaptured in the same management region in which they were released (Figure 7). Median distance between release and recapture locations was 41 nmi and there were no migrations across management boundaries judging from release and recapture points. One fish at large for 213 days was recaptured only 7 nmi from its release location in southern New England. Of the fish that were at large during fall and spring migrations, one Gulf of Maine release moved into deep water (>270 m), possibly Wilkinson Basin, returned to ~ 40 m depth in the spring and was caught 23 nmi from its release point. The other (SNE release) remained in relatively shallow water (~40 m) and was recaptured 86 nmi southwest of its release location. Two fish tagged in spring near the continental slope in 170-290 m were recaptured a month later ~56 nmi to the north/northwest in 58 m. Overall, the results suggest that movements can be rapid and that monkfish in deep water do migrate onshore, but that some fish remain in shallower water throughout the winter. Evidence of long distance movements (e.g. > 100 nmi) is not evident from release and recapture locations; however, geo-location estimates may suggest otherwise.

Habitat Use and Behavior

Two fish released in the autumn (both 68 cm at release) were recaptured the subsequent summer after 241 and 248 days at large, providing a view of habitat use and behavior during fall, winter and spring (Figure 10). One of these fish, released in the western Gulf of Maine (S-DST 4119, sex unknown), exhibited high frequency off-bottom movements during the first 35 days after release. This was associated with increasing depth, which stabilized at about 150 m. After about 2 months at 150 m (mid-January), the fish again moved to deeper water (210-250 m) where it remained for 2 months before making a sudden jump to ~160 m following an off-bottom movement to 120 m. The fish moved steadily shallower during the next 2 months, then descended to 190 m and ascended to 30 m within about 2 weeks. The fish was captured about 3 weeks later in ~30 m of water only 2 nmi from its release location. Temperature experienced by the fish during the fall excursion to deeper water fluctuated between ~7-12^{o}C, was ~7-9^{o}C during the first residency period at ~150m, and remained fairly steady at ~8.5^{o}C during the winter residency at greater than 200 m. During the spring migration, temperature dropped to as low as ~4.5^{o}C and then stabilized at around 6^{o}C during the two weeks prior to recapture.

The female released in fall in southern New England (S-4078) and recaptured in summer showed much less off-bottom movement immediately after release, however several episodes lasting 5-

10 hr were observed and were associated with a shift to slightly deeper water (~ 10 m deeper). From early December to early May, this fish remained in depths ranging ~45-50 m. Five excursions to the surface were observed in early March within a 5-day day period, with no associated change in depth (spawning runs?). During early May, a series of off-bottom movements were recorded, two of which reached the surface. These excursions generally lasted about 3 hr and many were associated with a small change in depth; however, the fish remained at depths of about 30-40 m from May until its recapture in July south of Long Island, approximately 86 miles southwest of the release point. The water temperature at release was about 13^{o}C, and increased to 14- 16^{o}C about 2 weeks after release. The change in temperature was associated with an increase in depth of about 5 m. Thereafter, temperature declined steadily to a low of 3.6^{o}C in early March. Temperature began to increase in April, about a month before off-bottom movements began again and was about 8^{o}C when the fish was recaptured.

These two fish provide examples of the types of behavioral information that can be gleaned from the DST data. In future analyses we will compare models of tidal amplitude and frequency to tidal signals and depth data from the tags to estimate geo-location data for each fish.

Growth

Growth increments for 8 fish that were at large for 40-248 days were extrapolated to annual rates. Seasonal variation in growth rates was accounted for by calculating the proportion of time that recaptured fish were at large during each season. The expected proportion of annual growth during each season was estimated from seasonal size at age data for ages 5-7 (Figure 11A, from Richards et al. 2008) as 7% during winter, 82% during spring, 10% during summer and <1% during fall.

The adjusted annual growth estimates were highly variable. Two females grew at a rate of 5-8 cm per year (9-12% increase over their size at release), while two other females measured 1 cm shorter at recapture than release (Figure 11B, 11C). Males (n=2) grew only 2-3 cm per year (3-5% increase per year). The sex of two fish was unknown; one of these grew at a rate similar to the males (1 cm (2%) increase per year) and the other similar to females that showed a growth increment (6 cm (11%) increase per year).

Possible reasons for fish apparently shrinking include measurement error (mis-reading the scale or poor positioning on the measuring board), differences in body conformation before and after death, or actual shrinkage (Huusko et al. 2011). One female that lost 1 cm in length (64 cm at release) was at large for only 33 days (mid-April-mid-May), was returned in poor condition, and described as ‘very skinny’ when processed in the laboratory. The other (72 cm at release) was at large for 72 days during July-September and was in a ‘spent’ reproductive state at recapture. Given the slow expected growth rates in summer-fall and the relatively short time at large, growth might have been too slow to disguise an error in release measurement.

Three fish recaptured within 9 days of release give further insights into the potential scale of errors in length estimates. All 3 fish measured larger when dead than they had at release 3-9 days earlier (0.5 cm, 1 cm and 3 cm). Discrepancies in estimated lengths may come about for several reasons. Monkfish often gape their mouths when in the tagging box and the mouth must be held closed in order to get an accurate measurement. In addition, the live fish often do not lie straight on the measuring board, but have a lateral twist (as if swimming) which must be straightened to get an accurate measurement. This can be surprisingly difficult, as these are strong, healthy animals that are not particularly relaxed under the conditions of tagging. Another factor is that muscle tone of dead fish is relaxed, which likely makes the fish measure somewhat longer when dead than alive.

Age Validation

The age validation work is part of the Master's thesis by Crista Bank of SMAST, which is expected to be completed during the second half of 2012. All three age structures from the injected recaptured fish will be analyzed to look for the chemical marker and the subsequent banding pattern. The annual banding pattern from the marked fish will be compared to the presumed annuli from the current ageing method to determine its accuracy. Monkfish also are being held in captivity at the SMAST sea water lab and injected with a chemical marker. The goal is to keep monkfish alive for at least a year in a system with controlled temperatures that mimic seasonal variations. To date two fish have lived a year after marking and 3 others have lived over 6 months and are currently alive.

Tag Mechanical Issues

We had calibration issues with four of the six Star-Oddi DSTs recaptured (the Lotek tags have not yet been evaluated). Assuming that the average depth recorded while the tag was on the fishing vessel should have been approximately 1-2m, we estimated that the 4 biased tags were off by 13, 20, 25, and 166 m. Fortuitously, the tag that was off by 166 m was left running for ~6 months after recapture while in storage on land. The readings from this time period revealed that the depth estimates were drifting over time. We used this type of information to adjust the depth estimates for each biased tag. We currently have no data on temperature calibration.

The Lotek tags released had been left over from an earlier project and were nearing the end of their battery life. Of the four L-tags recovered, two were downloadable. One of the defunct tags appeared damaged, perhaps due to being caught in the gillnet hauler mechanism.

A critical issue for the development of geolocation estimates from depth-recording DSTs is the clarity of the tidal signal in the depth readings. Despite bias in many of the tags, the accuracy appears sufficient to estimate tidal amplitude and frequency (Figure 12).

Conclusions

We can address several of our objectives and hypotheses with the data currently in hand. More definitive conclusions will be possible when further tags are returned and analysis of the tidal signals is completed, and upon completion of the age validation work (C. Bank thesis).

Distances moved (judged by release and recapture locations) were not as extensive as we had anticipated and there were no obvious migrations across management boundaries. Overall, the results show movement between deep and shallow water, but also that some fish remain in shallower water during most of the year.

Off-bottom movements were frequently observed and often accompanied by a change in depth, suggesting that selective tidal transport may aid migration of monkfish, as has been suggested previously. Other off-bottom movements were not associated with a change in depth, and could be indicative of vertical migration for spawning.

The suggestion of sex-specific differences in growth rates of monkfish is significant because sex differences in growth have not been apparent in standard age and growth studies. The growth data from the few tags recaptured thus far is highly variable, so must be viewed with caution. However, if we continue to find a pattern of slower growth in males in this size/age range, it will suggest that the aging method is not accurate or fails in older fish. This could have implications for the growth and natural mortality assumptions underlying the assessment model. The validation work using the chemically-marked recaptured fish and laboratory experiments is expected to shed further light on the aging method.

Partnerships

This project has been of mutual interest to fishermen and scientists for two general reasons. First, it provides insights into the behavior of monkfish that could benefit fishermen in their operations, and help scientists better understand the context for assessment and management. Secondly, it has the potential to improve the stock assessment through greater understanding of monkfish stock structure, growth and aging methods for monkfish.

Both fishermen and scientists have been key players throughout the project, with fishing boats providing the platform for tagging, and fishermen recapturing and returning the tagged fish. The project would have had no success at all without the participation of fishermen. Few boats were involved in the tagging; however, fishing vessels of all types had the potential to participate in recapturing and returning tagged fish. The project fostered broad participation through our outreach efforts to alert fishermen to watch for tagged fish. Relationships between the fishing industry and scientists have been productive and positive throughout the project.

Impacts and Applications

The full beneficial impacts of this project will be realized when more tags are returned, the geo-location analysis is developed, and work on the aging method validation is completed (C. Bank thesis, anticipated completion late 2012). The most important immediate impact is the suggestion of differing growth rates between male and female monkfish of the size range recaptured (~50-80 cm). This could have implications for the growth and natural mortality assumptions underlying the assessment model, and in addition may suggest that the aging method either is not accurate or fails in older fish. These conclusions are highly tentative at present because of the low sample size and high variability in growth rates observed, but if borne out by further tag returns, have the potential to significantly improve the quality of the inputs to the assessment model for monkfish.

Those who would best benefit by being aware of the project results include the New England Fishery Management Council's Monkfish Plan Development Team, the Age and Growth Unit of the Northeast Fisheries Science Center, and the Population Dynamics Branch of the Northeast Fisheries Science Center.

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Related projects

The work under this NEC grant has been leveraged by additional funding under the Monkfish Research Set-Aside program for fishing years 2008, 2009, 2010, and 2011. The RSA projects funded additional DST tagging (tags and sea time) as well as laboratory experiments related to age validation by C. Bank as part of her master's thesis.

Presentations

Presenter: Graham Sherwood
Title: Archival Tagging Study of Monkfish
Meeting: Northeast Consortium Annual Participants' Meeting
Date: March 25, 2009
Location: Portsmouth, NH

Presenter: Larry Alade
Title: Developing Surgical Methods for Implanting Archival Tags in Monkfish
Symposium: Advances in Tagging and Surgical Procedures
Meeting: American Fisheries Society
Date: Sept. 3, 2009
Location: Nashville, Tennessee

Presenter: Anne Richards
Title: Archival Tagging of Monkfish
Meeting: Northeast Consortium Annual Participant's Meeting
Date: Oct. 2010
Location: Portsmouth, NH

Presenters: Jon Grabowski, Graham Sherwood, and Crista Bank
Title: Archival Tagging of Monkfish
Meeting: Monkfish Cooperative Research Meeting
Date: March 1, 2011
Location: New Bedford Fishermen's Club, New Bedford, MA

Presenter: Anne Richards
Title: Monkfish, the Coolest Fish
Meeting: NMFS Port Agents monthly meeting

Date: April 8, 2011
Location: Webinar to NMFS Northeast Region port agents

Presenter: Crista Bank
Title: Age Validation of Monkfish Using Oxytetracycline in Field Experiments and Laboratory Trials
Meeting: 2010 Joint Meeting of Ichthyologists and Herpetologists
Date: July 9, 2010
Location: Providence, Rhode Island

Student Participation

This project will fulfill part of the research requirements for a master's thesis by Crista Bank at the University of Massachusetts at Dartmouth, School of Marine Science and Technology. The thesis title is "Age Validation of Monkfish, *Lophius americanus*".

Published Reports and Papers

Grabowski, J. H., and G. Sherwood. 2011. Movements, Growth, and Habitat Use of Monkfish, *Lophius americanus*, based on Archival Tagging and Otolith Elemental Analyses. Final Report for 2008 Monkfish Research Set Aside Program Contract Number: NA08NMF4540431.

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GMRI DST Monkfish Tagging Website: http://www.gmri.org/mini/index.asp?ID=34&p=93

Future Research

Future research should include increasing the number of DSTs released, expanding the geographic extent of releases, and broadening the size range of released monkfish.

Error in length measurement of live vs. dead monkfish should be examined in more detail, and greater effort should be made to ensure accuracy in measurement of monkfish to be released.

A non-injurious mark for the ventral surface of the monkfish should be developed to enhance detection of DST-tagged fish during processing by fishermen.

Outreach specifically to groundfish trawlers should be intensified because no returns were received from the trawl sector, which dominates the Gulf of Maine monkfish fishery.

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Table 1. Dates and locations for tag release trips, with numbers tagged on each trip.

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
4/15/2011	Shamrock	So. New England	Bill McCann	77
7/9/2011	Adventura	So. New England	David Iglesias	9
7/11/2011	Finest Kind \II	So. New England	Rob Walz	26
		Total DSTs released	W. Gulf of Maine	91
			So. New England	208
			Total	299

Table 2. Meta-data for recaptured DST-tagged monkfish.

		Release				Recapture					
DST #	Gender	Date	Region	Mgmt Region	Total Length (cm)	Date	Region	Mgmt Region	Total Length (cm)	Days at Large	Growth Increment (cm)
4114	M	11/10/2009	SNE	South	58	6/11/2010	SNE	South	60.5	213	2.5
4078	F	11/10/2009	SNE	South	68	7/16/2010	SNE	South	75.5	248	7.5
4128	F	10/24/2010	WGOM	North	65	10/27/2010	WGOM	North	68	3	3
4127	F	10/24/2010	WGOM	North	74	10/27/2010	WGOM	North	74.5	3	0.5
4119	unk	10/24/2010	WGOM	North	68	6/22/2011	WGOM	North	69	241	1
5448	M	4/15/2011	SNE	South	60	5/25/2011	SNE	South	61	40	1
5429	F	4/16/2011	SNE	South	64	5/19/2011	SNE	South	63	33	-1
L12773	F	4/16/2011	SNE	South	59	10/18/2011	SNE	South	63	185	4
L12757	F	7/11/2011	SNE	South	77	7/20/2011	SNE	South	78	9	1
L12775	F	7/11/2011	SNE	South	72	9/21/2011	SNE	South	71	72	-1
L12766	unk	7/11/2011	SNE	South	54	11/7/2011	SNE	South	57	119	3

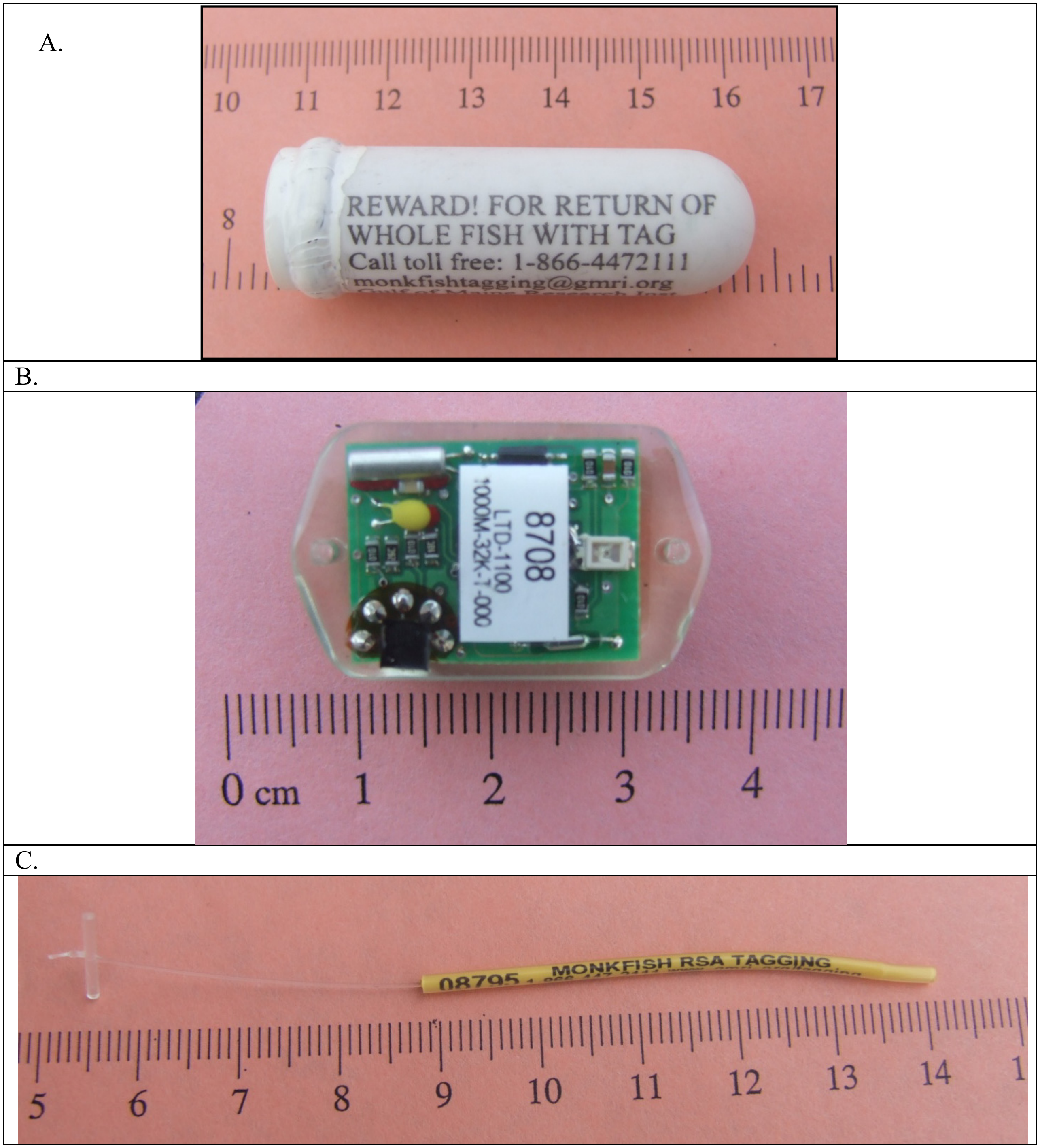


Figure 1. Tags used in this study. (A) Star-Oddi Centi data storage tag (for internal implantation), (B) Lotek data storage tag (for external attachment), (C) Floy t-bar tag for external mark. Scale is cm.

A.

B.

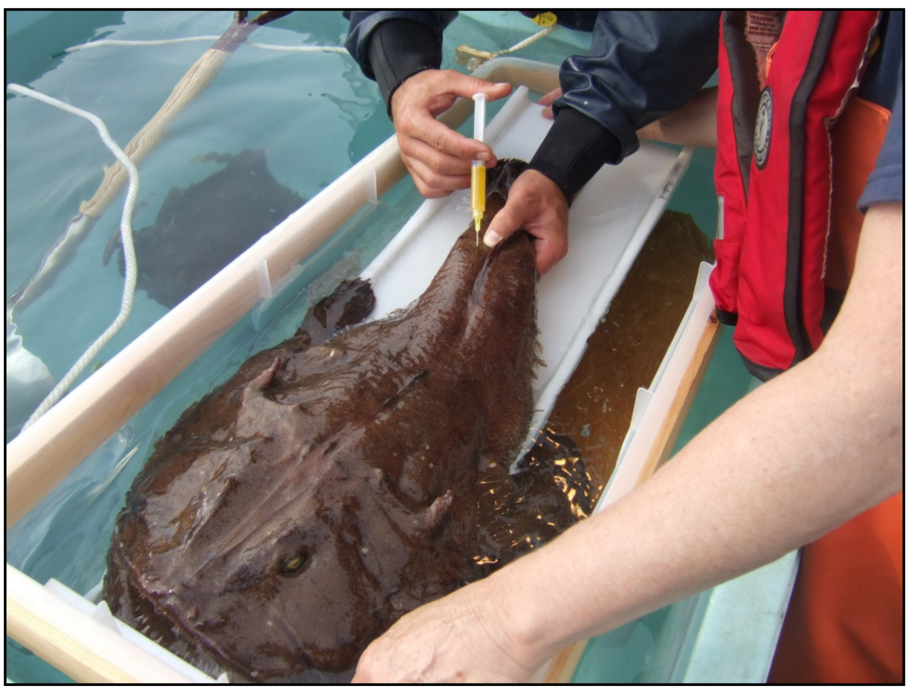


Figure 2. (A) Placement of DST and t-bar tags on monkfish ready for release. (B) Intramuscular injection with OTC.

Figure 3. Tissue damage and discoloration caused by OTC injection in fish at large for 248 days.

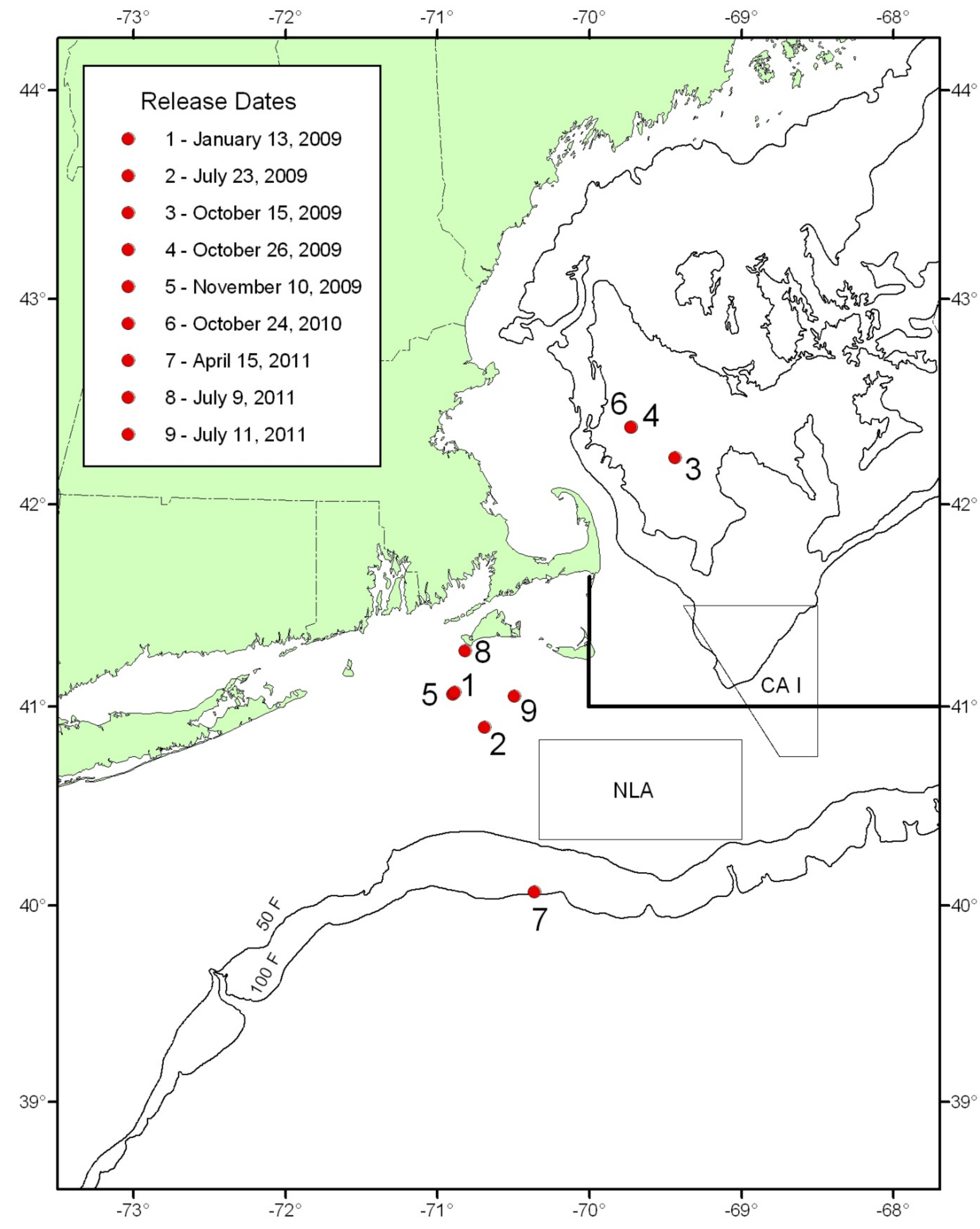


Figure 4. Release locations of DST-tagged monkfish during 2009-2011.

Figure 5. Tagging box used to hold specimens during tagging operations (box elevated for this photo; during normal operation box is submerged more deeply).

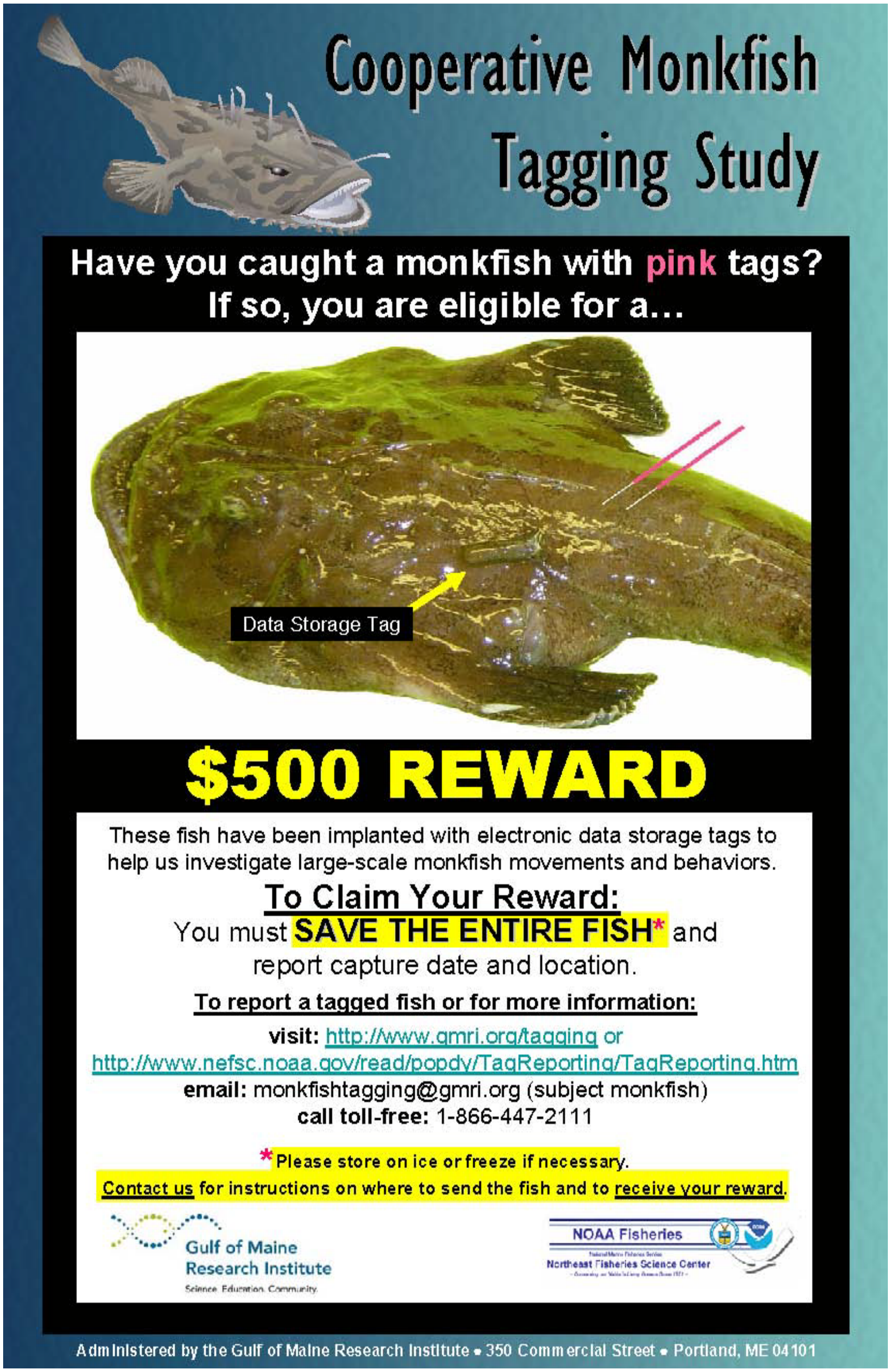


Figure 6. Poster used for outreach to fishermen.

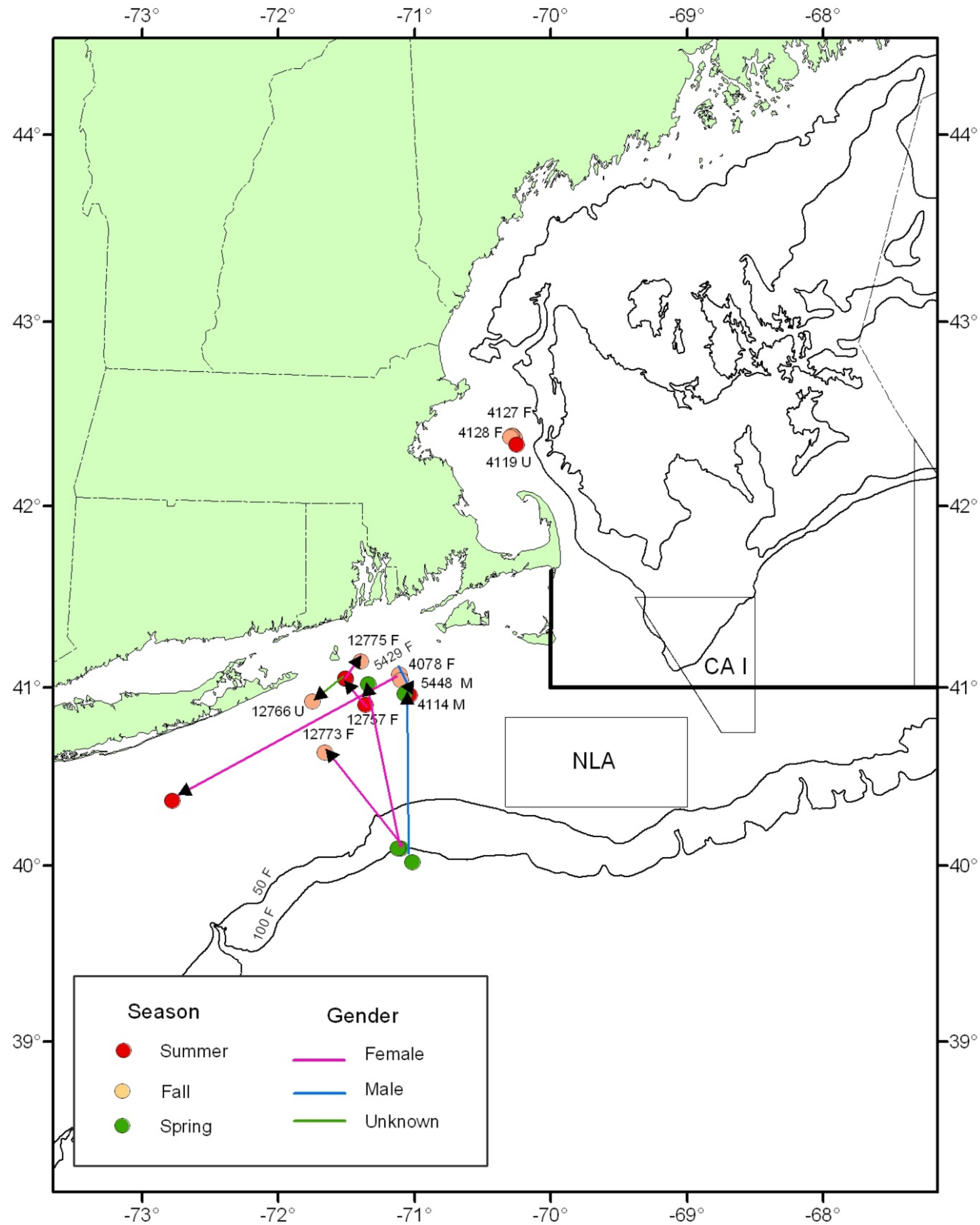


Figure 7. Map of recapture and release locations. Dot color indicates season of release or recapture, line color indicates sex of recaptured fish, numbers are DST tag numbers (numbers beginning with 12 are Lotek tags) with sex designated by ‘M’, ‘F’ or ‘U’.

A.

B.

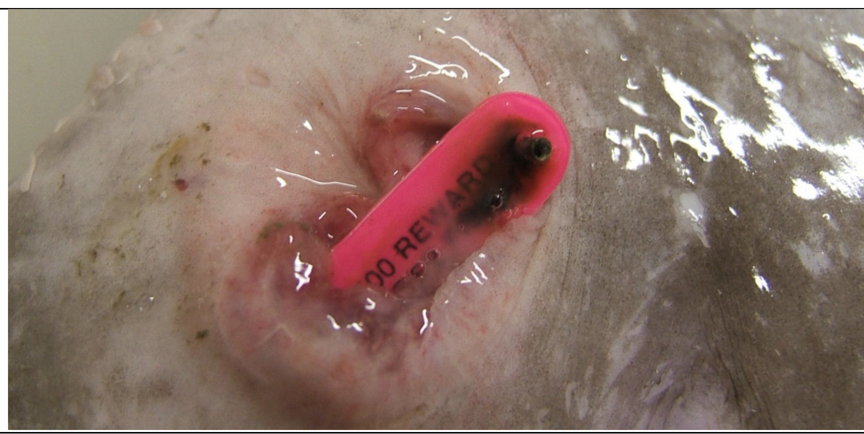
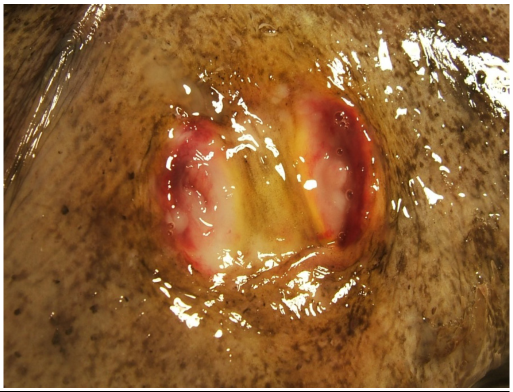


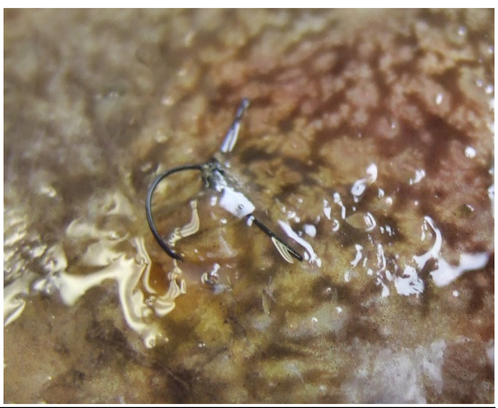
Figure 8. Monkfish tagged with external L-DST and recaptured after 119 days. (A) Dorsal surface with L-DST, (B) ventral surface showing anchor for L-DST.

A.

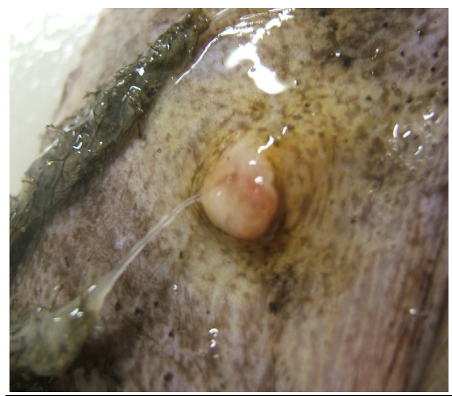


B.

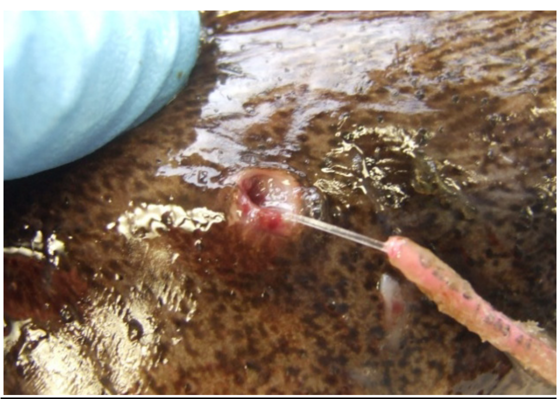
C.



D.

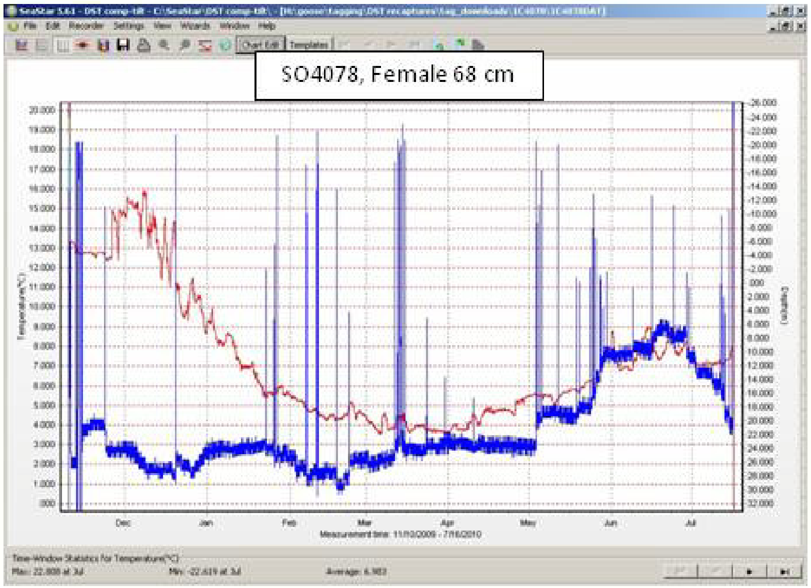


E.

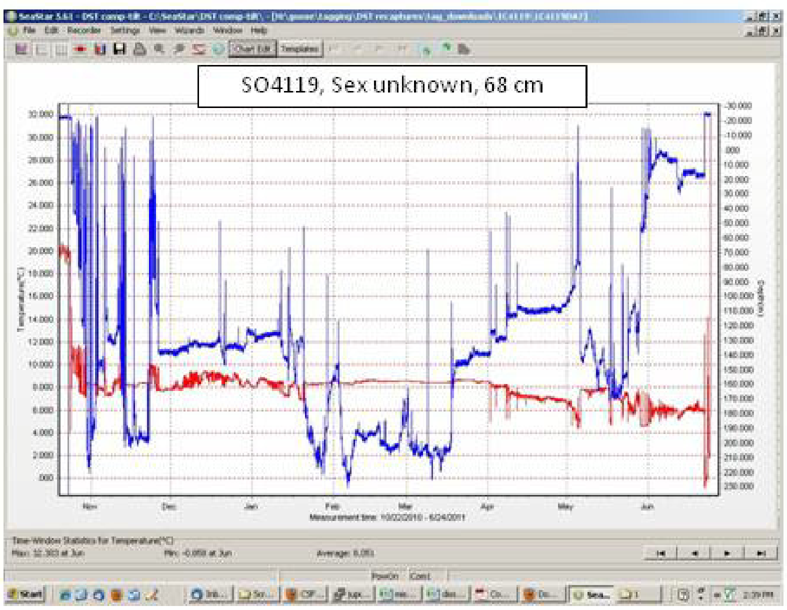


F.

Figure 9. Attachment sites and tag fouling of recaptured monkfish. (A) Dorsal surface where L-DST was attached externally for 72 days (L-DST # 12775), (B) ventral surface showing anchor for same Lotek external DST (L-DST # 12775), (C) Dorsal surface showing healed incision site of monkfish tagged with internal S-DST at large for 213 days (S-DST # 4119), (D) insertion site for external t-bar anchor tag on fish at large for 185 days (L-DST # 12773), (E) insertion site for external t-bar anchor tag on fish at large for 88 days (L-DST # 12766), (F) t-bar tags fouled with algae on fish at large for 185 days (L-DST # 12773).



Released SNE
11/10/2009
Recaptured SNE
6/16/2010
At large 248 days
Female, 68 cm at release
Grew 7.5 cm



Released WGOM
10/24/2010
Recaptured WGOM
6/22/2011
At large 241 days
Gender unknown, 68 cm at release
Grew 1 cm

Figure 10. Temperature and depth readings for two fish released in fall and recaptured in late spring or early summer. Temperature (C) red, depth (m) blue.

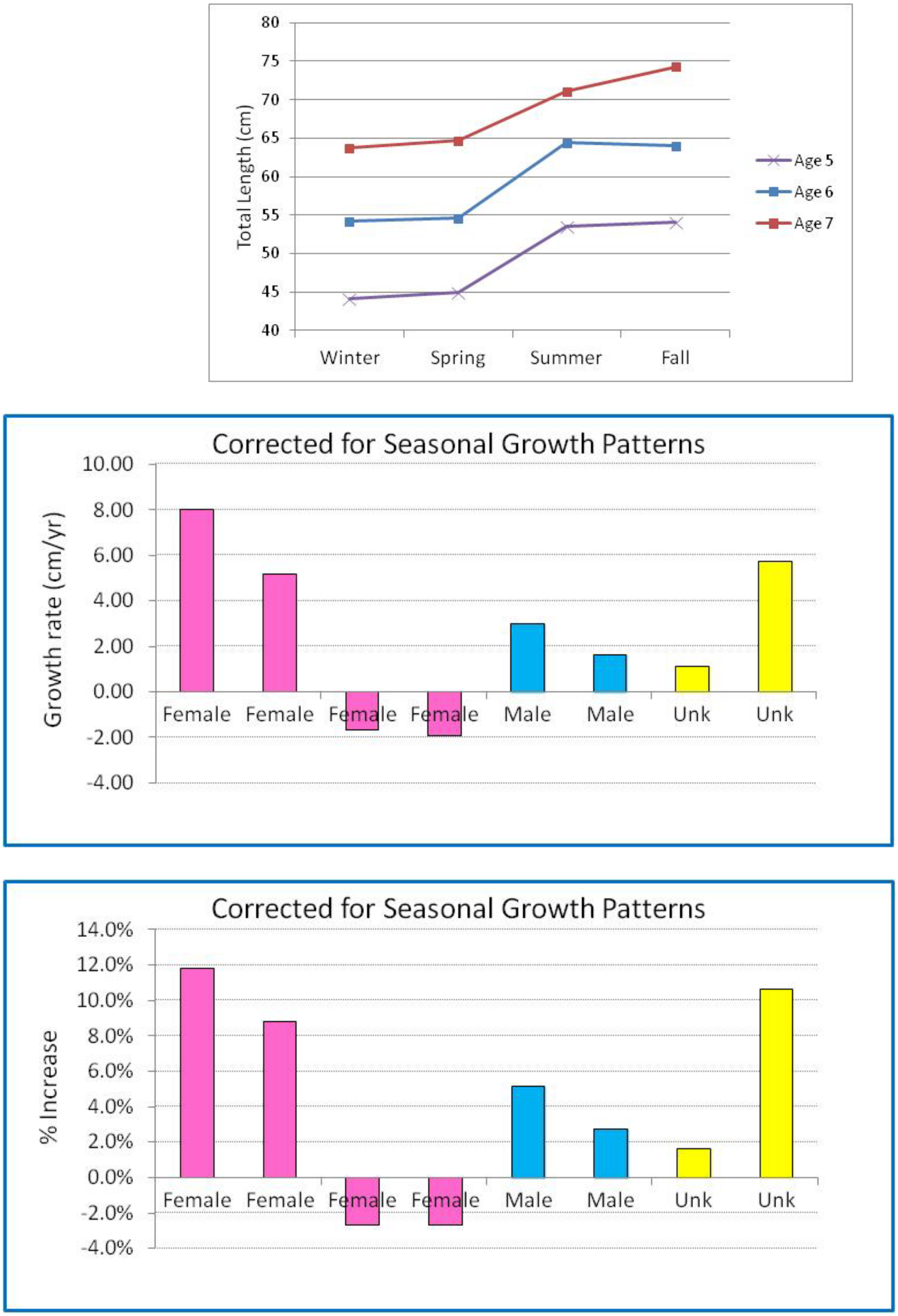


Figure 11. (A) Seasonal variation in growth based on survey length at age data (from Richards et al. 2008), (B) Annual growth increment of recaptured fish adjusted for seasonal growth rates while fish was at large, (C) Annual growth increment as percent of length at release. Unk = sex unknown.

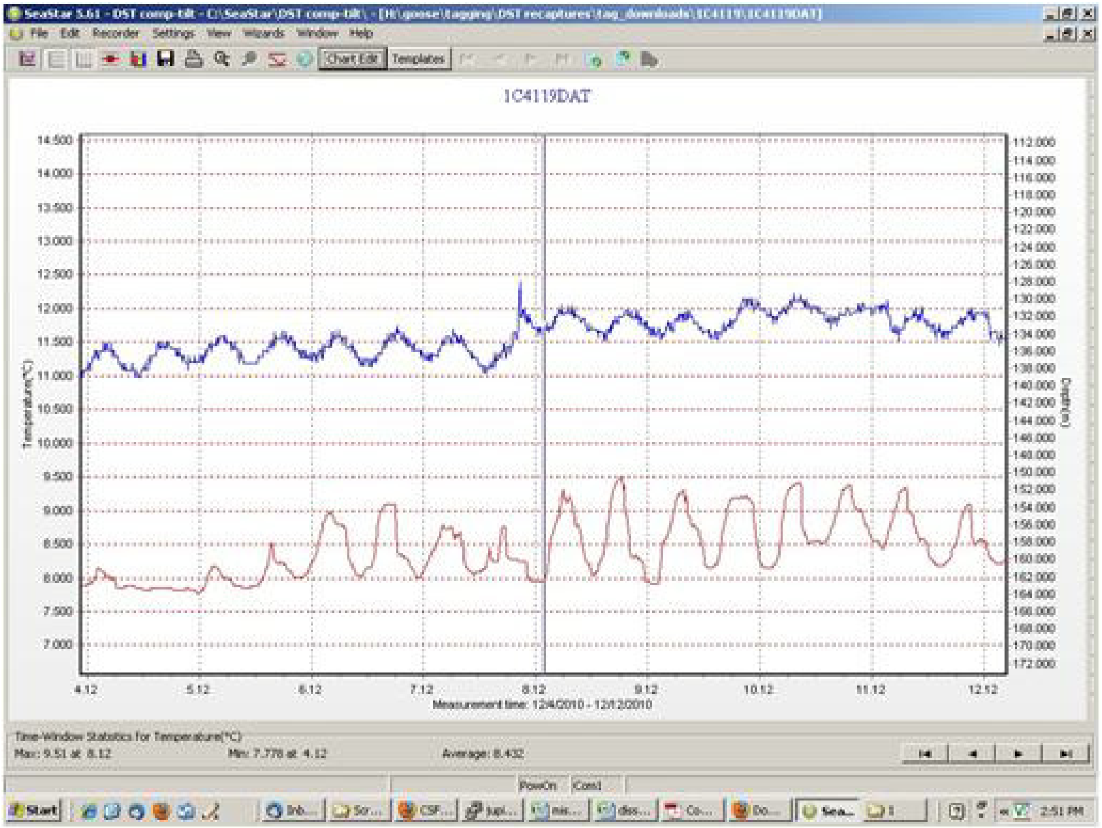


Figure 12. Temperature and depth records from DST showing tidal signal (cyclical increase and decrease as tide rises and falls).

Appendix 1. Article from Commercial Fisheries News, February 2010.

The Northeast's Fishing Newspaper for over 36 years

From the pages of: **Commercial Fisheries News**

February 2010 • Volume 37 Number 6 **A Compass Publication**

Pavel Ivanov photo

Monkfish tagging trip aboard gillnetter Gertrude H, with researcher Larry Alade.

COMMERCIAL FISHERIES NEWS • FEBRUARY 2010

Researchers, fishermen tag monkfish; probe north/south mixing rates

by Janice M. Plante

WOODS HOLE, MA – It takes a bit of skill to do surgery on a monkfish, especially at sea in the bitter cold.

But several researchers have mastered the art, making delicate incisions in the tail of each fish to surgically implant bullet-shaped data storage tags. They did it 150 times in 2009 aboard commercial fishing vessels and, as the new year opened, were prepping to head out to sea to do it again.

Newport, RI-based fisherman Ted Platz, the industry partner on three of the 2009 trips, said the teams now had the system down pat.

"We've figured out ways to get a lot of tags out in a short period of time," he said.

Aboard Platz's Gertrude H, researchers and fishermen worked together to tag 18 fish in January, 26 in July, and 54 in December, all in Southern New England, which is considered part of the "southern" area for monkfish management purposes.

Gillnetter Tim Caldwell was the industry partner for the project's Gulf of Maine trips, carrying researchers aboard his C. W. Griswold. Together, they tagged six fish in October and 46 in November.

Tagging teams were hoping to make a third northern-area trip with Caldwell in late January as *Commercial Fisheries News* was going to press.

Finding a rhythm

By the third trip in December on Platz's boat, everyone knew their roles. Platz and a crewman worked to pull burly monkfish from the net, while two, two-person teams carried out surgeries simultaneously.

"The trick for us was hauling the net really, really slow," Platz said.

That took some getting used to. Commercial fishermen, after all, haul for a living, and slow is not the name of the game.

But slow hauling after a short, one-night soak produced live fish in prime condition – just the right candidates for tag implantation.

At first, the teams tried keeping monkfish in holding tanks on deck, lining up several fish in advance for tagging. But that didn't work because the fish became stressed.

"They got slimy with mucus when we put them together," said Platz, who worked with crewman Pavel Ivanov on the first tagging trip and Sergey Yuminov on the second two.

So, going against the grain, the gillnetters gave way to the slow-haul method, only supplying fish as needed, so that each of the sharp-toothed monks could have its own tank.

Monkfish Tagging Program photo

Fishermen and researchers say that recovery of the information recorded by data storage tags (DST) is key to learning more about monkfish behavior. DSTs are surgically implanted at-sea, and the live monkfish are returned to the water. Above, NEFSC researcher Anne Richards and Curt Brown of GMRI are doing surgery on a monkfish during a tagging trip aboard the Gertrude H.

Monkfish Tagging Program photo

Researchers are able to complete the tag implant surgery and have the live monkfish back overboard in 5-7 minutes.

The teams soon fell into a rhythm. Industry partners handled the net, providing researchers with fish as needed, and researchers did the tag implantations. They injected each fish with oxytetracycline to mark its vertebrae, otoliths (ear bones), and dorsal spines for aging studies that will be done after the fish are recaptured.

Altogether, it took between five and seven minutes to tag and inject each fish and gently put it back overboard.

Jon Grabowski of the Gulf of Maine Research Institute (GMRI) in Portland, ME, one of the tagging program's project leaders, said, "I watched those fish swim away. They looked very healthy."

Two tag types

The tagging work is part of a years-long collaboration between gillnetters and three of the region's most prominent research institutions – the Northeast Fisheries Science Center (NEFSC) in Woods Hole, GMRI, and the University of Massachusetts-Dartmouth's School for Marine Science and Technology (SMAST).

GMRI and fishermen have been tagging monkfish since 2007 with conventional T-bar tags – the ones that look like antennae sticking out of the fish. This work has been carried out through the Monkfish Research Set-Aside (RSA) Program, which is directly financed by industry. Fishermen collectively give up 500 monkfish days-at-sea per year to help fund research projects through the RSA program.

The T-bar tagging by itself has begun to provide important clues about monkfish movements, but this latest data storage tag (DST) work, also financed by the RSA program with additional support from the Northeast Consortium, goes even further.

"With the conventional T-bar tags, you know where the fish were released and where they were recaptured, but you have no idea where they have been in between," said Anne Richards of the science center, one of the project leaders for the DST work.

Many questions

With DSTs, commonly called archival tags, researchers can learn much more than the release-and-recapture points of a monkfish's travels. These remarkable tags additionally record time, temperature, and pressure, roughly every 10 minutes, for up to five years.

The pressure measurement is key because it can be used to estimate how deep a particular monkfish was swimming – all the way down to 1,500 meters, equivalent to 4,950 feet.

And that's what people really want to know: How deep do these monkfish go? How much time do they spend at depths beyond the reach of trawl surveys and commercial fishing activity? Do they travel from inshore to offshore and back again or visa versa? Do they move from south to north or the other way around? Where do the females go at certain times of the year when they seem to disappear? How deep do they go? Maybe they go *very* deep.

"These are big, overarching questions," said Grabowski. "We want to establish migratory patterns. We want to establish how much exchange there is between management areas. Is one area a source of monkfish and the other one a sink? Are there seasonal patterns of migration? Do they vary from the Gulf of Maine to Southern New England to the Mid-Atlantic Bight?"

Grabowski believes that finding answers to these questions is critically important to the commercial fishery.

"It's a very valuable fish species," he said. "It's important that we get it right."

Keep an eye out

So many questions and so much hope for answers, all contained in tiny canisters sutured just under the surface of the tail-skin on 16"-to-20"-long monkfish.

The tags leave a noticeable bulge, an obvious clue that something is different about the fish.

"It looks like someone's thumb was sewn in," said Platz. "It's pretty hard to miss."

But fearing that busy fishermen might pass by what could be mistaken for a large growth, researchers also attached two, bright pink T-bar tags along the midridge area of the tail. And those pink antennae are practically impossible to overlook.

Furthermore, researchers are hoping that the high reward for returning a DST-

GMRI photo

I cannot emphasize enough how integrally involved the industry has been. They guide us to where the fish are. We use their vessels. We have been really fortunate to have so much support from industry.

—Jon Grabowski

Monkfish tagging: who, what, where, why at a glance

● **WHO**: Commercial fishermen and researchers from the Northeast Fisheries Science Center, the Gulf of Maine Research Institute (GMRI), and the University of Massachusetts-Dartmouth School for Marine Science and Technology (SMAST) are all involved in the collaborative tagging program.

● **WHAT**: Two types of tags are being used. Data storage tags, also called archival tags, look like bullets implanted just under the tail skin. T-bar tags stick out of the tail like colored antennae.

● **WHERE**: So far, tagging has taken place in the Gulf of Maine and Southern New England, and plans are in the works to expand tagging into the Mid-Atlantic and offshore areas. The Northeast Consortium and the industry-financed Monkfish Research Set-Aside Program have paid for the work with overhead and staff/research support from GMRI, SMAST, and the science center.

● **WHY**: The purpose of this enormous effort is to learn more about monkfish migration patterns, monkfish behavior, and the level of intermixing between the northern and southern management areas. Additional research, which is being conducted simultaneously on recaptured fish, is focusing on monkfish aging. **/cfn/**

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tagged monkfish – $500 per fish – will entice fishermen to keep a keen eye on their catches.

DSTs expensive

Getting data storage tags back from recaptured *whole* monkfish is absolutely crucial to the success of the project, according to every researcher involved.

These tags do not transmit information to satellites like some ultra-high-end archival tags. Instead, they serve as time capsules, storing data for downloading onto a computer after the fish is recaptured.

The tags are wildly expensive, which has limited the number of DSTs the tagging teams can put in the water. Once this current round of tagging is complete, the teams will have implanted a total of 190 high-tech Star-Oddi DST centi-TD loggers at $360 a pop.

They also have on hand an additional 40 or so lower-quality DSTs, courtesy of SMAST, for external attachment. These 40 won't provide quite as much information and probably won't record as long as the Star-Oddi tags, but it's another tagging opportunity that everyone welcomes.

"We're using every opportunity we can to get as many tags out there as possible," said Richards.

And that includes more T-bar tagging.

Practice makes perfect

Given that the archival tags are so valuable, researchers wanted to be sure they were right on the money with tag placement and fish survival rates.

So, before any of the at-sea tagging got underway, researchers spent a year honing their surgical skills in the lab with the help of a separate Northeast Consortium grant.

And now, with four trained "surgeons" and a fairly slick tagging system, the tagging teams are ready to keep going as long as they can buy more tags and receive funding for future projects.

"We can learn so much about monkfish behavior from these tags," said Richards.

She has plenty of questions of her own.

"Where do these fish spawn?" Richards wondered. "At the surface? At the edge of the continental shelf? Could they be riding currents to migrate? They're hydrodynamically designed. Their pectoral fins are like wings, and there have been sightings of monkfish at the surface. Are these fish going to Canada?"

While the information contained in those tiny canister-like DSTs probably won't answer all of those questions definitively, the stored data will provide important pieces of a very big puzzle.

T-bar tag results

Promising as it all is, the limiting factor with these remarkable data-rich archival tags is their cost; $360 apiece is a lot of money.

In contrast, conventional T-bar tags run less than a dollar each.

"The trade off is you can put out a lot of T-bar tags really cheap," said GMRI's Graham Sherwood.

In 2007 alone, GMRI and fishermen tagged 2,770 fish during the fall. It was the very first monkfish tagging study in the Northeast.

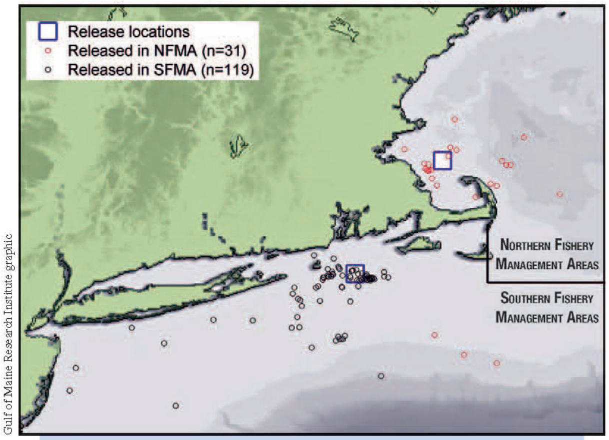
Of the 1,006 fish tagged in the north, 1.7% were recaptured, and of the 1,764 tagged in the south, 3.9% were recaptured. Only fish that were "at liberty" for more than 30 days after being released were counted as "recaptures" in the study, and most of the recaptures occurred

Pavel Ivanov photo

Three monkfish tagging trips were made aboard Ted Platz's gillnetter Gertrude H. Pictured here during the January 2009 trip, from left, Platz and researchers Crista Bank of SMAST and Larry Alade of the NEFSC.

Monkfish Tagging Program photo

Gillnetter Tim Caldwell is the industry partner for the tagging project's Gulf of Maine trips, carrying researchers aboard his C. W. Griswold. Caldwell is pictured above during a 2007 trip when monkfish were tagged with conventional T-bar tags, work carried out through the Monkfish Research Set-Aside Program.



Gulf of Maine Research Institute graphic

In addition to showing the line marking the northern and southern fishery management areas, the chart shows monkfish tag release/recapture locations. Note recaptured fish represented by red circles were tagged and released in the northern area. Black circles are for recaptured fish released in the southern area.

within 10 months of release.

The results were intriguing. Contrary to popular thinking, 9.1% of the fish tagged in the northern area were estimated to have moved to the south (see chart, below). However, none of the fish tagged in the south had moved north.

Therefore, the study concluded that mixing rates were "low and unidirectional," and average movement was to the southwest.

But no one was putting undue weight on these results, especially since researchers strongly suspect that at least some monkfish move from south to north.

"The only data we have so far is from those 2007 fish," said Sherwood, who headed up the project. "It's a very preliminary snapshot of what's going on. No juveniles were tagged, and they may be the ones that are moving north. We need to tag in other seasons and in other areas. Plus, our return rate for the north was very low."

The study did show that monkfish have the potential to travel great distances. According to Sherwood, one monkfish tagged and released off Boston was recaptured off New Jersey.

More in 2010

During 2010, GMRI hopes to get an additional 5,000 T-bar tags in the water, this time further south into the Mid-Atlantic and further offshore, as well as during the spring instead of the fall.

And, researchers also intend to train fishermen to do the tagging themselves. They'll meet with participating industry members to ensure they understand tagging methods and what's needed for data collection.

Yet even before any further training, researchers expressed full confidence that fishermen can take the lead on the at-sea T-bar work. Not only will this save valuable time and resources, but it will allow the tags to be more widely distributed.

Grabowski, a project leader for the 2010 T-bar work, said, "The fishermen involved in this are very interested in the science. They told us, 'You know, we can do these tags ourselves. You guys don't have to be on the boat.'"

All of the researchers involved in the tagging project expressed sincere appreciation for the partnerships they have developed with fishermen.

"I cannot emphasize enough how integrally involved the industry has been in all of this," Grabowski said. "They guide us to where the fish are. We use their vessels. We have been really fortunate to have so much support from industry. That kind of buy-in is invaluable."

From gillnetter Ted Platz's perspective, the work is worth the effort.

"It's what the fishery needs," he said. "We need to know about the mixing rates from north to south and how these fish move. I think there are a lot of misconceptions about the lives these monkfish lead. We need to do what it takes to get better science." ■

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Find a tagged monk? Save *whole* fish fresh, not frozen

WOODS HOLE, MA – Anyone lucky enough to haul up a monkfish outfitted with a valuable data storage tag (DST) can claim a $500 cash reward simply by saving the fish – the whole fish – and shipping it to researchers or arranging for a pick-up.

The bullet-shaped, canister-like tags are surgically implanted in the tail of the fish and form a significant bump under the skin. And, to further grab people's attention, two pink T-bar tags, which look like bright antennae, stick out around the midridge area of the tail.

Researchers are asking fishermen to save the *entire* fish, not just the tail, and, if at all possible, to keep the fish on ice in "fresh" condition. Freezing is a backup if necessary, but it's nowhere near as good as fresh.

"It's really important that we get the whole fish back," said Anne Richards of the Northeast Fisheries Science Center, one of the project leaders for the DST tagging work.

"It's way better to get a fresh fish than a frozen one, but frozen is better than rotten," she said.

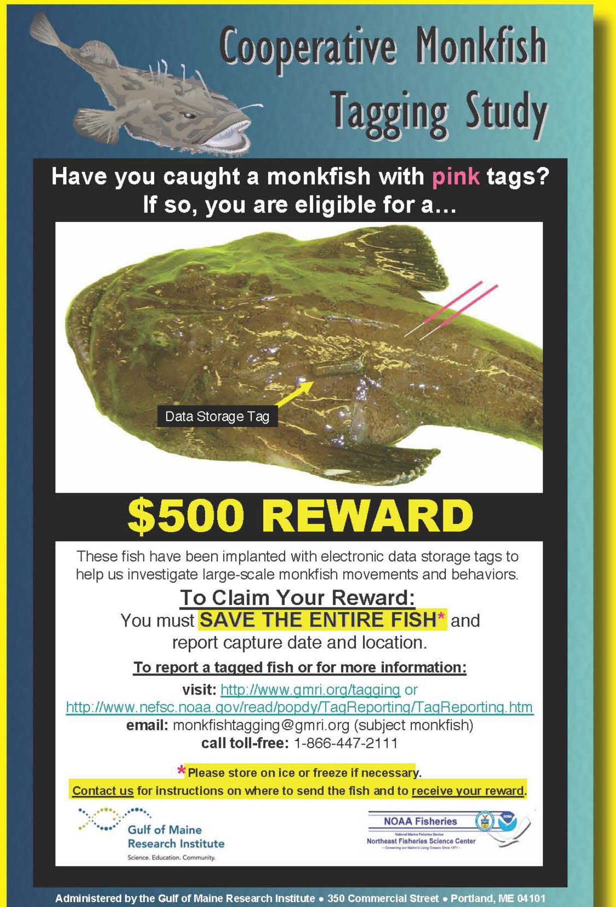
The whole fish is important because researchers at the science center, the Gulf of Maine Research Institute (GMRI), and the University of Massachusetts-Dartmouth School for Marine Science and Technology are carrying out a variety of different studies with numerous parts of the fish.

Among other things, researchers want to look at each fish's gender, reproductive state, length and weight at recapture, stomach content, vertebrae, dorsal spines, and otoliths.

"We're taking every kind of sample possible for genetic studies, feeding and aging studies, reproductive biology studies, and microchemical analyses to tell us where these fish have been," said Richards.

Researchers considered various options for tag placement but settled on the tail.

"That way, if the tag is missed on the boat and the tail goes into the market, it might be caught at the dealer or consumer level, or even during processing," Richards said.



What to do

Any fisherman who catches one of these DST-tagged monkfish should record the location of the recapture, save the fish on ice, and, as soon as possible, call the toll-free number to alert researchers to the important find. They'll tell you what to do from there.

The number is 1-866-447-2111.

The electronic tags are expensive to buy, costing $360 each. But each one can log up to five years worth of priceless data.

"That's why we're trying our best to get high return rates," said GMRI's Graham Sherwood, who's involved in the project.

For more information about tag returns and the tagging program in general, visit the GMRI web site at <www.gmri.org/tagging> or the science center web site at <www.nefsc.noaa.gov/read/popdy/TagReporting/TagReporting.htm>.

Janice M. Plante

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Monkfish aging study may alter old thinking

NEW BEDFORD, MA – Like many other fish species, monkfish can be aged by reading the number of "rings" on certain bony body parts such as otoliths, vertebrae, and dorsal spines. It's like counting the circles on a slab of tree trunk. Three rings means the fish is three years old. Ten rings means it's 10 years old.

Or does it?

Scientists are beginning to question whether this long-accepted aging technique is completely suitable for monkfish, especially the older ones.

"We could be underestimating age. We're not sure if a ring is laid down every year when growth slows down," said Crista Bank, a technician at the University of Massachusetts-Dartmouth School for Marine Science and Technology (SMAST) who is also working on a master's thesis about the subject.

Yet knowing the age of monkfish is key to understanding their basic biology. So that's why researchers have embarked on a new series of studies to get to the root of the matter.

"We want to validate that the aging method is accurate, which will give us more confidence in our stock assessments," said Bank.

While the primary purpose of Bank's monkfish work at SMAST is to determine whether the current aging methodology is producing good results, she also is investigating whether one particular aging tool is preferable over another.

Is it better to count rings on otoliths – those tiny, calcified inner ear bones – or on vertebrae, which distinctly show rings without even being sliced? Or what about the first dorsal spine – the one with the "fishing lure" dangling from it? That's what some European scientists use to age monkfish.

In addition to surgically implanting data storage tags into monkfish, researchers also inject the fish with oxytetracycline. The antibiotic "marks" the fish for aging studies and may help reduce the chance of infection at the tag incision.

Monkfish Tagging Program photo

Graham Sherwood of the Gulf of Maine Research Institute (GMRI) has been deeply involved in the monkfish tagging program and its related studies. He emphasized the importance of all of the various aging work.

"There's a real difficulty in aging monkfish," he said. "We really need to know how long they live."

There's a real difficulty in aging monkfish, and we really need to know how long they live.
—Graham Sherwood

Oxytetracycline

Some of the aging work is being carried out during monkfish tagging trips.

Researchers, working aboard commercial fishing vessels, have been surgically implanting data storage tags into monkfish tails and then injecting the fish with oxytetracycline.

The tagging project is designed to produce more information about monkfish migration patterns and north/south mixing rates, but the oxytetracycline injections are part of the aging studies.

The oxytetracycline "marks" the fish. It works by leaving a light glow or stain on the specific ring that was being laid down at the time the fish was caught, tagged, and injected.

Then, when the fish is recaptured, researchers will be able look for the marked ring with ultraviolet light, which will help them determine how much growth occurred between tagging and recapture, assuming the fish isn't recaptured before it has time to grow.

Crista Bank also is keeping live monkfish in holding tanks at SMAST.

"Growth in the lab won't be like actual growth in the wild, but we should be able to see seasonal growth patterns," she said. "This also will help us confirm whether the oxytetracycline method is working."

Bank participated in all but one of the 2009 tagging trips and is one of four researchers who have mastered the surgical procedure used to implant the high-tech electronic data storage tags into monktails. She also has taught other researchers to do oxytetracycline injections so the work can continue even when she's not onboard.

Oxytetracycline is an antibiotic. Anne Richards of the Northeast Fisheries Science Center, one of the project leaders in the monkfish tagging program, said using the antibiotic for aging studies might have an ancillary benefit following tag surgery.

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"It should help with healing by reducing the chance of infection at the tag site," she said.

Microchemical work

In another phase of the aging work, researchers plan to save otoliths from recaptured monkfish for future microchemical analyses that may help them better interpret growth rings.

The people involved hope to age fish chemically by looking at the ups and downs of certain microchemical components in the otoliths, such as with the element strontium. Researchers may be able to track seasonal variations in temperature, for example, by looking at differences in strontium concentrations.

It's complicated and highly technical work for sure, but it has the potential to provide amazing results.

Graham Sherwood said GMRI researchers ran a single otolith through the process at Memorial University in St. John's, Newfoundland.

"We thought it was an eight-year-old monkfish," he said. "But after the analysis, it looked like it might have been more like 13 years old."

Thanks to industry

The aging studies will be years in the making and won't produce any immediate results, but fishermen are supportive of the effort, knowing that better aging information will lead to better stock assessments, which then will lead to better management.

With this in mind, industry has been working hand-in-hand with researchers, taking them to sea when needed and supplying them with fish.

Bank, who was readying to meet a fisherman at the dock one Friday night in mid-January to pick up yet another live monkfish for her laboratory holding tanks, expressed deep appreciation for industry's support.

"Without them, we couldn't do any of this," she said. "We rely on their help."

Janice M. Plante

Monkfish Tagging Program photo

Crista Bank, an SMAST technician, is working on a study of current monkfish aging methodology.

Pavel Ivanov photo

Above, NEFSC's Larry Alade with the T-bar tags. GMRI hopes to get an additional 5,000 T-bar tags in monkfish in 2010. Researchers intend to train fishermen to do the tagging, training them on tagging methods and what's needed for data collection.

Types of Tags

Fishermen are asked to save the entire fish, if they land a monkfish that has been implanted with a data storage tag, see below. The canister-like tags create a visual bump under the skin in the tail of the fish. The fish have also been marked with two pink T-bar tags, which stick out around the midridge area of the tail.

Monkfish Tagging Program photo