Northeast Consortium Final Report

Project Title: **Yellowtail Flounder Tagging Study**

Principal Investigator: Steve Cadrin
Northeast Fisheries Science Center
Cooperative Marine Education & Research Program
School for Marine Science & Technology
200 Mill Road, Suite 325
Fairhaven, MA 02719 U.S.A.
(508)910-6358 (508)910-6396 fax
Steven.Cadrin@noaa.gov

Periods of Performance: FY 2003 grant, October 2003-September 2004
FY 2004 grant, October 2004-September 2005
FY 2005 grant, October 2005-September 2006

Date of Submission: September 30, 2009

Steven X. Cadrin

ABSTRACT

A collaboration with commercial fishermen tagged over 45,000 yellowtail flounder (*Limanda ferruginea*) with conventional disc tags and data-storage tags in all three New England stock areas with the objectives of estimating movement among stocks areas and mortality as well as providing growth observations. The pattern of release and recapture locations documents frequent movements within stock areas with a less frequent movement among stock areas. Data-storage tags reveal distinct periods of on-bottom and off-bottom behavior associated with movement to different habitats. Simulation of yellowtail flounder life history, stock status, fishery dynamics and the pattern of releases suggest that fishing mortality and movement estimates are confounded and cannot be independently estimated with tagging data alone. Accordingly, survival and recovery rate were estimated for the New England resource as a whole using tag-recovery models. Tag-recovery estimates of survival confirm the general magnitude of mortality estimates from age-based stock assessments, and greater survival of females than males. An integrated catch-at-age model is being developed to include tag recovery data with fishery and survey data to estimate mortality and movement simultaneously. Comparison of scale samples collected during release and recovery confirm the current interpretation of one annulus per year. Overall, the collaboration of fishermen and scientists was successful in independently confirming mortality rates and age determination from conventional age-based analyses and advanced the understanding of movement behavior of a species that was previously perceived to be 'sedentary.'

INTRODUCTION

Yellowtail flounder (*Limanda ferruginea*) is one of the principal resources of the northeast groundfish complex, with major fishing grounds on Georges Bank, off southern New England and off Cape Cod. The fishery for yellowtail is among the most productive and valuable in New England, yielding 3.7 million lb and $5.5 million to U.S. fishermen in 2008 (NMFS 2009). However, with all three stocks currently rebuilding from an overfished condition, the potential yield of yellowtail is much greater than the current yield (the estimated maximum sustainable yield from the three New England stocks is 65 million lb; NEFSC 2008).

Stock Assessment

Managing the recovery of yellowtail resources and maintaining optimum yield require precise stock assessments and accurate forecasts of the population and fishery. Although yellowtail flounder stock assessments provide valuable information for fishery management advice, several major sources of uncertainty persist (NEFSC 2008). The source of this uncertainty is not well understood, but may result from movement among stock areas, lack of information on the effect of closed areas on population dynamics, insufficient surveying of areas closed to fishing, inaccurate age determinations, misrepresentative sampling of distributional patterns, underreported catch, or inaccurate assumptions about natural mortality (NEFSC 2002; TRAC 2004; NEFSC 2008).

The southern New England-Mid Atlantic stock is not rebuilding at the expected rate, apparently because recruitment has not been strong and fishing mortality has not been reduced enough, despite management restrictions like the year-round closure of the Nantucket Lightship Area since December 1994 (NEFSC 2008). Although the stock definition of Southern New England-Mid Atlantic yellowtail was recently revised (Cadrin 2003), information on movement of yellowtail between southern New England and Mid Atlantic areas, as well as mixing with the adjacent Cape Cod and Georges Bank resources is limited to historical studies (Royce et al. 1959, Lux 1963a).

Status of the Cape Cod-Gulf of Maine yellowtail stock is also problematic for northeast groundfish management. The stock assessment suggests excessive fishing mortality and overfished stock size (NEFSC 2008). Therefore, the status of the Cape Cod-Gulf of Maine yellowtail stock is a focus of groundfish management in the Gulf of Maine. Movement of yellowtail to and from the Cape Cod grounds is not well known. Population dynamics of Cape Cod yellowtail may be greatly influenced by mixing with adjacent stocks, because the Cape Cod grounds are relatively small in comparison with Georges Bank and the southern New England shelf (Hart and Cadrin 2004).

Previous Tagging Studies

Movement of yellowtail flounder off New England has been addressed by several historical and more recent tagging studies. Royce et al. (1959) tagged and released yellowtail on U.S. fishing grounds from 1942 to 1949 and concluded that groups of yellowtail are relatively localized (e.g., most tagged fish were recovered within 80 km of the release site), short seasonal migrations occur, and little mixing occurs among fishing

grounds (except for frequent movement from the Mid Atlantic Bight to southern New England waters). Lux (1963a) also tagged yellowtail off U.S. fishing grounds and concluded that groups of yellowtail move seasonally within fishing grounds, with a small amount of seasonal mixing among groups.

In 1963, Lux (1963b) tagged yellowtail flounder off Cape Ann. All recaptures were near the release site, except for one fish that moved northward 50 km to the Isles of Shoals. Tagging studies from Canadian waters indicate that yellowtail flounder are relatively sedentary: the longest observed movement from an unpublished tagging study on the northeast Scotian Shelf was less than 50 km (Neilson et al., 1986), and yellowtail tagged from three studies on the Grand Bank traveled an average of 59 km (Walsh, 1987, Morgan and Walsh, 1999, Walsh et al., 2001).

From 1999 to 2002, yellowtail were tagged and released on eastern Georges Bank (Stone and Nelson, 2003); none of the recaptured fish moved off the Bank, and all but one were recaptured on the eastern portion of the Bank. A summary of all previously published yellowtail movements off the northeast U.S indicates that 95% of fish tagged in the northern Gulf of Maine moved to the Cape Cod fishing grounds, and 70% of fish released in the Mid Atlantic moved to southern New England. Conversely, nearly all other recaptures were in the area where they were tagged (98% of fish from the Cape Cod grounds, 97% from Georges Bank, and 94% of recaptures from southern New England). When both Cape Cod-Gulf of Maine and southern New England-Mid Atlantic areas are combined the regional residence is 97%.

Although data from historical tag recaptures is available (Royce et al. 1959, Lux 1963a), and suggests some mixing with the southern New England and Georges Bank stocks, the studies were not explicitly designed to estimate mortality or mixing rates. These data are up to 50 years old and may not represent the current environmental or stock conditions. The likelihood of older yellowtail moving from the Cape Cod grounds to the northern Gulf of Maine is also not well known.

OBJECTIVES

The yellowtail flounder tagging study was designed to address sources of uncertainty in yellowtail flounder assessments. The study provides valuable information on movement, mortality and growth, thereby complementing the current stock assessment methods for yellowtail and improving the reliability of scientific advice for effective fishery management. Furthermore, such collaborative research is building an open working relationship between fishermen, NMFS, state and academic researchers. This proposal was developed with the interaction of fishery scientists and yellowtail fishermen. Through a series of port visits and meetings, industry leaders offered their knowledge of seasonal yellowtail distributions, fishing practices, and practical field experience, and scientists provided input on population modeling, statistical design, and technical protocols. The result is an integrated sampling and analytical plan that is both efficient in the field and technically rigorous for reliable population estimates.

There are several objectives of the Yellowtail Flounder Tagging Study:

- estimate movement rates among yellowtail fishing grounds
- provide independent estimates of mortality
- confirm age determinations
- foster cooperative relationships between scientists and fishermen.

PARTICIPANTS AND PARTNERSHIPS

The greatest resources available to the project are its personnel. Fishermen and researchers have cooperated to develop the general approach and technical details of the tagging study through several meetings from Rhode Island to Maine. All cooperators were invited to three meetings to reflect on field work, review results and plan future work. Six fishermen and 33 scientists attended the first meeting in Woods Hole on January 14, 2004. Seven fishermen and 29 scientists attended the second meeting in Woods Hole on May 2, 2005. Twenty-one fishermen and 13 scientists attended the third meeting in New Bedford on March 1, 2006. Detailed summaries of the meetings are available online (www.cooperative-tagging.org).

Fishing Partners:
Many fishermen have contributed to this study. Three fishermen, representing the three stock areas for yellowtail flounder, were involved in all aspects of planning and interim decision making:

David Goethel, F/V Ellen Diane
23 Ridgeview Terrace, Hampton, NH 03842
603 926-2165
EGoethel@comcast.net

Rodney Avila, F/V Trident
369 Belair Street, New Bedford, MA 02745-1603
508 998-1659, 508 995-6345 fax
RodAvila@comcast.net

Fred Mattera, F/V Travis & Natalie
113 Lewiston Avenue, West Kingston, RI 02892
401 364-7994
fm@nestco.necoxmail.com

Other fishermen who have been involved in tagging and attending planning meetings: Carlos Ageuas (F/V Victory), Bill and Jason Amaru (F/V JoAnne-A III), Rodney Avila Jr. (F/V Trident), Bruce Bannick (F/V Sarah Beth), Ed Barrett (F/V Phoenix and F/V Sirius), Antonio Barroqueiro (F/V Lady of Grace), Tom Bell (F/V Karoline Marie), Tony Borges (F/V Sao Paulo), Ron Borjeson (F/V Angenette), Carl Bouchard (F/V Stormy Weather), Ray and Rich Canastra (Whaling City Auction), Luis Fidalgo (F/V Vila De Ilhavo), Steve Follett (F/V Heather Lynn), Jim Ford (F/V Lisa Ann II), Paul Harvey (F/V Ing Toffer II), Manny Marquinhos (F/V Victory), Luis Martins (F/V Victory), Shawn McLellan (F/V Elizabeth), Maggie and John Raymond (F/V Olympia), Luis Ribas (F/V Blue Skies), Dennis Robillard, Jr. (F/V Julie Ann) and Jaime Santos (F/V Lady of Grace), Tracy Stubbs (F/V Ing Toffer II) and Proctor Wells (F/V Tenacious), and dozens more have returned tags.

Scientific Partners:
Many scientists collaborated on this study and have contributed to its design. Threer scientists have served as the primary program coordinators:

Azure Westwood, Northeast Fisheries Science Center
Current address: School for Marine Science & Technology
200 Mill Road, Suite 325, Fairhaven, MA 02719 U.S.A.
(508) 910-6316
awestwood@umassd.edu

David Martins, School for Marine Science & Technology
200 Mill Road, Suite 325, Fairhaven, MA 02719 U.S.A.
(508) 910-6392
dmartins@umassd.edu

Josh Moser, Northeast Fisheries Science Center
166 Water St. Woods Hole MA 02543
(508) 495-2246
Joshua.Moser@noaa.gov

Three scientists served as data analysts and modelers:

Larry Alade, Northeast Fisheries Science Center
166 Water St. Woods Hole MA 02543
(508) 495-2085
larry.alade@noaa.gov

Anthony Wood, School for Marine Science & Technology
200 Mill Road, Suite 325, Fairhaven, MA 02719 U.S.A.
(508) 910-6358
awood@gso.uri.edu

Daniel Goethel, School for Marine Science & Technology
200 Mill Road, Suite 325, Fairhaven, MA 02719 U.S.A.
(508) 910-6358
dgoethel@umassd.edu

Many other scientists contributed to the design, field work, outreach, database development, analysis and interpretation:
- *NMFS*: Steve Murawski, John Boreman, Frank Almeida, Fred Serchuk, John Hoey, Paul Rago, Chris Legault, Tim Miller, Cathy Sumi, Stacy Kubis, Talia Bigelow, Sam Matulich, Gary Shepherd, Bill Overholtz, Nathan Keith, Jonathan Duquette, Rob Johnston, Kevin McIntosh, Bill Duffy, Dave Radosh, Jay Burnett, Sarah Pregracke, Vaughn Silva, Patricia Yoos, Heather Sagar, Earl Meredith, Sarah Babson-Pike, Mike Palmer , Steve Kelly, Erin Kupcha, Katie Lovett, Joe Mello, Anthony Morales and Chris Zanni.

- *MADMF*: Jeremy King, John Boardman, Brian Kelly and David Pierce
- *SMAST*: Jon Loehrke, Greg DeCelles, Sally Roman, Adam Barkley, Rodney Rountree, Joachim Groeger, Russ Kessler and Darin Jones
- *RIDFW*: April Valliere and Sarah Pierce
- *Canada DFO*: Heath Stone
- *University of Maryland Eastern Shore*: Eric May, Andrea Johnson and Erica Anuszewski
- *Northeast Consortium, University of New Hampshire:* Chris Glass, Rachel Gallant
- *Manomet Center*: Greg Morris and Kris Joppe-Mercure
- *REMSA Observers:* Janine L'Heureux and Meryl Segal

METHODS

The general approach was based on an experimental design that represents the entire population and an analytical design that models movement and mortality. Thereby, the experimental design corresponded to the analytical design, and population estimates support all three technical objectives (movement, mortality and growth) with one study.

All phases of the proposed research, from the field protocol to public outreach, were developed cooperatively between New England groundfish fishermen, the Northeast Fisheries Science Center and other research agencies. The project contracted commercial fishermen and their vessels to work with scientists to tag and release yellowtail on all fishing grounds off New England, proportional to geographic patterns of abundance. The geographic design was based on statistical fishing areas, with releases in each area proportional to relative abundance of yellowtail (according to NEFSC groundfish surveys; Figure 1, Table 1). Such a design allowed for the estimation of movement among areas and mortality. The field protocol and analytical design were peer reviewed at "a workshop to review and evaluate the design and utility of fish mark - recapture projects in the northeastern United States" and considered to be a valid approach to address the project objectives (Tallack et al, eds. 2005).

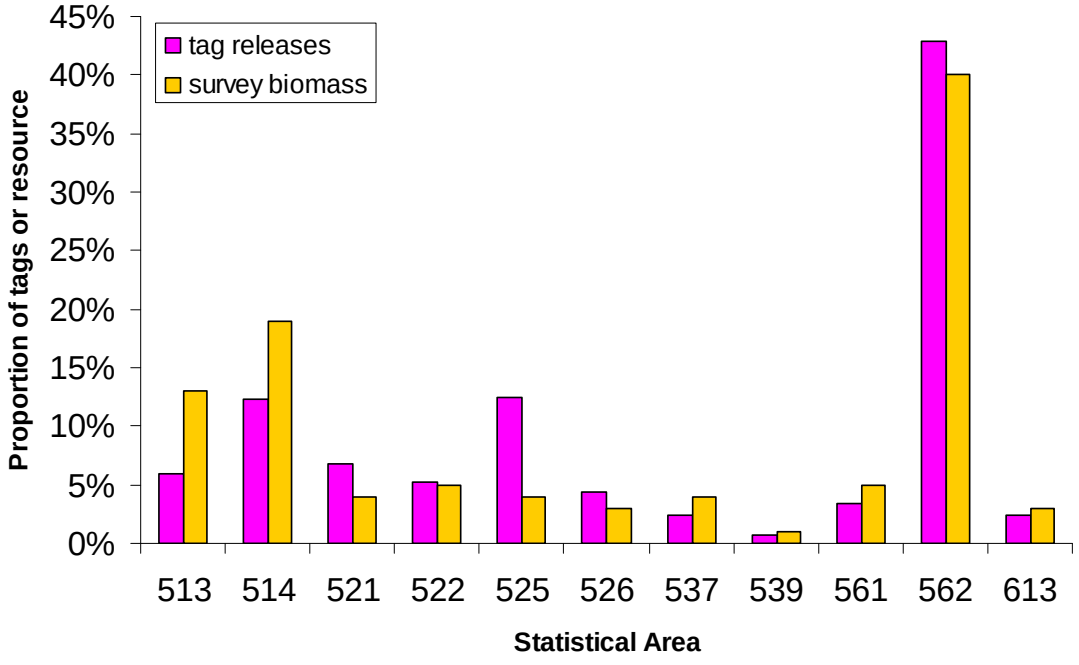


Figure 1. Distribution of tag releases by statistical area in comparison to survey biomass.

Table 1. Distribution of tag releases by statistical area in comparison to survey biomass ('%' indicates percent tags recovered).

	Tag Releases						2003-2006
area	2003	2004	2005	2006	Grand Total	%	Survey
513	3	1392	247	943	2585	6%	13%
514	2025	1192	480	1616	5313	12%	19%
521	2129	43	378	393	2943	7%	4%
522	710	784	84	686	2264	5%	5%
525	118	3978	817	459	5372	13%	4%
526	117	524	32	1202	1875	4%	3%
537	199	269	284	283	1035	2%	4%
539	170	30	0	101	301	1%	1%
561	423	476	57	534	1490	3%	5%
562	2906	9096	3387	3072	18461	43%	40%
613	292	331	231	205	1059	2%	3%
	9092	18115	5997	9494	42698	100%	100%

Yellowtail were captured using commercial otter trawls with large mesh (6.5") and relatively short tows (30 min). All legal-sized fish (>33cm) in viable condition, and some sublegal sized-fish from low density tows in southern New England-Mid Atlantic were tagged with either Peterson discs or data-storage tags. Releases were during the spawning season (May-August; with the exception of 1% of releases in autumn of 2003). The field protocol is detailed in Appendix A.

Peterson discs and data storage tags were distributed proportionally. Tag specifications were:
Peterson Discs; Floy Tag 7/8" round, fluorescent pink, labeled "cooperative-tagging.org, tag#, $1000 lottery (or $100 reward), toll free 877-826-2612, provide tags & location and date." Most fish were tagged with blank discs on the blind side, with the exception of approximately 10% of releases sampled for scales which were labeled "take some fish scales & return to 166 Water Street Woods Hole MA 02543."

Data-storage tags; Lotek LTD 1100, 32K memory, 8mm x 16mm x 27mm; time (dynamic storage & intervals), depth (+/- 0.04psi up to 735psi) & temperature (+/- 0.19o C), 3 year battery, labeled "tag#, Mail tag, date, location to 166 Water Street Woods Hole MA 02543". Oval disc tag labeled "cooperative-tagging.org, $100 reward, toll free 877-826-2612."

Holding Experiments

Holding experiments were performed to assess tag retention and tagging-induced mortality. In 2004 and 2005, tank experiments were conducted to assess tag-induced mortality. On the last tow of four inshore tagging trips, 30 fish were kept in a flow through tank on board, and transported to a flow through holding tank in Woods Hole via oxygenated shipping bags maintained at approximately 10°C. Fish were fed regularly and observed daily. One experiment observed 20 tagged fish and 10 untagged controls for 35 days. They were also held for up to a year to observe tag retention. A second experiment acclimated 30 untagged fish for 2 weeks, after which 20 were tagged. Subsamples were removed from the holding tank at durations of 0, 24 and 168 hrs. Tissue samples around the tag site were preserved and analyzed for histological reaction at the University of Maryland Fish Pathology Lab.

In 2005, small cages and a deployment system were designed to evaluate tagging-induced mortality of yellowtail flounder, a necessary component of the tagging study. Cages are cylindrical (6' diameter, 2' high), made of 1-inch coated wire mesh, with two 50” cement runners for stability. Cages were initially deployed in 24-26 fathoms. Our experimental design involved collecting yellowtail in Ipswich Bay using tagging protocol (i.e., short tows with little bycatch of other species and immediate placement in flow-through tanks). We tagged 15 fish and placed them in a cage floating at the surface by the boat. We also placed 15 untagged fish in the cage for control observations. Tagged and control fish were selected using the quality control procedures in the tagging protocol to insure that viable fish are included in the study. Cages were lowered to the bottom. Oceanographic equipment (Hydrolab©) was deployed on a cage during deployment to monitor water quality during the experiment.

After three or four days, cages were hauled to the surface to observe survival of tagged and control fish. The ratio of survival of tagged and control fish was used to estimate tag-induced mortality. Survival of all tagged and control fish is an alternative estimate of mortality that includes that trawl-capture system as well as the effect of tagging. Tissues were collected from five tagged fish and three control fish from each cage deployment to assess tag-induced stress. Preserved tissues will be analyzed by the University of Maryland Eastern Shore (UMES) Fish Pathology Lab for histological examination. Tissue analysis was funded by the UMES-NOAA Living Marine Resources Cooperative Research Center, associated with tank studies for yellowtail flounder. Each of the three cages was loaded with fish and deployed four times (totaling 12 deployments with 360 fish) from June 6 to 20, 2005. Cages were retrieved after three or four days. Fish were inspected for viability and condition and subsampled for tissue analysis.

Tag Recapture and Outreach System

Tag recaptures are from a year-round commercial fishery with some seasonal geographic closures. The reward system for reporting recaptures involves $1000 lottery tags, 280 high-value ($100) rewards, and $100 rewards for returning data-storage tags. The outreach system includes reward posters, brochures, website (cooperative-tagging.org), annual letters to yellowtail fishermen, press releases, and a toll free number (877-826-2612). Every fisherman who reports a recapture is contacted via a phone call and ‘thank

you' letter with a map detailing movements of the tagged fish. Fishermen who return data storage tags, also receive a graph of the temperature and pressure data from that tag. Mailings and posters about the program have also been distributed to fish processors, fishing associations, NMFS port agents, NMFS Observer Program and research institutions from Nova Scotia to New Jersey. Project hats are given to leading tag returns and collaborators.

In response to suggestions at the 2nd Annual Yellowtail Tagging meeting (May 2 2005, Woods Hole), a new double-sided reward poster was designed with information detailing the project. The poster incorporated pictures of the new $100 yellow disk tag and new orange scale blanks. Posters were translated in Portuguese, French and Spanish to foster better communication between scientists and fishermen in New Bedford and Canada. To compliment the new database, phone logs have been carefully revised to collect more information without compromising critical recapture information. Scale envelopes labeled with yellowtail tagging pertinent information have been distributed throughout the ports by key cooperators and through mailings. Discussions at the 3rd Annual meeting (March 1 2006, New Bedford) focused on understanding recapture patterns and increasing outreach to fisheries that catch yellowtail incidentally.

Since the project began in 2003, 103 $100 rewards have been issued and nine $1000 lottery drawings have been hosted at fishing venues throughout New England. In addition to the standard "thank you" letters and maps, the project initiated an "Outstanding Partner" Award to the vessel with the most tag returns. A framed certificate and "thank you" letter signed by the Director of the NEFSC is mailed to the partner and posters announcing the merit are distributed for display in fishing supply houses and around the waterfront. Fifteen $1000 lotteries have been conducted from the Maine Fishermen's Forum to the New Bedford Working Waterfront Festival and several local meeting of fishermen's associations.

The toll free number for reporting tags (877-826-2612) is maintained and answered by a project coordinator at NEFSC. The website was updated to include more information and a user-friendly appearance. Several new features include a "Porthole Page", new stock assessments, a policy on lottery drawings and recent publications. The website is maintained and updated regularly with press releases, lottery winners, and data tag returns.

Analytical Design

The analytical model is based on the assumption that the observed pattern of recaptures is a function of harvest rate in each area and movement among areas. If the population of tagged yellowtail is representative of the entire population, the estimates of movement and mortality will also be representative. The analytical design will relate the observed number of tag returns (*r*) to a predicted number of tag returns:

$$1) \qquad \tilde{r}_i^t = n_i^t \beta_i^t \frac{F_i^t\left(1-e^{-(F+M)}\right)}{\left(F_i^t + M\right)}$$

and tags at the beginning of a time step is a function of abundance at the beginning of the time step in all areas, movement to the area (or residence in the area) and survival in the area:

$$2) \qquad n_i^{t+1} = \sum_j \alpha_{ij}^t S_j^t n_j^t$$

where

n_j^t is the number of tags present in area *j* at time *t*

β_i^t is the reporting rate in area *i* at time *t*.

F_i^t is the fishing mortality rate in area *i* at time *t*.

M is the natural mortality rate

$\alpha_{i,j}^t$ is the proportion of tags in area *j* that move to area *i* at time *t*

S_i^t is the survival in area *i* at time *t* [$S=e^{-(M+F)}$]

The parameter β_i^t can be calculated as the ratio of lottery tag returns to high value ($100) tag returns, assuming that all recaptures if $100 tags are reported. The parameters $\alpha_{i,j}^t$ (movement) and F_i^t (fishing mortality) can be estimated to fit model predictions to the observed frequency of seasonal returns by area.

The number of tag returns and the duration of the study will dictate how many parameters can be reliably estimated. The model has flexible spatiotemporal resolution, so that stock areas can be analyzed by statistical areas, and movements can be analyzed by season, if the number of tag returns supports such detail.

<u>Simulations</u> - Performance of the movement-mortality model on the number and pattern of tag releases was evaluated by simulation. Details of the analysis are reported in Alade (2008). An age-structured model of a single cohort was simulated for each stock, using the 2005 groundfish assessments (NEFSC 2005). Forward projections for 2006-2008 abundances were generated by randomly sampling 2004 VPA fishing mortality estimates, assuming a lognormal distribution with a calculated measurement error (i.e. estimated CV's from the time series of VPA estimates) for each stock (Georges Bank 33% CV; Cape Cod-Gulf of Maine 35% CV and Southern New England-Mid Atlantic 44% CV). Using the movement-mortality model, predicted recaptures were generated assuming a fixed natural mortality rate of 0.2 and a the reporting rate calculated from the ratio of

lottery and high-value tag recoveries. Measurement errors and process errors were simulated around true recaptures, assuming a lognormal distribution at various levels of precisions (10%, 25%, 50% and 75%CV). Model simulations were repeated 100 times for several scenarios, with mortality and movement parameters estimated by comparing the randomly generated recapture datasets to the "true" recaptures using a least square estimator. Relative performance of the model for each simulated case scenario was evaluated by calculating the relative bias and the 80th percentile confidence limits between the mean of 100 estimates and the "true" reference value in the model. Covariance analyses were also conducted to evaluate independence among parameter estimates from the simulations.

Tag-Recovery Analysis - Program MARK was used to apply a variety multi-period tagging models to the yellowtail flounder tagging data. MARK allows the user to apply various types of mark-recapture models and derives model parameter estimates according to maximum likelihood estimation (White and Burnham, 1999; Cooch and White 2004). Brownie-type dead recovery models (Brownie et al., 1985) were used to estimate the probability of yellowtail flounder survival (*S*) and a tag-recovery rate probability (*f*). Recovery rate (*f*) is a compound parameter representing the four probabilities of surviving the tagging process, retaining the tag, harvest in the observed time period, and being reported. The model assumes that the probability of survival and recovery is the same for all marked animals, and that tagging is instantaneous relative to the sampling occasions.

Recovery data were entered into program MARK in a triangular recovery matrix format (Brownie *et al*., 1985; White & Burnham, 1999) with I = number of months of tagging data and J = number of months of recovery data:

3) $$r = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1J} \\ & r_{22} & \cdots & r_{2J} \\ & & \ddots & \vdots \\ & & & r_{IJ} \end{bmatrix}$$

Matrices of expected values based on each model structure were developed. For example, for a tagging study with I months of tagging data and J months of recovery data, the fully time dependent model is represented by the matrix (Brownie et al., 1985):

4) $$E_r = \begin{bmatrix} N_1 f_1 & N_2 S_2 f_2 & \cdots & N_1 (S_1 \ldots S_{J-1}) f_J \\ & N_2 f_2 & \cdots & N_2 (S_2 \ldots S_{J-1}) f_J \\ & & \ddots & \vdots \\ & & & N_I f_J \end{bmatrix},$$

where N_i is the number of individuals tagged in year i, f_i is the tag recovery rate in year i, and S_i is the survival rate in year i. Each of the elements in the expected matrix has a

multinomial likelihood associated with it and the product of the likelihoods is maximized during the parameter estimation procedure.

The recovery matrix was examined with a suite of models exhibiting both time-dependent and constant survival, as well as time-dependent and constant recovery rate. Akaike's information criterion (AIC) was used to rank and select the model that achieved an optimal balance between the parsimony of the model and the goodness-of-fit, where parsimony decreases as the number of parameters in the model increases. Fit was judged with the model likelihood (L):

5) $$\text{AIC} = -2\ln(L) + 2P$$

where P is equal to the number of parameters. Program MARK modifies this equation to account for differences in effective sample size (N) and lack of fit (c):

6) $$\text{QAIC}_c = \frac{-2\ln(L)}{c} + 2P + \frac{2P(P+1)}{N-P-1}$$

This equation is known as the quasi likelihood adjusted AIC (Anderson et al.1994; Burnham and Anderson 2002).

An index using normalized Akaike weights (w) was also calculated for each model (i) to quantify the differences in support between models (Buckland et al., 1997):

7) $$w_i = \frac{e^{\frac{-\Delta QAIC_i}{2}}}{\sum e^{\frac{-\Delta QAIC_i}{2}}}$$

A goodness-of-fit test was carried out to determine how well the general model with all possible parameters (fully time-dependent) fit the data. Each of these simulations used the data to generate a variance inflation factor ($\hat{c}$) for the general model. A model solution that perfectly conforms to the assumed error distribution would produce an expected variance equal to the observed variance would have a $\hat{c}$ value of 1.0, while deviations of $\hat{c}$ above or below 1.0 indicate over or under-dispersion, respectively. Generally, a $\hat{c}$ value greater than 3.0 indicates poor model fit (Lebrenton *et al.*, 1992; Cooch & White, 2004).

The results from the top models determined through the model selection criterion outlined above were then examined for biologically realistic parameter estimates. Models that estimated multiple parameters to be at their boundaries (e.g., S=1.0) were rejected in favor of the next ranked model.

<u>Integrated Model</u> - A forward projecting, multi-stock statistical catch-at-age model that analyzes a variety of data sources, including tagging data, to help inform movement estimates between sub-populations is being developed. The model is being applied to

yellowtail flounder in the northeastern United States, including the three distinct sub-populations (each with its own catch at age, surveys, and vital rate data) and four years of mark-recapture information. Details of model specification are reported in Goethel et al. (2009).

Growth – Marginal increment analysis is an indeterminant age validation technique that is frequently used, because it is inexpensive and often more practical to conduct than validation experiments. This method determines the seasonality of band and ring deposition and considers age as a relative scale (i.e. age is not known). An annulus is composed of one band pair; a band is defined as one translucent or one opaque band; an increment is a measurement of a partial to complete growth bands or band pairs.

Scale samples of released and recaptured yellowtail were pressed by placing them onto a hard plastic slide, placing a laminate slide on top of the scale samples and a second plastic slide on top of the laminate slide, and running the slide through a scale press. The final product was a scale impression that could then be viewed on the light projector. Scale images were processed for marginal increment analysis. Age was determined from digitizing scale images. The light projector was used to eliminate regenerated scale samples and identify the focus of the scale as well as the consecutive annuli or growth checks. Once the scale impressions were aged distances from the focus to the edge of individual annuli were measured using Image Pro-Plus software. By measuring the individual annuli and comparing the measurements between the mark and the recapture events, growth during time at large was determined (Figure 2).

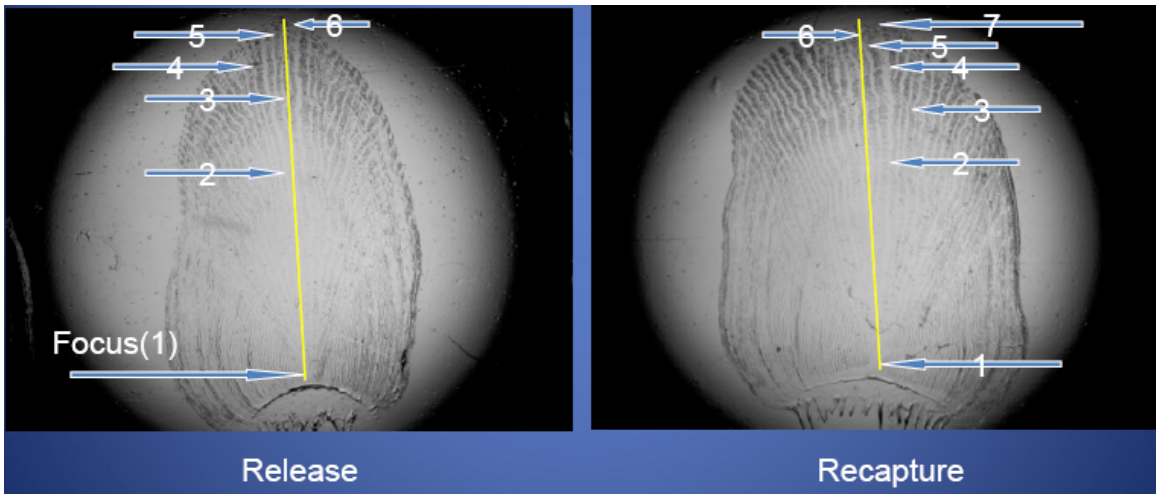


Figure 2. Example scale samples at release (left) and recapture (right) with annuli indicated.

Data

Modifications and improvements to the existing yellowtail flounder tagging database were made. The 2003-2006 tagging data underwent rigorous quality control procedures, resulting in the correction of many data entry errors. This process, although time consuming, improved the quality of the existing data and resulted in changes to the structure of the database.

Several data fields were added to improve our ability to quickly summarize the release and recapture data and generate GIS maps for outreach. The individual tag release records have been linked to the tow data, resulting in location information for every tag. The quality of the recapture data has been greatly improved through this process. Vessel hull numbers have been added to keep better track of participating vessels. A lookup table has been added that produces the statistical area where fish were recaptured. The addition of fields for data quality coding (i.e. recapture data and recapture location) has enabled the data to be filtered by quality of data.

The structural changes to the database lead to modifications of our field protocol. The field data sheets were re-designed and preparations for field work were changed to further improve data collection at sea. The data sheets now have record numbers for each fish tagged, tag series are assigned to scientists to improve record keeping, and standardized comment codes related to fish condition have been added. Additionally, prior to field work, tags are organized in sequential order for deployment to minimize recording errors. These changes have greatly improved the quality and efficiency of data collection in the 2005 tagging season.

The transition to a relational database will greatly improve our ability to analyze these data. We will be able to link to other NEFSC databases such as the weighout and logbook data. Additionally, the yellowtail flounder data are being used as a model for the design of a multi-species mark-recapture database which will house data from all NEFSC tagging projects.

Data from tag releases and recaptures are continually being added to the yellowtail tagging database. When the project is complete, a comprehensive database will be provided to the Consortium. Preliminary data can be provided upon request. The Northeast Fisheries Science Center has dedicated resources to maintain the yellowtail tagging database indefinitely as a part of the NEFSC Mark-Recapture Database System (MRDBS).

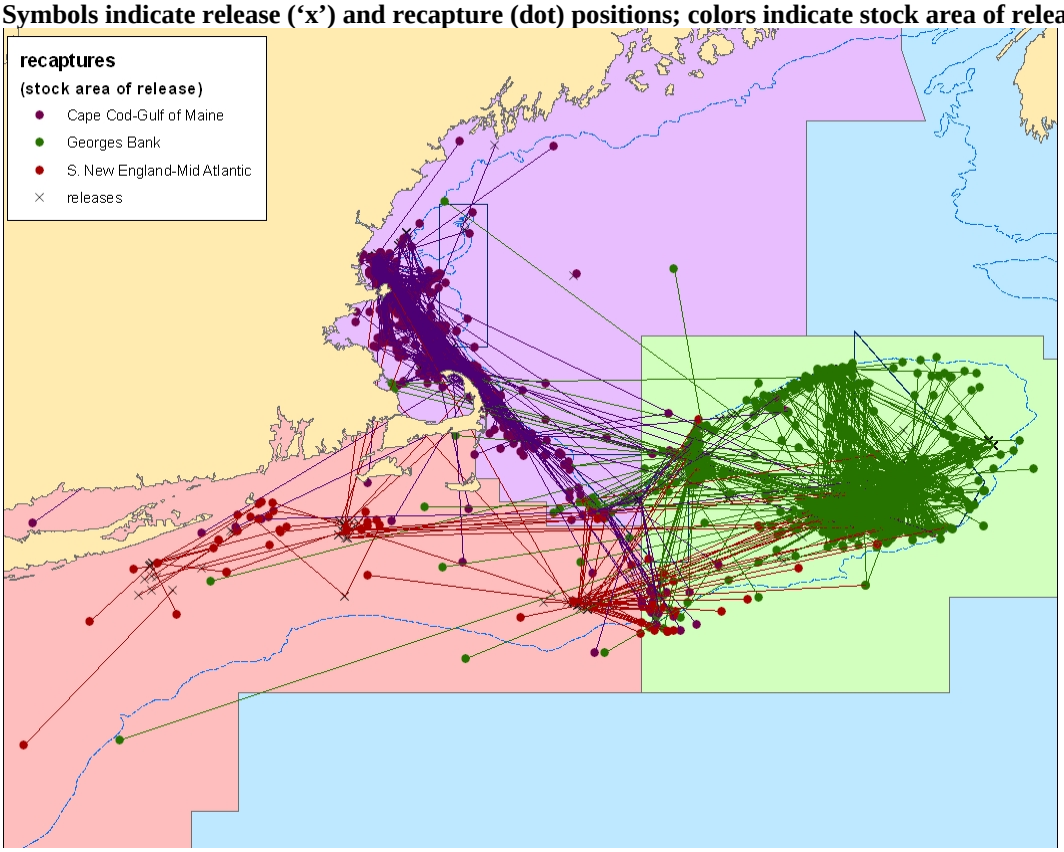
RESULTS AND CONCLUSIONS

As of September 30 2009, tags from 3,853 recaptured fish were reported. Preliminary results indicate frequent movements within the Cape Cod and Georges Bank stock areas with a less frequent movement among stock areas. Recapture data with known recapture location indicates 96% residence in Cape Cod-Gulf of Maine (with 3% movement to Georges Bank and 1% movement to southern New England-Mid Atlantic), 98% residence on Georges Bank (with 1% movement to Cape Cod-Gulf of Maine and <1% movement to southern New England-Mid Atlantic), and 48% residence in southern New England-Mid Atlantic (with 37% movement to Georges Bank and 15% movement to southern Cape Cod-Gulf of Maine; Table 2). However, most movement from southern New England to Georges Bank was from the Nantucket Shoals area (Figure 3).

Table 3. Residence and movement of tagged yellowtail flounder with respect to management areas.

Release	Recapture Stock								
Stock	CCGOM	GB	SNEMA	Unknown	Total	CCGOM	GB	SNEMA	Total
CCGOM	1054	39	11	82	1186	95%	4%	1%	100%
GB	33	2374	12	148	2567	1%	98%	0%	100%
SNEMA	14	47	36	3	100	14%	48%	37%	100%
Total	1101	2460	59	233	3853				

Figure 3. Residence and movement of tagged yellowtail flounder with respect to management areas Symbols indicate release ('x') and recapture (dot) positions; colors indicate stock area of release.



Eight percent of all lottery tags have been returned; 14% of $100 reward tags and 11% of data tags were returned. The relative return rate of lottery tags to high-value tags indicates a 59% reporting rate (Table 3), which is exceptional for a commercial fishery.

Table 3. Total releases and recaptures by tag type. The ratio of recovery rate from lottery tags and high-value tags indicates a 59% reporting rate.

Tag Type	Releases	Recaptures	%
Lottery tags	44501	3713	8%
$100 tags	381	54	14%
DSTs	779	86	11%
sum	45661	3853	8%
%lottery /% $100			59%

An analysis of recapture rate by sex, size, condition code and damage code (Table 4) indicates that females had a greater recapture rate than males (particularly small males), fish categorized as 'good' had the same recapture rates as those that were 'excellent,' and all damage codes had similar recapture rates (except 'net marks' which may be excluded from mortality analyses and 'lymphocystis' which is a natural condition).

Table 4. Recapture rate (recaptures/releases) by category.

Sex	recap/rel
female	8%
male	6%

Sex, Condition	
female, excellent	9%
female, good	8%
male, excellent	6%
male, good	6%

Female size range	
33-35cm	8%
36-38cm	9%
39-41cm	8%
42-44cm	8%
45-47cm	8%
48-55cm	9%

Male size range	
33-35cm	7%
36-38cm	5%
39-41cm	5%
42-44cm	10%
45-47cm	8%
48-55cm	9%

Condition	Recap/Rel
excellent	8%
good	8%

Damage Code	Recap/Rel
anal tear	9%
bruising	8%
ambicoloration	8%
ripe	8%
old wound	8%
fin damage	7%
sea lice	7%
abrasions	7%
fin tear	6%
anal extrusion	6%
scale loss	6%
net marks	5%
lymphocystis	3%

Tag retention and Tag-Induced Mortality
Results from the first tank experiment showed different patterns of mortality which suggested that tag-induced mortality may be substantial, but better controls are needed. Results from the second holding experiment showed no histological reaction at the tag sites, so the mortality observed in holding experiments may not be related to tagging. The long-term holding study observed no tags lost, with some fish held for over a year.

Results from the cage experiments indicated low overall mortality of tagged and control fish. Of the 360 fish in the experiment, only 15 died, and more control fish died than tagged fish. Six fish died in the second deployment, which was associated with poor weather conditions and cage movement. Therefore, it appears that the trawl-capture and caging system impose more mortality than tagging. Analysis indicates no tag-induced mortality, because more control fish died than tagged fish, and approximately 3% mortality from the capture and cage system. Removal of data from a cage where sandfleas were observed eating live fish, suggests 1% mortality from the trawl-capture system.

The cage experiments were considered so successful and efficient that they were also conducted on Georges Bank in summer 2005. Although deploying cages offshore was more difficult, results also suggested low to negligible tag induced mortality. In 2006, cage experiments were conducted with each release event to improve estimates of tag-induced mortality. Preliminary results confirm a minimal tag-induced mortality.

Movement-Mortality Model
Although the movement-mortality model performed well on historical tagging data for yellowtail from Royce et al. (1959), application to recent tagging data failed to converge on estimates of movement and fishing mortality within reasonable constraints. Results from all simulated scenarios are reported in detail by Alade (2008). In summary, the simulations of moderate movement rates (10-25% per year) and moderate precision of input data (10% to 25% CV) show that fishing mortality and movement were well estimated (<10% bias). Conversely, for scenarios that simulate no movement, low movement (5%) or high movement (45%), model estimates tend to be confounded, indicating that movement rates and fishing mortality could not be effectively differentiated in the model. The implication of these results is that there is a substantial penalty for imprecise input data, and parameter correlation may be a problem for some applications. Based on initial applications of the movement-mortality model and simulation results, movement and mortality were not simultaneous estimated solely from tagging data. Survival was estimated for the entire New England resource, and integrated modeling with fishery catch at age and survey data was initiated.

Survival Estimation
Releases occurred in monthly batches over a 39 month period from June 2003 to August 2006, mostly in early summer (Figure 4). The full recovery matrix included a total recapture rate of 7.9% (Table 5). There was a significantly higher rate of recapture for females (8.4%) than males (6.5%). Several model variations with both time-dependent

and time-independent parameter estimates as well as gender specific parameter estimates were successfully fit to the full data.

Table 5. Number of releases and annual recaptures used for survival estimates.

		Number recaptured per year				
Year Marked	Number Marked	2003	2004	2005	2006	2007
2003	10122	526	403	72	18	3
2004	17783		628	492	96	18
2005	6084			440	96	23
2006	9918				490	152
Totals	43907	526	1049	1004	700	196

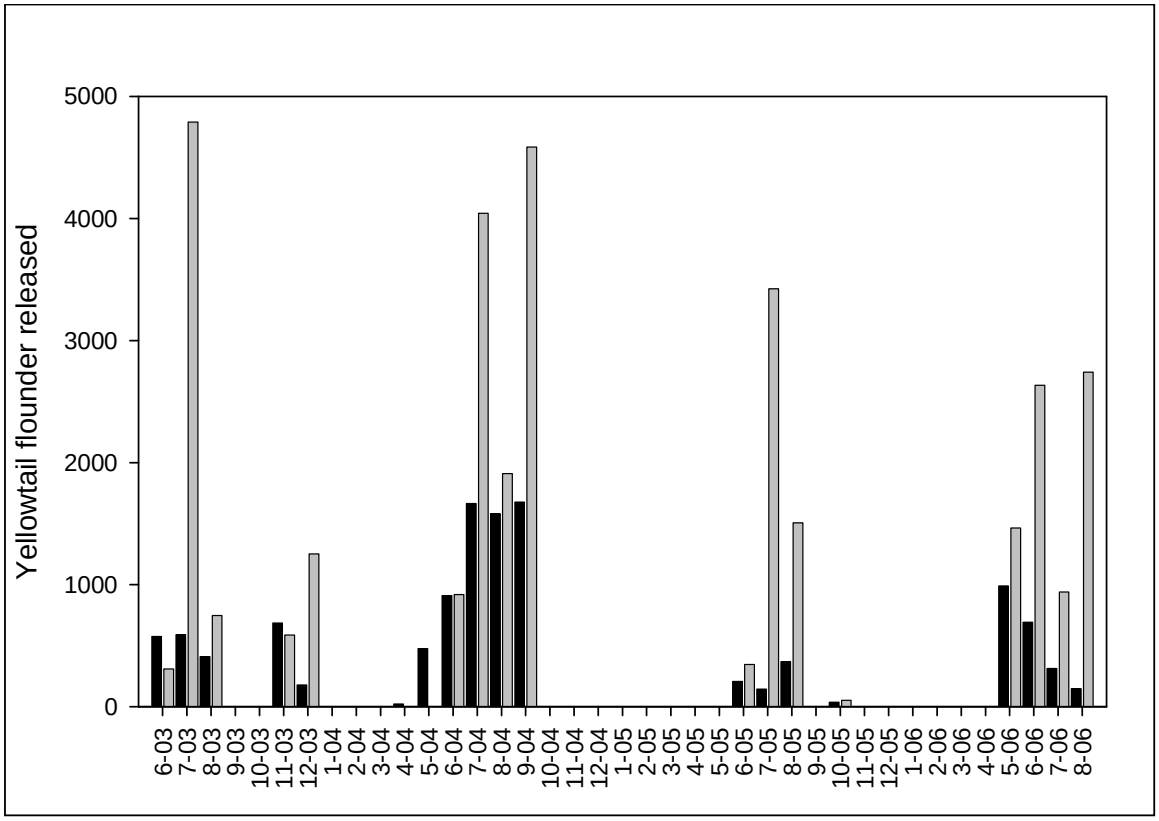


Figure 4. Monthly releases of tagged yellowtail flounder, alternate months are shaded black and gray.

All of the top ranked models determined by model selection had a time-dependent recovery rate parameter (f_t) with varying levels of gender dependence on both recovery rate and survival (S_g). Following the goodness-of-fit adjustment to the models, full

weight was given to the model with a time dependent survival and time-dependent gender specific recovery rate. The two best models had a time-varying survival estimate. However, many of the estimates were at the upper boundary of *S*=1.0 due to sparseness in the data, so the two models with time-specific survival were not considered.
The optimum model for the full dataset was a model with constant survival and time- and gender-dependent recovery rate (Table 6).

Table 6. Alternative parameter configurations for survival (*S*) and recovery rate (*f*). Parameters were estimated by month (*t*), for the entire time series (.) or by gender (*g*). The optimal model is shaded.

Model	QAICc	Delta QAICc	QAICc Weights	Model Likelihood	Num. Par	QDeviance
{S(t) f(g*t)}	19765.56	not considered due to many boundary estimates for survival				
{S(t) f(t)}	19813.70	not considered due to many boundary estimates for survival				
{S(.) f(g*t)}	19825.54	0.00	0.73	1	111	1181
{S(g) f(g*t)}	19827.51	1.97	0.27	0.37	112	1181
{S(g*t) f(t)}	19847.22	21.68	0.00	0	163	1098

A constant rate of survival of 0.89 per month was estimated from the top model with a standard error of 0.016. Recovery rate estimates ranged from 0.001 to 0.078 for males and 0.001 to 0.037 for females. Noticeable peaks in the recovery rate for females were observed in May through August of each year (Figure 5). These peaks were present but less evident in the trend for male recovery rate.

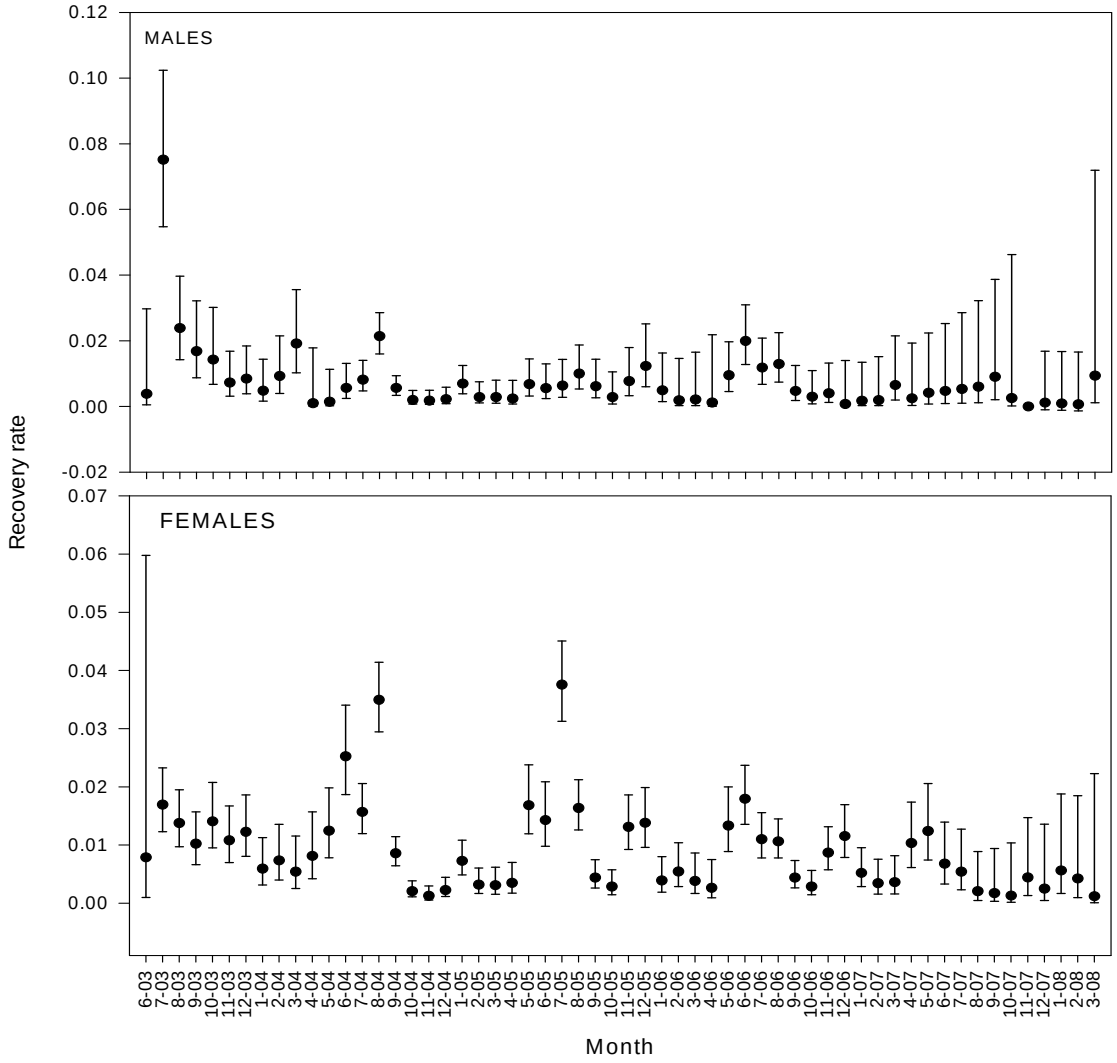


Figure 5. Estimates of recovery rate by gender and month.

Recent assessments of New England yellowtail flounder stocks indicate intense mortality is occurring, but the mechanisms causing this mortality are uncertain. It has been suggested that the high mortality estimates could be a result of the inconsistencies between fishery and survey data used in the assessments (ICES 2008). However, the tag-recovery analyses appear to corroborate that the yellowtail flounder population is experiencing a high level of mortality. The total annual mortality estimate of 1.4 derived from this study is similar to stock specific mortality estimates from the yellowtail flounder assessments for 2003 to 2006 (Figure 6). The high total mortality estimates from analysis of tagging data independently confirm the high estimates of mortality from age-based stock assessments.

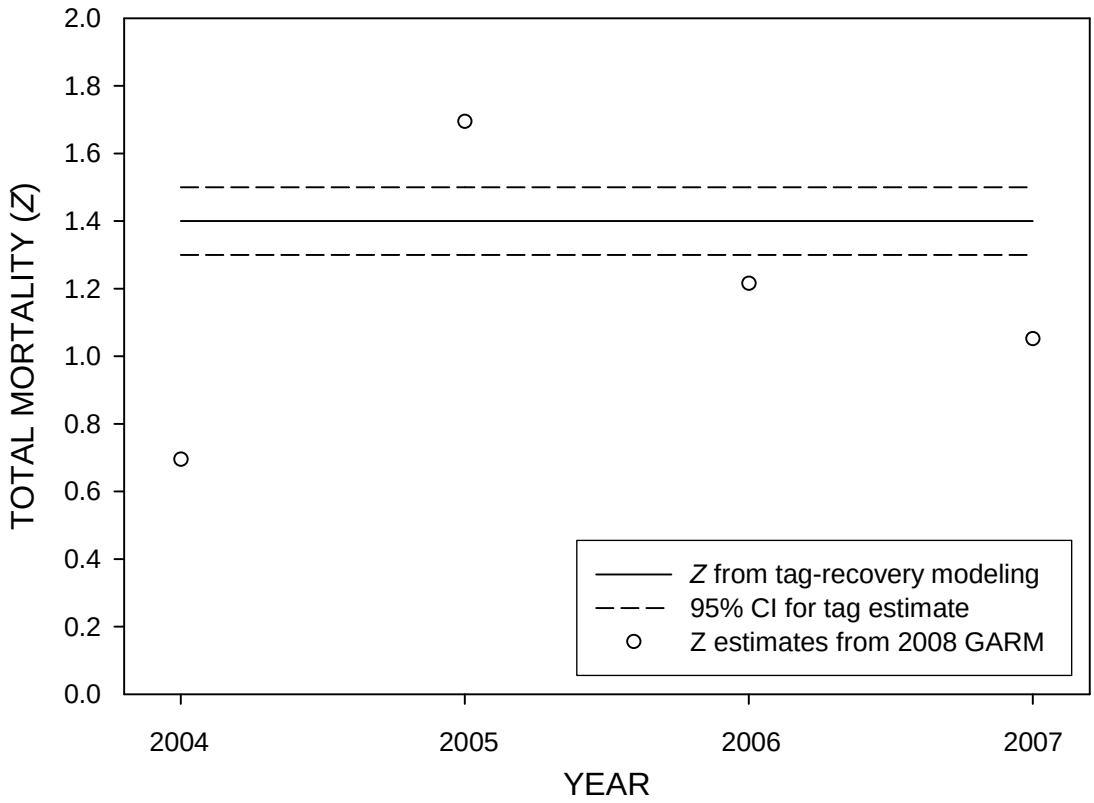


Figure 6. Estimate of survival (horizontal line) and 95% confidence limit (dashed lines) and annual estimates of mortality from age-based stock assessments (data from NEFSC 2008).

Integrated Model

Although this model development is continuing, preliminary results demonstrate the importance of accurate stock boundaries and a robust experimental design for tagging studies that accounts for issues such as cost, reporting rate, and a representative time series of tag releases and returns that correspond with the other data sources.

Data-storage tags

Eighty-three data-storage tags were returned (Cadrin and Moser 2006). All tags at large more than one month indicated distinct off-bottom movements. Off-bottom movements were typically in evening hours, between 18:00 and 22:00, lasting an average of four hours, ascending to an average of 15m off-bottom (Cadrin and Westwood 2004). The frequency of off-bottom movements varied geographically, an average of once every ten days off Cape Cod, and once every three days on Georges Bank. Tidal geolocation has been tested (Cadrin et al. 2007), and geolocation of tag deployments continues in partnership with SMAST oceanographers.

These results illustrate how archival tags enhance the interpretability and power of tagging studies. Until recently, the well-studied yellowtail flounder was thought to be a "sedentary" fish, feeding on epibenthic fauna and limited to relatively shallow, sandy

habitats. This strict habitat preference and the discontinuous distributions of such habitats were considered to limit movement among offshore banks and shelves, thereby maintaining geographic stock structure. The movement patterns indicated by disc tags likely involves passive drift in midwater currents, similar to patterns observed for other flatfish species. Therefore, the use of electronic tags reveals an important aspect of yellowtail behavior that was not apparent after decades of intense research.

Growth

Approximately 4,000 scale samples were taken during tag release, but only 131 scale samples were taken at the recapture event. Most (53%) of the recapture sample came from George's Bank, 44% came from the Cape Cod Gulf of Maine, and only 4% came from Southern New England-Mid Atlantic Stock. There were 113 females and 114 males in the paired release-recapture samples. The sample supported the current knowledge that one annulus is formed per year (Figure 7).

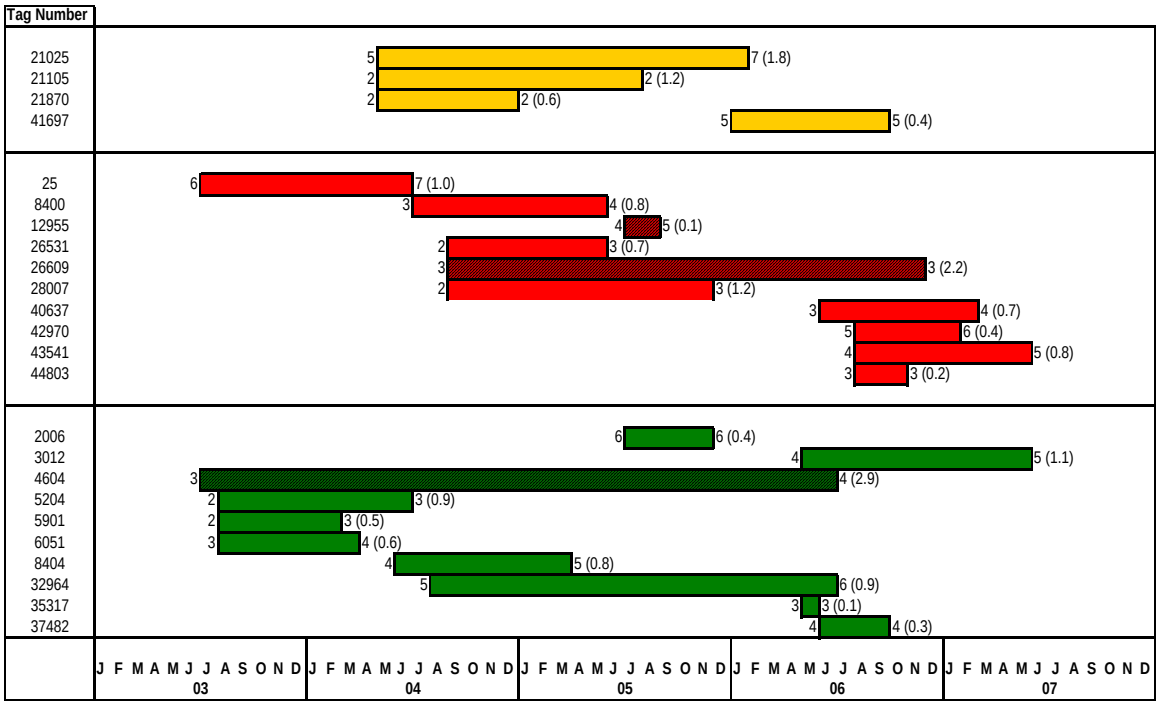


Figure 7. Time at large from release (left edge of bar) and recapture (right edge of bar) with age determined at release and recapture as well as time at large, in years (values in parentheses). Striped bars represent annuli counts at recapture that do not correspond with time at liberty).

Impacts and applications

The field protocol and analytical design were peer reviewed at "a workshop to review and evaluate the design and utility of fish mark - recapture projects in the northeastern United States" and considered to be a valid approach to address the project objectives (Tallack et al, eds. 2005). Preliminary applications of the analytical model were reviewed at the 2005 and 2006 cooperators' meetings. The few recaptures in southern New England present a modeling challenge producing extremely low fishing mortality estimates in

southern New England and unrealistically high movement rates into southern New England.

2008 Groundfish Assessment Review Meeting -Working papers were presented to the GARM data meeting (Woods Hole, October 29-November 2 2007. Several terms of reference were addressed by the GARM (excerpts from peer review panel report):

> ***1. Do results of tagging experiments support existing stock definitions for yellowtail flounder?*** *Cadrin et. al. (WP C5) reported the results of a large tagging study undertaken to describe the exchange amongst the Georges Bank and SNE yellowtail stocks. While they consider the results preliminary, they indicate high movement on Georges Bank but low movement between the Southern New England / Cape Cod and Georges Bank stocks. Overall, however, the study corroborated the location of the stock boundary between these components and the current stock structure of yellowtail in the region.*
>
> ***2. Can migrations among stock areas be quantified?*** *Cadrin (C6) also undertook modeling yellowtail tag recapture data using a formulation in which movement and mortality were considered separately. While the model showed promise, it did not adequately fit the tagging data, with significant trends in residuals in evidence. Simulations suggest that the model may not perform well when true movement rates are low, due to parameter correlations between mortality and movement. It was suggested that auxiliary information, such as external estimates of fishing mortality or of movement inferred from biomass estimates from the NMFS surveys, be used to constrain model fitting. It was concluded that while the model is a possible future application for yellowtail, the current model cannot currently provide quantified estimates of migration rates.*
>
> ***3. Develop appropriate analytical models for estimation of migration and fishing mortality -*** *Two models were considered to estimate migration and fishing mortality rates for yellowtail stocks in the GOMA, which have extensive tagging databases available. The first model, the movement – mortality model used for yellowtail, was an update of an existing formulation which modeled movement and mortality separately. It made a number of assumptions but could not resolve model fit issues in relation to migration of yellowtail between Georges Bank and Southern New England. Thus, it was considered a preliminary formulation that required further development. An exploration of the sensitivities of this model to various assumptions on measurement and process error (Alade, C7) was instructive in identifying the model's strengths and weaknesses and guiding future work.*
>
> *The second model, MARK, was also used to explore yellowtail migration and mortality processes. As with the first model, it too had difficulty fitting the yellowtail tagging data. Auxiliary data could also be useful in improving model performance. While promising, it too was considered preliminary and not yet ready for use in the assessments. Given the difficulties that these models have encountered to date, it may instructive to model the tag-recovery data from each stock area separately to compare to the multi-stock analyses. This is the approach used in analysis of tag data from striped bass, which also uses the MARK reparameterization of the Brownie models. Also, models built on a monthly time scale may be attempting to analyze a finer timescale than these*

approaches were designed for, as they have been applied most commonly on an annual scale.

The tag data can also provide Petersen estimates of exploitation rate, which can be accompanied by sensitivity analysis of violations of the assumption that all recaptured high-reward tags are reported (e.g. test effect of a 90% reporting rate of high reward tags, etc.). A number of studies can be consulted which illustrate the approach, which is currently the primary analysis applied by the ASMFC Striped Bass Tagging Subcommittee and blue crab. It was noted that the models presented at the meeting can be reformulated to provide Petersen estimates. Insight on the implications of assumptions can be gained by comparing the results of different model formulations, which the NEFSC is encouraged to undertake as part of its analysis of the tagging data for this GARM.

4. Consider use of tagging data to "inform" stock assessment *- It was noted at the meeting that there is a trend in fisheries population modeling to fully incorporate tagging processes within stock models. However, there is benefit to maintaining the tagging models separate from the assessment models. They provide a means to potentially estimate mortality rates independent of assumptions about the level of natural mortality required in catch-at-age models. The two modeling approaches are independent views of the same underlying processes and differences can yield insight on the veracity of the assumptions used in each. Also, the tagging data series is short and inclusion of the tagging data directly into the population model would imply a relatively low contribution to the likelihood function of the stock models.*

Working papers were also presented to the GARM models meeting (Woods Hole, February 25-29 2008). Several terms of reference were addressed by the GARM (excerpts from report):

For certain stocks that are aged, utility of statistical catch-at-age vs. VPA based models with respect to Retrospective patterns, Flexibility to account for alternative parameterizations, Ability to incorporate external sources of information, especially tagging and environmental data and Ability to estimate parameters incorporating prior, external information - When competing hypotheses of partial recruitment are being considered, all information, including external sources of data, should be examined to inform the merits of each. For example, it may be possible to disaggregate the plus group catch to assist in hypothesis testing. Analyses of tagged fish presented at the meeting offered promise for evaluating hypotheses about partial recruitment. A number of different hypotheses emerged at the meeting that could be formally investigated which the Panel encouraged. A domed fishery partial recruitment is at odds with the results of tagging analysis presented at this meeting, which suggested no dome. There was discussion at the meeting on the potential confounding of the tagging results by other processes (e.g. gear avoidance, emigration, tag reporting rate), and although none of these appeared likely, there was insufficient time at the meeting to fully explore the alternatives. Thus, while a domed partial recruitment on the older age groups appears unlikely, further exploration of external data could be undertaken to corroborate this.

Related projects

This study was designed to complement the programmatic surveys and fishery sampling for yellowtail flounder stock assessments. It was coordinated with the Southern New England yellowtail tagging studies conducted by the School for Marine Science and Technology, and the Yellowtail Industry Based Survey funded by NMFS Cooperative Research Partners Program. The tagging funded by the Northeast Consortium continued the initial yellowtail tagging funded by NMFS Stock Assessment Improvement Program in 2003. Tagging protocols, material and results are shared with Canada Department of Fisheries and Oceans to provide observations on eastern Georges Bank for the cooperative study. The holding studies are supported by a separate project development grant from the Northeast Consortium, and histological analyses are supported through a UMES-NOAA Living Marine Resources Cooperative Research Center grant.

Presentations:

- Azure Westwood was awarded 'Best Poster' at the 2004 International Council for the Exploration of the Seas Annual Science Conference (September 19-29 2004, Vigo Spain) for the poster "The use of electronic tags to study fish movement: a case study with yellowtail flounder off New England."
- Steve Cadrin presented "Movement of Yellowtail Flounder: A Cooperative Tagging Study" at the Ninth Flatfish Biology Conference (December 1 2004, Westbrook CT).
- Steve Cadrin presented "Tagging Yellowtail Flounder with Commercial Fishermen" at the 61st Northeast Fish and Wildlife Conference (April 17-20 2005, Virginia Beach VA).
- Larry Alade presented "Application of a Mark and Recapture Model to Historical Data for Yellowtail Flounder off New England" and "A Pilot Study on Tag-induced Mortality of Yellowtail flounder (*Limanda ferruginea*)" at the 2005 American Fisheries Society Annual Meeting (September 2005, Anchorage AK)
- Steve Cadrin presented "Stock identification of New England groundfish" at a workshop on "Conservation units of managed fish, threatened or endangered species, and marine mammals" (February 14-16 2006, Silver Spring MD).
- Steve Cadrin presented the keynote address for AFS Southern New England Chapter meeting "Advanced Technology for Fishery Science: experiences with archival tagging" (June 14 2006, Fall River MA).
- Larry Alade presented "Performance of a movement-mortality model on simulated Yellowtail flounder data" at the 2006 American Fisheries Society Annual Meeting (September 2006, Lake Placid NY)
- Steve Cadrin presented "Implementing a more holistic approach to cooperative research" at the ICES symposium on Fishing Technology in the 21st Century (November 2006, Boston MA).
- Steve Cadrin presented "Accounting for population structure in stock assessment: past, present and future" at the AIFRB 50th Anniversary Symposium, Future of Fishery Science in North America (February 12-15 2007, Seattle WA).
- Steve Cadrin presented a keynote address, "Bridging disciplinary gaps for ecosystems science through collaborative research, advanced technologies and

education" at the 2007 AFS Symposium on How to Implement Integrated Ecosystem-Based Management in Fisheries (September 2007, San Francisco CA).

- Steve Cadrin presented "Studying movement of yellowtail flounder with electronic tags" at the 2007 AFS Symposium on "Use of tagging Technology for Ecosystem Studies (September 2007, San Francisco CA).
- Larry Alade presented "A simulation-based approach for assessing the performance of a yellowtail flounder, *Limanda ferruginea*, movement-mortality model" at the AFS 138th Annual Meeting (August 17-21 2008, Ottawa ON).
- Dan Goethel presented "A spatially explicit model of yellowtail flounder" at the AFS 138th Annual Meeting (August 17-21 2008, Ottawa ON).
- Tony Wood presented "Survival of yellowtail flounder (*Limanda ferruginea*) in the northwest Atlantic derived from tag-recapture data" at the AFS 138th Annual Meeting (August 17-21 2008, Ottawa ON).
- Steve Cadrin presented "Stock assessment applications of cooperative yellowtail flounder tagging programs" at the Northeast Regional Tagging Symposium (October 17 2008, Durham NH).
- Dan Goethel presented "A Brief History of Integrated Stock Assessment Models with Tagging-informed Movement and Application of a Spatially Explicit Assessment to Yellowtail Flounder" at a workshop on Spatial Structure and Dynamics of Walleye Pollock in the Bering Sea (July 7-11 2009, Seattle WA).
- Steve Cadrin presented "Incorporating Tagging in Stock Assessments: Hard-Learned Lessons from New England Groundfish" at a workshop on Spatial Structure and Dynamics of Walleye Pollock in the Bering Sea (July 7-11 2009, Seattle WA).
- Dan Goethel presented "A Spatially Explicit Stock Assessment Model Incorporating Tagging Data" at the ICES Annual Science Conference (September 21-26 2009, Berlin Germany).

Future research

Several aspects of this research that are beyond the scope of the proposed research:

- An integrated analysis of fishery, survey and tagging data is being developed to allow movement between stock areas in an age-based stock assessment model.
- Geolocation of data-storage tag deployments, including tidal geolocation during on-bottom behavior and tidal transport during off-bottom behavior.
- Explore stock-specific growth estimates from size at release and recapture over the observed time at large.

REFERENCES

Alade, L. 2008. A Simulation-Based Approach for Evaluating the Performance of a Yellowtail Flounder (*Limanda ferruginea*) Movement-Mortality Model, University of Maryland Eastern Shore. PhD: 316p.

Burnham, K.P. and G.C. White. 2007. Program MARK: Survival Estimation from Populations of Marked Animals. Proceedings of EURING (European Union for Bird Ringing) 2007. Springer Verlag.

Cadrin, S.X. 2003. Stock structure of yellowtail flounder off the northeastern United States. Univ. Rhode Island Ph.D. Dissertation. 148p.

Cadrin, S.X. and C.M. Legault. 2005. Southern New England-Mid Atlantic yellowtail flounder. NEFSC Ref. Doc. 05-13: 2-103-128.

Cadrin, S.X., C.M. Legault and J. King. 2005. Cape Cod-Gulf of Maine yellowtail flounder. NEFSC Ref. Doc. 05-13: 2-129-152.

Cadrin, S.X. and J. Moser. 2006. Partitioning On-bottom and Off-bottom Behavior: a case study with yellowtail flounder off New England. ICES CM 2006/Q:14.

Cadrin, S., G. Shepherd, T. Sheehan, S. Kubis, J. Moser, A. Westwood. 2007. Using information from electronic tags for stock assessment of northeast fishery resources. pp 60-61 In Workshop on Advancing Electronic Tag Technologies and Their Use in Stock Assessments. NOAA Tech. Mem. NMFS-F/SPO-82.

Cadrin, S.X. and A.D. Westwood. 2004. The use of electronic tags to study fish movement: a case study with yellowtail flounder off New England. ICES CM 2004/K:81

Goethel, D.R., C.M. Legault and S.X. Cadrin. 2009. A Spatially Explicit Stock Assessment Model Incorporating Tagging Data. ICES CM 2009/ J:02.

Hart, D. and S.X. Cadrin. 2004. Yellowtail flounder (*Limanda ferruginea*) off the northeastern United States, implications of movement among stocks. pp 230-244 in Species Conservation and Management: Case Studies. H.R. Akçakaya et al., eds. Oxford University Press.

Hilborn, R. 1990. Determining fish movement patterns from tag recoveries using maximum likelihood estimators. Can. J. Fish. Aquat. Sci. 47: 635-643.

Legault, C.M., H.H. Stone and C. Waters. 2007. Stock Assessment of Georges Bank Yellowtail Flounder for 2007. TRAC Ref. Doc. 2007/05.

Lux, F.E. 1963a. Identification of New England yellowtail flounder groups. Fish. Bull. 63: 1-10.

Lux, F.E. 1963b. Yellowtail tagged south of Cape Ann. Bureau of Commercial Fisheries memorandum, Woods Hole, Massachusetts.

Morgan, M.J. and S.J. Walsh, S.J. 1999. An update of results of tagging experiments with juvenile yellowtail flounder in NAFO division 3LNO. NAFO SCR Doc. 99/23.

NEFSC (Northeast Fisheries Science Center). 2002. Assessment of 20 Northeast Groundfish Stocks through 2004. NEFSC Ref. Doc. 02-16.

NEFSC (Northeast Fisheries Science Center). 2005. Assessment of 19 Northeast Groundfish Stocks through 2004. NEFSC Ref. Doc. 05-13.

NEFSC (Northeast Fisheries Science Center). 2008. Assessment of 19 Northeast Groundfish Stocks through 2007. NEFSC Ref. Doc. 08-15.

NMFS (National Marine Fisheries Service). 2009. Fisheries of the United States. Current Fishery Statistics No. 2008.

Neilson, J.D., P. Hurley and R.I. Perry. 1986. Stock structure of yellowtail flounder in the Gulf of Maine area: implications for management. CAFSAC Res. Doc. 86/64.

NMFS (National Marine Fisheries Service) 2004. Fisheries of the United States, 2003. Current Fisheries Statistics No. 2003.

Porch, C. 2003. Pro-2BOX (ver. 2.01). Assessment Program Documentation, ICCAT.

Royce, W.F., R.J. Buller and E.D. Premetz. 1959. Decline of the yellowtail flounder (Limanda ferruginea) off New England. Fish. Bull. 59: 169-267.

Stone, H.H. and C.W. Nelson. 2003. Tagging studies on Georges Bank yellowtail flounder for 2002. DFO Res. Doc. 2003/056.

Tallack, S., Rago, P., T. Brawn, S. Cadrin, J. Hoey, and L. Taylor Singer. 2005. Proceedings of a workshop to review and evaluate the design and utility of fish mark - recapture projects in the northeastern United States. NEFSC Ref. Doc. 05-02. (available online http://www.nefsc.noaa.gov/nefsc/publications/crd/crd0502).

TRAC (Transboundary Resources Assessment Committee). 2004. Report of the Meeting held 15-17 June 2004. TRAC Proceedings 2004/01.

Walsh, S.J. 1987. Some observations on the movement of tagged yellowtail flounder (Limanda ferruginea) on the Grand Bank, NAFO Divisions 3LNO. NAFO SCR Doc. 87/46.

Walsh, S.J., M.J. Morgan, W.B. Brodie, K.S. Dwyer and L. Mansfield. 2001. A new tagging program for yellowtail flounder on the Grand Bank, NAFO Divisions 3LNO. NAFO SCR Doc. 01/53.

Appendix A. Tagging and Data Collection Protocol

Tagging Check List

PAPERWORK/OTHER

•Captain's Haul Logs
•Scientific Research Permits
•Tagging Data Sheets (water-resistant)
•Clip board
•Scale envelopes
•Mechanical pencils/lead, paper clips
•Camera
•Field season folder with info

CAGE EQUIPMENT

•3 cages
•3 high fliers
•3 buoys (+any extras deemed necessary for floatation
•Buoy lines, extra line
•Anchor lines + anchors (if necessary)
•Hog rings and hog ring pliers
•Hydrolab
•Video camera

How to fill out Captain's Log

•The Captain and Chief scientists are to arrange specific areas to fish based on the contract agreement prior to departure.
•Insure that the captain has enough haul logs for the trip. Explain how to properly fill out the sheets. Fill in all fields on the data sheet. Important points to remember:

- *Trip ID:* On day trips, each day is entered as a new number (i.e. Day 1 = 01, Day 2 = 02, etc.) For trips of duration greater than 1 day, the same number should be entered for every day aboard the same vessel (i.e. Day 1 = 10, Day 2 = 10, etc.)
- *Haul #:* Haul numbers will reset for single day trips but not for multi-day trips.
- *Wind direction* can be circled if it is an estimate. Exact wind direction readings, from a computer or anemometer, should be written in the wind direction box (i.e. the wind direction is 93º).
- *Begin* and *End haul* times should be entered in 24 hour clock mode.
- *Total catch* should equal the sum of individual species estimates including yellowtail. Yellowtail weights should not be recorded as a count. If you count the number of fish, assume each one weighs 1 kg (2.2 lbs). Multiply your count by 2.2 and record in the box marked "YT Catch Estimated".
- Make any comments about torn gear, net obstructions or other observations in the *"Comments"* section.

Getting ready to tag

•During steam out of prior to tow haul back, pre-arrange the lottery tags numerically. Organizing them on a nickel pin with 50 per pin.
•Ready the tag box with the following:
-Pins
-Pink blanks and Orange scale blanks
-Lottery tags (pre-arranged numerically)
-$100 reward tags
-Data storage tags and DST oval blanks
-Rubber bands, scale envelopes, pliers, pencils and a timing device
•The chief scientist should activate enough DSTs to last for 1 day. Be sure to record the time they were

activated (24 hour clock).
•Designate and record on the data sheet who will tag and record.
•Pre-fill the tagging data sheet with the heading information (Vessel name, date, etc.)
•During haul back, set up the deck in a way that is appropriate and safe based on the deck configuration.
•Set up a tagging bench or station
•Set up live well (s) and run the deck hose to fill.

Activating the Data Tags

•Hold the tag with its yellow bead thermistor to your right. The magnetic reed switch will be at the top edge of the tag.
•To begin a recording session, tap the tag at its upper right or left corner 4 times with one pole of a magnet. The four taps must occur within two seconds and the magnet must not come near the tag for the following two seconds. After each tap, move the magnet at least 2-inches away from the tag. The magnet does not need to actually touch the tag.
•The light-emitting diode (LED) will blink brightly to indicate that the tag has started. It will then blink at 14- and 15-second intervals (an average of once every 14.06 seconds), one blink corresponding to each sample that is taken.
•If the LED blinks approx. twice each second, the tag is in a rapid-recording test mode. To clear this, tap the tag 4 times with the magnet. The test mode will drain the battery more quickly than the normal recording mode.

Specifics to Fishing

•The priority is to obtain fish that are strong and healthy enough to be tagged and released in good to excellent condition (see condition ratings on page 11).
•Captain is responsible for finding concentrations of yellowtail
•Tow duration is to be short, no more than 40 minutes, to ensure small enough tows to process without undue stress and exposure to the fish. Ideal tow duration is between 15-30 minutes, depending on the area and time of day.
•If tows come up with few yellowtail and numerous skates and other species, move to another area. Bycatch, particularly skates, damage the condition of yellowtail.
•Do not begin another tow while fish are being released, even if this compromised the amount of tows that can be done per day.
•For day trips, perform 6-10 tows per day, depending on steam time and weather.
•For offshore, multi-day trips, make as many tows as possible in day light hours. Stop fishing before dusk.

Sorting the catch

•Have Captain estimate total catch (in pounds) and record on his tow data sheet.
•Choose the quickest most efficient way to isolate live yellowtail from the catch.
•With straight yellowtail tows, bag can be dumped in live well (if using a large live well).
•If the tow is mixed species, dump the tow on a wet deck.
•Gently select yellowtail from the mix and place upright in the live well (s).
•If there are enough people, have the crew isolate the yellowtail while the scientific staff begin tagging.

Fish Condition

•Gloves are not required to handle the fish (it is easier to handle the fish without gloves). If gloves are preferred, use rubber gloves that will not cause scaling. If no gloves are used, make sure hands remain wet when handling fish.
•Chose a fish from the live well and assess its condition. Only tag EXCELLENT or GOOD rated fish:

- Rate the fish (1) if it is in EXCELLENT condition. Excellent fish will be lively, scale condition clean and relatively unscathed. Operculum or mouth movement may be noticeable. Fish feel robust and have strength when held against the measuring board. No blood clotting present around gills or operculum. Fish may be flapping, although yellowtail are generally calm, even when in excellent condition.
- Rate the fish (2) if it is in GOOD condition. Good condition fish are those that generally look healthy, exhibit some signs of an excellent fish. Strong body with no large abrasions of defects.

•Fish rated (3) are in poor condition and unfit to tag. Fish is unacceptable to tag if it appears that the chance of survival is low, heavy abrasion is present, body is flaccid, and there is little movement or reaction to handling. Notate why fish is unfit to tag (i.e. "giant gash, gilled, heavily abraded" etc.) or if the fish is dead ("beheaded, torn body" etc.)

Sexing

•Determine the sex of each fish. Maturity stage is not necessary to notate.
•Determine the sex by candling the fish. Hold the fish up to the sunlight and examine the ventral area of the blind side.
•Nearly all legal sized females should be mature (if tagging during the spawning season) and have a large ovary extending posteriorly from the abdominal cavity.
•Inspect the ventral area of the blind side to determine if an ovary is extending into the ventral tail meat:
- If there is darker tissue extending from the abdominal cavity toward the caudal area, code as "female."
- If the ventral and dorsal portions of the tail (posterior to the abdominal cavity) are identical in color, code as "male."

Measuring

•After the condition of the fish is deemed excellent or good, proceed to measure the fish.
•Minimize the time out of the water and handling of the fish.
•Fish size: Measure from end of snout to end of tail (to 1cm accuracy).

- Southern New England tagging areas – Tag all sub-legal (less than 33cm) fish and legal (33+ cm). Gauge the size and capability of sub-legal fish to carry a DST before applying data storage tags.
- All other tagging areas – Tagging legal fish is priority (33cm +). Tag sub-legal fish as time allows and not to detract or affect the quality or progress of tagging legal fish. Chief scientist can decide whether a fish is too small to tag.

Applying Peterson Disks

•Locate lateral line arch on blind side of fish. Place the pin with blank disk installed just above the middle of line arch. Puncture the fish.
•Make smooth, clean puncture at a perpendicular angle to fish body until blank is flush with blind side.
•Place pink disk (with side labeled "Call toll free 1-877-826-2612…") facing away from fish on nickel pin, flush with fish body.
•To trim the pin, place needle-nose pliers slightly above flush with tag, cutting edge up and trim the pin. There should be about 1 inch of pin left once trimmed.
•Grab the end of pin with the tips of needle nose pliers. Crimp pin in a U-shape. Close gap between crimp tightly. Crimp should measure approx. 3 mm.
•Bend crimp over with pliers so it's at a perpendicular angle to the post of the pin (parallel to the fish body). Insure there is space between tag and bend (approx. 3-4 mm, depending of fish size) to allow room for growth. For sub-legal fish, allow approx. 12-24 mm for growth, depending on fish size.
•Release fish immediately if it remains lively. If not, allow a minute or so of recovery in the live well before release.
•Release the fish head first to minimize re-orientation and time in warm surface waters.
•If you get a left-eyed yellowtail, treat and tag the same as right-eyed fish. Notate in comments on tagging data sheet.
•What you will need: 1) Activated data tags, 2) pink oval backing tags, 3) nickel pins, two per tag, 4) pliers, 5) tweezers for taking scales, and 6) scale envelopes.
•Make sure the tag has been activated by watching for a red flash on the tag. If activated during the trip, the flash should be every 15 seconds to 1 minute.
•Data tags are applied using 2, 3" nickel pins (instead of the 1 used for disk tagging).
•Ready the oval backing tags by placing a pin in one end. Make sure the labeled side will be facing out.
•Align the oval blank similarly to the disk tag, above and centered to the lateral line arch.
•Insert the first pin at a perpendicular angle to the fish body. This is very important in aligning the tag correctly over the pins.

•When the pin and oval disk are in place, insert the second pin, getting the two pins as parallel as possible to each other.
•Fit the data tag, return address label up, over the pins.
•Trim the pins one at a time. Place the needle-nose pliers slightly above flush with tag, cutting edge up and trim. There should be about 1 inch of pin left once trimmed.
•Grab the end of pin with the tips of needle nose pliers. Crimp pin in a U-shape. Close gap between crimp tightly. Crimp should measure approx. 3 mm.
•Bend crimp over with pliers so it's at a perpendicular angle to the post of the pin (parallel to the fish body). Insure there is space between tag and bend (approx. 3-4 mm, depending of fish size) to allow room for growth.
•For sub-legal fish, chief scientist will decide whether the fish is big enough to carry a data tag. If tagging, allow approx. 12-24 mm for growth, depending on fish size.
•Be sure to record the time when the fish is released for every data tag deployed.

Getting Scale samples

•Scale samples are to be collected for the following fish:
- All $100 tags
- All data tags
- $1000 lottery tags that are applied with orange or pink scale sample backing tags.

•Chief scientist will decide how many scale samples to collect.
•Generally, taking scales from at the beginning of each tagging session is helpful in assuring scales are collected from fish in the best condition.
•Only take scales from fish in excellent condition.
•If taking scales will compromise fish health, take scales from next fish.
•Pluck 5-10 scales using forceps from just above the lateral line, approx. midway on body of fish.
•Place scales in a small envelope and label with the station information, date, sex and length of the fish.
•Record any comments on the data sheet.

Filling out the tagging data sheet

•Paper is "Right in the Rain" water-resistant.
•Trip ID and Haul #: (refer to page 7, ("Filling out the Captain's Log").
•Each tagger will have a pre-arranged set of tags on nickel pins. The tag numbers to be used will be recorded at the beginning of the haul for each tagger and modified at the end of the haul after all the fish have been tagged.
•Record the number of live and dead discards.
•Note the condition of the fish. There are 2 categories, "trawl damage" and "biological comments". Check all that apply to the fish being tagged.
•Make any additional comments in the "Comments" field to the far right.
•Be sure to record the page numbers and all heading information on each sheet used. Each 2-sided sheet is considered one page and given the same number.
•The recorder must tally the total fish tagged and discarded at the end of the tagging session.

Recapturing a tagged fish

•Remove the tag from ALL recaptured fish. Do not re-use the tag.
•Treat each fish as a recapture and record (if from a previous trip) and location. Take scales from high reward, DST's and scale-labeled blanks. Use the tag recapture phone sheets to record the information.
•Tag number
•Date
•Latitude/Longitude
•Length (if the fish was released on a separate trip)
•Make any observations about the tag wound area and health of the fish.
•In the "Reported By:" category, write "T" which stands for "Tagging cruise"
•If there are a large number of recaptures from the same day or trip, move to a new fishing spot.