Northeast Fisheries Science Center Reference Document 09-09

Proceedings from a Workshop to Identify Future Research Priorities for Cod Tagging in the Gulf of Maine

12 February, 2009, Gulf of Maine Research Institute

Compiled and edited by: Shelly Tallack

With contributions from:
Peter Auster, Steven Cadrin, Jonathan Grabowski, Hunt Howell, Lisa Kerr, James Lindholm, Jon Loehrke, David Martins, Timothy Miller, Graham Sherwood, Laughlin Siceloff and Rebecca Zeiber

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Hosted by Gulf of Maine Research Institute, 350 Commercial Street, Portland, ME 04101

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1. Executive Summary

Under the NOAA Award # NA07NMF4720278 (Task 1), the Gulf of Maine Research Institute (GMRI) coordinated and hosted "A workshop to identify future research priorities for cod tagging in the Gulf of Maine" (February 12, 2009). Attendance at this workshop was by invitation only, to ensure that the group was varied, with a balance of individuals from industry, science (with interdisciplinary backgrounds) and management.

The primary objectives included: (1) review the knowledge we have gained from current and recent cod tagging studies, (2) identify major gaps in information currently remaining, (3) identify priority future tagging-related research which is still needed for the GOM region, and (4) prepare and distribute a meeting summary for future reference.

This workshop enabled regional industry and science stakeholders to review a synopsis of cod research findings from the last decade (2000-2009). With tagging and migration studies as the primary focus, the group listened to updates and research summaries from five regional cod tagging projects, each using a variety of tagging technologies (e.g. conventional tags, data storage tags and acoustic tags) and a variety of analytical approaches for interpreting the spatial movement information. These projects ranged dramatically in terms of spatial scale, duration and research objectives and both region-wide intensive conventional tagging initiatives (i.e. the Northeast Regional Cod Tagging Program) and more fine-scale, localized cod behavior research (e.g. UNH's acoustic tagging study) were represented. In addition, two presentations addressed the importance of accurate data interpretation for tagging studies, with a specific focus on reporting rates. Two further presentations addressed specific ecological concepts for cod, including: (1) potential ecotypes in cod, and (2) juvenile cod and association with habitat types and closed areas.

Question and answer sessions after each presentation, enabled the group to identify outstanding knowledge gaps for cod in the Gulf of Maine region, with particular attention to cod life-history, habitat use, stock structure and management. These ideas were re-visited in the afternoon during a more intense discussion session; at this time, cod tagging-related research needs for the Gulf of Maine region were reviewed and prioritized. A detailed summary of formal research recommendations for future cod tagging research in the region is provided in this document (see section 4.2, p. 41). These research recommendations were then prioritized by the workshop participants (Table 2). However, the group's top-priority research recommendation is summarized as follows:

> *"Recent and historical cod tagging data (and genetic data) suggest substantial movements across current stock boundaries and considerable heterogeneity within current management units. Best available science indicates the need to re-visit, re-analyze and re-assess the stock management boundaries; this task will be best achieved by an interdisciplinary team."*

2. Workshop background

The Gulf of Maine Research Institute (GMRI) is currently contracted by NOAA Fisheries under Award # NA07NMF4720278, Task 1. The scope of work contracted incorporates three objectives including: 1) maintain tagging data and outreach infrastructure of the Northeast Regional Cod Tagging Program (NRCTP) to maximize the tag returns; 2) advance ongoing data analyses and prepare the NRCTP data for inclusion in the 2008 GARM for Atlantic cod; and 3) design and prepare for future advanced cod tagging research to target gaps in migration information as identified through current analysis.

This workshop served to enable regional industry and science stakeholders to review a synopsis of cod research findings from the last decade. With tagging and migration studies being the primary focus, the group (see Annex 1, p. 51 for a list of workshop attendees) listened to updates and research summaries from five regional cod tagging projects, each using a variety of tagging technologies (e.g. conventional tags, data storage tags and acoustic tags) and a variety of analytical approaches for interpreting the spatial movement information. These projects ranged dramatically in terms of spatial scale, duration and research objectives and both region-wide intensive conventional tagging initiatives (i.e. the Northeast Regional Cod Tagging Program) and more fine-scale, localized cod behavior research (e.g. UNH's acoustic tagging study) were represented. In addition, two presentations addressed the importance of accurate data interpretation for tagging studies, with a specific focus on reporting rates. Two further presentations were less tagging focused, but addressed specific ecological concepts for cod, including: (1) potential ecotypes in cod, and (2) juvenile cod and association with habitat types and closed areas.

Question and answer sessions after each presentation, enabled the group to identify outstanding knowledge gaps for cod in the Gulf of Maine region, with particular attention to cod life-history, stock structure and management. These ideas were re-visited in the afternoon during a more intense discussion session; at this time, the Gulf of Maine region's research needs were reviewed and prioritized before compiling a list of formal research recommendations for future cod tagging research in the region.

2.1 Objectives

The objectives of this workshop are summarized as follows:

1) Review the knowledge we have gained from current and recent cod tagging studies.
2) Identify major gaps in information currently remaining.
3) Identify priority future tagging-related research which is still needed for the GOM region.
4) Prepare and distribute a meeting summary for future reference.

2.2 Agenda

Following is the agenda as modified during the course of the workshop (time of day omitted). Question and answer sessions took place after each presentation, with in-depth reviews and discussion taking place during the afternoon sessions.

Breakfast	***Presenters***
Introductions & overview of workshop goals	
Review of recent cod tagging studies:	
• Northeast Regional Cod Tagging Program: a review of findings from 2003-2009	*Shelly Tallack*
• School for Marine Science and Technology (UMASS) tagging review & update	*Dave Martins & Jon Loehrke*
• University of New Hampshire tagging review & update	*Laughlin Siceloff*
• Acoustic tagging of cod in the Stellwagen Bank National Marine Sanctuary, PIER/NURC-UConn	*Shelly Tallack, on behalf of James Lindholm, Peter Auster & Ashley Knight*
Refreshment break	
Additional research concepts:	
• Reporting rates in tagging data	*Tim Miller*
• Understanding reporting behavior – GMRI questionnaire results	*Shelly Tallack*
• Cod and ecotypes	*Graham Sherwood*
• Juvenile cod: closed areas & habitat	*Jonathan Grabowski*
Lunch	
• Extended discussion and identification of new tagging research needs	
Refreshment break	
• Review and prioritization of research recommendations	
Wrap-up	

3. Presentations updates on cod research in the Gulf of Maine

Following are summaries of each presentation, including abstracts provided prior to the workshop. These proceedings serve to capture the key points made, both during the presentation and in subsequent discussions. Additional information sources for each project/presentation have been included, with references for websites, final reports and publications when available. A transcript of the day has also been included in Annex 3 (p. 53 onwards).

3.1 The Northeast Regional Cod Tagging Program: a review of findings from 2003-2009

Abstract(s) & collaborators

Presenter: Shelly Tallack, stallack@gmri.org

Collaborators: Shelly Tallack, Sarah Whitford, Pat Foote

Institution: Gulf of Maine Research Institute, Portland, ME

Abstract: The Northeast Regional Cod Tagging Program (NRCTP), a large-scale, international collaborative tagging program, was initiated in 2003 and provides the first region-wide, international snapshot of cod movements, mixing and growth across all three management areas. In recent years, these mark-recapture data (114,473 tag releases and >6,500 recaptures) have been analyzed for stock identification purposes. Two core assumptions when defining a stock are that the stock is self-sustaining and that neighboring stocks exist in isolation. Migration patterns observed in the current study may substantially violate both assumptions since considerable movements have been observed between different management areas. Analysis of raw and weighted data indicate exchanges between different areas which are likely related to spawning behavior, maturation and environmental conditions.

With the recent 2008 assessment of 19 groundfish stocks, including Atlantic cod, the NRCTP data have been reviewed and considered for incorporation into stock assessment models in a number of ways, including: (1) providing estimates of fish exchange between management areas; (2) providing supplemental estimates of fishing mortality (F) and natural mortality (M); and testing assumptions about dome-shaped selectivity and its implications on fishing mortality. Most recently, the NRCTP data were also presented at the January 2009 Transboundary Review Assessment Committee (TRAC) Workshop.

Spatial variation in key life-history characteristics (e.g. growth, maturation and natural mortality) is also relevant for stock identification. The NRCTP provides growth data from ~4,500 individual fish throughout the Gulf of Maine region; spatial variation is seen both within and between stock management areas. Specifically, the tagging data suggest that 5Y/GOM cod grow larger, but more slowly than cod on Georges Bank (5Z) and in the Bay of Fundy (4X).

The NRCTP data have also been analyzed for discussions on temporary and permanent closed areas. Originally undertaken in preparation for a workshop on rolling closures in the Gulf of Maine, these analyses are preliminary and it is also reiterated that the NRCTP was not designed to test closed area effectiveness. However, without sufficient studies geared towards answering

this question, these cod tagging data provide information which may be helpful in the future assessment of closed areas as management tools for cod in the Gulf of Maine.

The NRCTP demonstrates that mark-recapture data can play a role in the complex process of stock identification and stock assessment. The geographic scale and quality of data collected during the NRCTP also confirm the value of international, industry-science collaborative research initiatives. The incorporation of these data into both stock assessments and future management initiatives should be rewarding to the ~250 commercial and recreational fishermen who tagged cod for this Program, in addition to the >30 scientists who collaborated throughout the region.

Key presentation points

Program background and objectives: It was reiterated that the NRCTP was originally planned as a two-year program with four specific goals (i.e. 1-4), but that owing to the strengths of the program, the quality and extensive dataset and successful collaborations, these goals were extended (e.g. 5-10) through additional NOAA and DFO contracts as outlined below:

1) Develop a regional & international tagging infrastructure.
2) Strong involvement of industry, science & management partners.
3) Improve our understanding of cod movements in the Gulf of Maine region: T-bar tag 100,000 cod.
4) Make data & findings accessible to the public – effective outreach.
5) Maintain tag return infrastructure & rewarding system.
6) Outreach: Facilitate two industry/science workshops (Mar and Jun 2007) and undertake a major results-oriented mass mailing (Jan 2008).
7) Archive three historical cod tagging datasets (>182,000 tag releases, >10,000 tag recaptures).
8) Prepare data & analysis for inclusion in the Pre-GARM (Groundfish Assessment Review Meeting) workshops and the 2008 GARM.
9) Prepare data & analysis for inclusion in the January 2009 TRAC (Transboundary Resource Assessment Committee) Workshop.
10) Synthesize recommendations for future regional cod tagging needs.

Data review: The data were then reviewed, highlighting its major features, strengths and limitations which have implications for the analysis undertaken and future analysis possible. General data characteristics include:

- **Tagged cod releases:** A total of 114,473 cod were tagged and released throughout the study region between March 2003 and July 2005, with 96% of cod releases being achieved in the first 24 months of the program. The primary release seasons were spring and fall of each year, though some tagging took place all year round. The study design incorporated: single-tagged (84%) and double-tagged (16%) cod; and low-reward (98%) and high-reward (2%) tags.
- **Recaptures to date exceed 6,700 cod:** for each year's releases, the return rate is ~2% for two years, before tag-return decay sets in; tagged cod recaptures continue to be reported to

GMRI, albeit at a dramatically reduced rate (1-2 per week). Low-reward recaptures have exceeded 5% and high-reward recaptures have exceeded 11% - this information is used for reporting rates.

- **Who reports the data:** All sectors of the fishing industry have reported tags, but the majority of recaptures have been reported from commercial fishermen (57%) and fish processors (21%, with 72% of these coming from Canadian processors). Within the fishing fleet, the vast majority of tags have been reported from trawl gear (55%) compared with 19% from commercial hook gear, 14% from gillnet gear and 11% from recreational hook gear.
- **Seasonality in tag recaptures:** Tag recaptures peak each year during spring and summer, but the volume of recaptures has decreased dramatically since the summer of 2005.
- **Historical cod tagging datasets:** GMRI has error-checked and collated the UNH, SMAST and DFO cod tagging datasets into the same format as the NRCTP dataset; all data has been submitted to the Northeast Fisheries Science Center for uploading into the multi-species tagging database. T-bar cod tagging data for the region now totals ~182,000 cod releases and >10,100 recaptures for the time-frame 2000-2009.

Qualitative movement analyses: An overview of the qualitative movement analyses were then presented, with the aim of giving examples of analyses techniques applied to facilitate interpretation of observed cod movements by season, fish size and location. It was reiterated that since these data are from conventional (T-bar) tags, only the start and end information is collected, and this is in turn dependent on a fish being recaptured; as such, the data are influenced by fishing effort distribution, area closures and the timing of tag releases. Acknowledging these limitations, it has been possible to deduce the following:

- **Size differences in cod movement:** smaller cod (released <53 cm) show more limited dispersal than larger cod (53-72 cm and 73-92 cm) within the first year at liberty; the largest cod (released >93 cm) also showed less dispersal. It was hypothesized that this finding may be associated with shifts in forage habits with smaller and larger cod both feeding off more stationary inshore species, while the medium size groups forage further afield. It was also noted that for the largest fish (>93 cm), most had been tagged in the inshore WGOM waters where migration distances appear to be less; thus location-related movements may have compounded this finding.
- **Seasonal movement patterns:** the seasonal cod movement analysis methods were briefly reviewed before presenting the overall summary theory of how cod have been moving throughout the region for the 2003-2007 period. The dominant migration routes can be summarized as follows, with reference to Figure 1.
  - Georges Bank: Small fish recruit here from the Cape Cod waters (5Z), but most adult fish then stay offshore on Georges Bank, with seasonal northward movements into the Bay of Fundy (4X) during spring and summer. They return south to Georges Bank for fall and winter.
  - Bay of Fundy: For the spring and summer, most movements are confined to the Bay of Fundy (4X), but come the fall, these cod head south to Georges Basin (4X) and Georges Bank (5Z/4X) waters. Little exchange is seen between Bay of Fundy and Gulf of Maine (5Y) cod, except for in Passamaquoddy Bay.

- Inshore Gulf of Maine: The Program's largest cod were tagged in these inshore Gulf of Maine (5Y) waters. Of the cod released in this area, few were recaptured outside of the inshore Gulf of Maine waters. Instead, a shuffle northwards and southwards along the New Hampshire / Maine coastline has been observed. This finding is in line with the localized movement patterns documented in another recent cod tagging study for this area (Howell *et al.*, 2008). The NRCTP's data provides considerable evidence that the inshore Gulf of Maine (5Y) population recruits small fish from the Cape Cod region (5Z).
- Cape Cod and Nantucket Shoals: The majority of fish tagged here were sublegal in size and movements for the first year at large are fairly localized. During the winter of 2003-2004, a number of Cape Cod releases were reported from inshore waters off Rhode Island and Connecticut – this migration is thought to represent young fish seeking warmer waters during the cold snap of the 2003-2004 winter and this migration was less pronounced the following winter. These smaller, pre-adult fish appear to diverge as they mature and join adult populations; Cape Cod (5Z) fish were seen to recruit eastwards to the Georges Bank (5Z) area, but also northwards to the inshore Gulf of Maine area (5Y).

- **Transboundary movements:** It was reiterated that these movement patterns do not support the assumption often applied during stock assessments that neighboring stocks exist in isolation and are self-sustaining – these cod movements show inter-annual migration trends across cod stock management boundaries, and also indicate that the 5Y stock in particular may be partially sustained by fish categorized as 5Z cod.

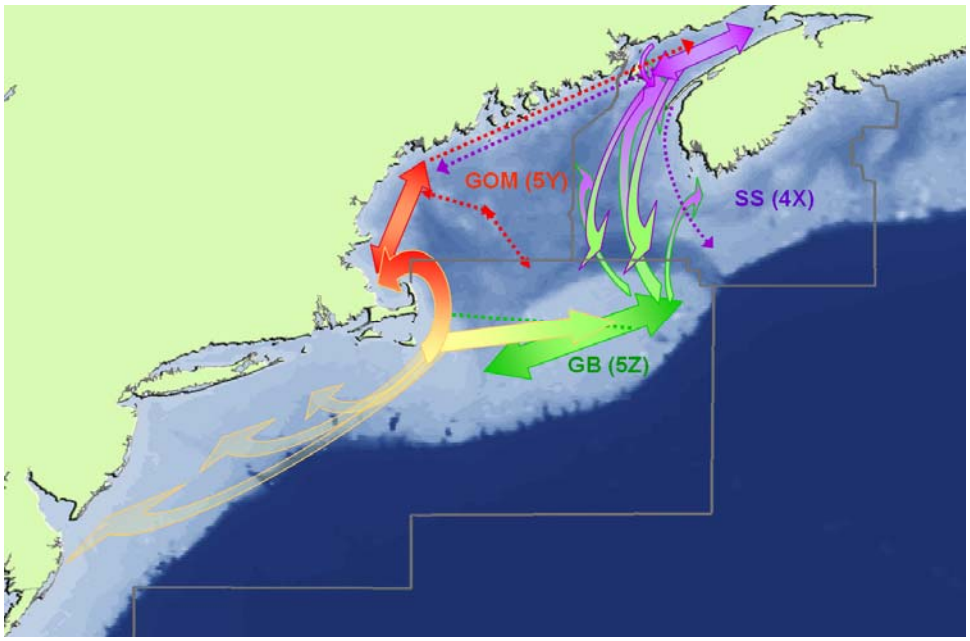

Figure 1: The primary migration highways proposed for Atlantic cod in the Gulf of Maine for the time-period 2003-2007.

Quantitative movement analyses: It was reiterated that the original NRCTP objectives did not include the quantification of stock mixing in Atlantic cod; had this been an objective the experimental design would probably have involved releasing tagged cod in proportion to estimates of cod biomass for each management area or statistical square. Since this was not done, GMRI has collaborated with stock assessment scientists at the NEFSC (Steve Cadrin, Mark Terceiro, Loretta O'Brien & Ralph Mayo) to develop a weighting model based on that documented by (Hunt & Nielson, 1993). The results of the weighting model were presented at the pre-Groundfish Assessment Review Meeting (GARM) workshops during 2007, in preparation for utilizing the NRCTP data in the August 2008 GARM.

- The resulting model (Tallack, 2007) was briefly outlined and the overall results presented. The outputs from the weighting model (which weighted tag releases using three different indices for cod biomass: survey derived, catch derived and VPA-derived) are so variable that it is difficult to determine which weighting method is most accurate. Inter-annual variability in movements, fishing effort and reporting rates indicated that it would be most wise to estimate mixing across a pooled time-frame (2003-2006) rather than for each year individually.
- A model which takes a finite-state continuous-time approach (FSCTA) to movement and mortality was also applied to the NRCTP data (Miller & Tallack, 2007). The FSCTA model calculates probability estimates for mixing rates between management areas, in addition to probability rates for tag reporting, tag shedding, and rates of natural and fishing mortality. The shedding rates estimated matched those derived by GMRI (~15%) and mixing probabilities calculated were also somewhat comparable to results obtained through the different weighting scenarios. The FSCTA results confirm that mixing rates for stocks range from 3-17% with the weakest mixing occurring between 5Y and 4X and the strongest mixing occurring between 5Z and 4X. Should the NRCTP data be utilized further in future cod stock assessments, the FSCTA technique poses the most promising tool for linking the movement data to stock assessment models, through it's estimate of fishing mortality (F).
- As in previous workshops, GMRI asked rhetorically "At what % is the mixing rate 'significant' enough for management and/or stock assessment methods to be changed?"

Growth: GMRI presented updated growth analyses using the GROTAG maximum-likelihood method (Francis, 1988). Growth analyses have been applied to cod defined by management area (5Z, 5Y and 4X), by transboundary management area (5Y, 5Z (less EGB), EGB and 4X) and for four general areas (Inshore GOM, Cape Cod, Georges Bank and Bay of Fundy) (Tallack, in review). These data were most recently presented at the Transboundary Resource Assessment Committee workshop (January 2009).

- The NRCTP provides growth data from ~3,675 individual fish throughout the Gulf of Maine region; spatial variation is seen both within and between stock management areas. Specifically, the tagging data suggest that 5Y/GOM cod grow larger, but more slowly than cod on Georges Bank (5Z) and in the Bay of Fundy (4X) (Table 1).
- **Comparison with length-at-age estimates:** These estimates are largely consistent with those derived from length-at-age data both through time (Begg *et al.*, 1999) and in the 2003-2006 time-frame (Tallack, in review).

- **Mean annual growth** estimates for a specific fish size enables the construction of growth trajectories which can take both fish size and migration into account. E.g. if cod settle in Cape Cod waters but then at a certain size move to inshore GOM vs. Georges Bank, the growth trajectory can be re-modeled, using mean growth increments by size and location.
- **Effects of tagging on growth:** Comparisons of single-tagged (32-120 cm, mean=59 cm, n=2454) versus double-tagged (30-124 cm, mean 61 cm, n=644) cod for the region as a whole suggest that growth can be significantly impacted by the insertion of T-bar tags; growth was faster (K=0.018 vs. K=0.016) for double-tagged cod, but asymptotic size was smaller ($L\infty$=132 vs. $L\infty$=138 cm). It is possible therefore, that the insertion of a single tag also affects growth in cod, but this is impossible to test in the NRCTP data.
- **Measurement error:** Measurement variability was found to be significantly higher in fish measured by fishermen than fish measured by scientists. This is not likely to present a problem for most movement analyses, but when assessing growth, measurements must be as precise as possible.

Table 1: GROTAG estimates of Von Bertelanffy growth parameters and mean growth rate (cm) per year for cod by management area and general area.

Von Bertelanffy estimates		**5Y**	**5Z**	**4X**	**IGOM**	**GB**	**CC**	**BofF**
Sample size	**n**	921	1747	501	878	387	843	353
Asymptotic length (cm)	$\boldsymbol{L_\infty}$	151	105	117	154	104	176	135
Growth	$\boldsymbol{K}$	0.13	0.31	0.22	0.13	0.26	0.13	0.16
Time (years) when size = 0cm	$\mathbf{t_0}$	-0.23	-0.15	-0.18	-0.24	-0.17	-0.21	-0.22
Mean growth (cm/year-1)		**5Y**	**5Z**	**4X**	**IGOM**	**GB**	**CC**	**BofF**
For a 40 cm cod		13.9	17.6	15.1	13.4	14.4	15.7	13.6
For a 100 cm cod		6.2	1.4	3.2	6.3	0.8	8.6	4.7

Closed area analysis on NRCTP data: While not a target objective of the NRCTP, these data have undergone preliminary, descriptive analysis to investigate cod movements relative to permanent and seasonal/rolling closures. These data were not designed to test the efficacy of closed areas, but these data may provide opportunistic (if limited) insight for those interested assessing closed areas. Most importantly, it is reiterated that since T-bar tags must be recaptured in order for movement data to be collected, cod movements within closed areas will be under-represented, since gear/fishing prohibitions dramatically restrict recapture and reporting potential from closed areas.

Applications of the NRCTP data to date: The NRCTP has far exceeded its original programmatic objectives and represents a highly successful example of collaborative research. The data collected between 2003 and 2009 have been considered and utilized to varying degrees at a number of assessment- and management-related venues including:

- The pre-GARM workshops in 2007 and the GARM in 2008;

- April 2008: Movements of spawning cod relative to rolling closures (Groundfish Spawning Closure Workshop: An Initial Conversation).
- October 2008: Movements relative to permanent closed areas prepared for groundfish PDT meeting
- January 2009 TRAC workshop: movement rates and growth for Eastern Georges Bank – connectivity with 5Z and 4X.

Further analysis needs: GMRI will continue to undertake analyses for as long as funding permits under the current NOAA award. Priority analysis needs identified include:

- Movements / growth relative to physical environment, e.g. bathymetry, temperature and salinity;
- In-depth investigation into cod homing patterns;
- Re-analysis combining the recent historical datasets – 2000-2009;
- Modifications to the NEFSC stock assessment models to fully maximize the utility of tagging data.

Key discussion points

- **Fishery fluctuations:** As planned, the NRCTP has captured a 'snapshot' of cod movement for the period 2003-2009. Overall, it was reiterated that the NRCTP has captured the cod fishery over a particular time-frame, but that fluctuations in cod dispersal, movement and the fishery are such that the findings of tagging studies will vary from decade to decade. It was cautioned that the findings from a tagging study are only applicable for the time period in which the study took place (Jon Grabowski, GMRI). The time-frame should be kept in mind during the application of results and this limitation and acknowledgement of natural fluctuations in the cod populations highlight the need for commitment to long-term tagging initiatives (Shelly Tallack, GMRI). Particular examples of changes/fluctuations noted by region include:
  - Nantucket Shoals: this snapshot provides a picture of cod movement and size distribution at a time when the traditional winter cod fishery has essentially disappeared (Eric Hesse, FV Tenacious).
  - Block Island: During the early years of this program it was difficult to find and tag cod around Block Island, yet that picture has changed in more recent years (2007-2009) with reports of 'whale cod' in this area.
  - Western GOM: When tagging in the WGOM area ~10 years ago many of the cod captured and tagged were ~90 cm; with time these fish have grown and cod in recent years have been caught with lengths up to ~150 cm. Last year (2008) the size dropped off dramatically and this was proposed as evidence of mortality with these large, old fish finally dying (David Goethel, FV Ellen Diane).
  - Passamaquoddy Bay: When there was a real fishery in this region historically, these fish showed linkages with Cape Cod; this is never seen in more recent years and the fish from Passamaquoddy Bay are considerably fewer (Don Clark, DFO). It was acknowledged that the NRCTP dataset does show a few cases of fish

tagged in Cape Cod being recaptured in the Bay of Fundy, but this movement was not observed often (Shelly Tallack, GMRI) and seems to represent a remnant movement pattern (Don Clark, DFO).

- Linkages between cod movement and forage: It was strongly agreed that forage sources are likely to be a key driver for migration patterns. In particular, the following were noted:
  - Downeast Maine: Locating and tagging cod in the downeast inshore waters was a struggle during the tagging time-frame of this project (2003-2005), yet a recent recovery of alewife in the Penobscot Bay area seems to have potentially led to higher catches of juvenile cod (and most recently, larger cod) in this area (Ted Ames, Penobscot East Resource Center - PERC). Though the linkage has not yet been proven, it is possible that forage base improvements are affecting the distribution of cod. The absence of forage fish in nearshore coastal regions elsewhere (e.g. capelin in more northerly waters) has been associated with reductions/disappearance of coastal cod populations which follow forage species (Graham Sherwood, GMRI) and as such, it is likely that if alewives return, so will cod.
  - Cape Cod: The more localized movements observed in the smaller cod (tagged around Cape Cod) may be in part due to a dependence on more stationary prey species (David Goethel, FV Ellen Diane).
- **Bay of Fundy to mid-coast Maine:** This was noted as a cod "black box" in terms of information on contemporary cod distribution and movement (Jonathan Grabowski, GMRI), spawning capacity (Ted Ames, PERC) and genetic information (Adrienne Kovach, UNH).
- **Growth:** The difference in growth rates observed for inshore GOM/5Y versus Georges Bank/5Z is likely a factor of migration and stability of environment/food source associated with movement patterns (Steve Cadrin, NOAA/CMER). The inshore GOM cod may grow slower at younger ages and growth appears to be more variable, yet they seem to attain a larger size overall. The more migrant fish of Georges Bank/5Z appear to grow faster when younger, but then growth appears to slow down, and few very large cod are recorded for 5Z; this has been particularly evident on Eastern Georges Bank where very few cod have been recorded over 100 cm in recent years (Don Clark, DFO). Overall, 5Y cod seem to have rebuilt better in recent years than 5Z cod (Steve Cadrin, NOAA/CMER).
- **Genetic sampling and growth:** Genetic sampling might improve our potential to detect real biological differences in growth if they do exist (Adrienne Kovach, UNH). In particular, the spring spawners in Western GOM appear to be genetically unique from all other cod in the region – as such, these fish might be most expected to show a growth difference if genetics play a role in determining growth. Certain genetic markers might be linked to growth, salinity, temperature, but at this point, it is not sufficiently understood just how the physical environment influences the genetic structure (Adrienne Kovach, UNH).

Project websites

- General Program website - http://www.codresearch.org
  - GMRI Final Reports for Northeast Regional Cod Tagging Program's contracts: http://www.codresearch.org/GMRI_Final_Reports.htm
  - 2009 Workshop: NRCTP Future of cod tagging http://www.codresearch.org/Workshop_Future_of_Cod_Tagging.htm
  - 2007 Workshops: NRCTP Industry-Science workshops http://www.codresearch.org/IndustryScienceWorkshop.htm
  - 2004 Workshop: Proceedings from the Mark-Recapture workshop: http://www.codresearch.org/WS/PROCEEDINGS_Fish_M-R_Workshop_Oct_2004.pdf
  - Meeting summaries: From 2003-2005: http://www.codresearch.org/Updates_Meeting_summaries.htm
- Database mapping website - http://www.gmamapping/codmapping.htm
- GMRI NRCTP webpage: http://www.gmri.org/mini/index.asp?ID=21&p=69

Project reports

Tallack, S.M.L., (2006). The Northeast Regional Cod Tagging Program. *Final report: submitted to National Marine Fisheries Service, Cooperative Research Partners Program*, Contract No. EA133F-03-CN-0016, June 2006: 91 pp.

Tallack, S.M.L., (2007). A description of tagging data from the Northeast Regional Cod Tagging Program (WP3A) and preliminary applications of weighting and mixing analysis (WP3C). *DRAFT REPORT: Submitted to National Marine Fisheries Service, Pre-GARM working group*, WP3A & WP3C, October 2007. Northeast Fisheries Science Center, Woods Hole, MA: 60 pp.

Tallack, S.M.L., (2008). The Northeast regional cod tagging program: Addressing critical management questions about cod movement and growth by ensuring maximum tag returns, advancing data analysis and incorporating historical tagging data into a regional, multi-program database. *Final report: submitted to National Marine Fisheries Service, Cooperative Research Partners Program*, Contract No. EA133F-03-CN-0016, May 2008: 35 pp.

Project publications

Tallack, S.M.L., (in review). Regional growth estimates of Atlantic cod, *Gadus morhua*: applications of the maximum likelihood GROTAG model to mark-recapture data in the Gulf of Maine region. *Fisheries Research*, Submitted September 2008.

Tallack, S.M.L., (in review). Stock identification applications of conventional tagging data for Atlantic cod in the Gulf of Maine. In, *Advances in Fish Tagging and Marking Techniques*. AFS, Proceedings from the International Symposium on 'Advances in Fish

Tagging and Marking Techniques', Auckland, NZ, February 24-28th, 2008: Submitted May 2008.

Tallack, S.M.L. & Whitford, S.L., (2008). Northeast Regional Cod Tagging Program - An overview of findings from data collected through the Northeast Regional Cod Tagging Program: a five year, international, collaborative study into cod migration in the Gulf of Maine region. January 2008. Produced by the Gulf of Maine Research Institute, in collaboration with NOAA Fisheries, Portland, ME: 16 pp.

Taylor, N.G. & Tallack, S.M.L., (in preparation). Integrating cumulative effects of size-selective fishing mortality on the distribution of individual asymptotic sizes for growth analysis and stock assessment of Atlantic cod in the Gulf of Maine waters.

Tallack, S.M.L., Rago, P.J., Cadrin, S.X. & Hoey, J.J., (Eds.), (2005). Proceedings of "A workshop to review and evaluate the design and utility of fish mark-recapture projects in the Northeast US", 05-02. *Northeast Fisheries Science Center Reference Document*: 141 pp.

3.2 An overview of the SMAST Cod Tagging Program - August 2000 to Present

Abstract(s) & collaborators

Presenters: David Martins, Jon Loehrke

Collaborators: David Martins[1]*, Jon L. Loehrke[1], Steven X. Cadrin[2]

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Abstract: Atlantic cod (*Gadus morhua*) tagging activities by the School for Marine Science and Technology at University of Massachusetts, Dartmouth (SMAST) was conducted in three phases. Phase 1, initiated in August 2000, was designed to release a total of 50,000 tagged fish, distributed equally in the Gulf of Maine and Georges Bank. Tagging kits were provided to 82 commercial fishing vessels engaged in a variety of fisheries including trawl, gillnet, lobster, and hook fisheries from Mohegan Island, ME to Long Island, NY. Recreational hook and line fishermen also participated in the tagging work. To date 25,923 cod have been tagged using T-bar tags and Data Storage Tags (DSTs), which continuously record temperature and depth. Releases occurred in four principal geographic locations. The largest concentration (44%) occurred within the Stellwagen Bank National Marine Sanctuary, while the second largest concentration (33%) occurred in Western Massachusetts Bay, primarily between Cohasset Harbor and Plymouth, MA. Other major release areas include along the Great South Channel, Georges Bank (16%), and around Cape Ann (7%). To date, 1162 recaptures (4.5%) have been reported.

Phase 2 tagging, conducted in partnership with the Northeast Regional Cod Tagging Program, occurred between April 2003 and February 2005 and focused solely on Georges Bank. The goal was to release 10,000 tagged cod in 2003 and another 10,000 tagged fish in 2004. Using New Bedford based trawl vessels with SMAST technicians onboard to tag fish, seven tagging cruises were conducted in 2003 and eleven in 2004-2005. A total of 20,884 tagged fish were released (7,896 fish in 2003 and 12,988 in 2004-2005). To date, 1,010 fish (4.8%) have been recaptured. Analyses of these data include studying movement patterns of spawning groups and estimating survival.

In Phase 3, efforts have focused on tagging spawning groups of cod in the Gulf of Maine, on Georges Bank, in the Great South Channel and on Cox's Ledge using both T-bar tags and DSTs. This work has been accomplished in collaboration with scientists from the University of New Hampshire and New York University, who are studying cod population structure through genetic analysis of samples obtained during the SMAST tagging operations.

Key presentation points

An overview of SMAST's three cod tagging phases was provided:

- **Phase 1 (2000-2003):** planned to deploy equal numbers of conventional T-bar tags in the Gulf of Maine (5Y) and Georges Bank (5Z) through a voluntary tagging design, where fishermen took tagging kits out during their routine commercial fishing trips. A total of 21,462 cod were released, predominantly in the western Gulf of Maine area.
  - Of the fish tagged within the Stellwagen Bank National Marine Sanctuary, 57% were recaptured within the sanctuary and 43% were recaptured outside the sanctuary.
  - This finding led to questions regarding the level of residency of cod and whether movements varied with fish size. A significant linear trend in displacement was found; large cod moved further than small cod (though the fit was poor). Small fish show localized movements until ~54 cm length, at which point their dispersal shows signs of increasing.
- Phase 2 (2003-2005) focused on Georges Bank and integrated its tagging efforts with the Northeast Regional Cod Tagging Program; during this phase, SMAST secured funding for dedicated tagging trips.
  - These data have been investigated using bagplots (2D boxplots) to investigate cod dispersal (distance and core direction of travel); these analyses provide a quantifiable visualization of relative dispersal between different tagging locations. This analysis approach confirms that cod tagged in the western Gulf of Maine (WGOM) area show less dispersal than cod tagged on Georges Bank (GB) or in the Great South Channel (GSC). Cod tagged Closed Area II dispersed further afield than cod in Closed Area I, though the mean distance travelled by cod released in each area was comparable at 66 nm (CA I, n=20) versus 71 nm (CA II, n=472).
  - Survival analysis using the Brownie dead recovery models are currently being undertaken by Anthony Wood and should be complete by June 2009. These analyses are being applied to the entire NRCTP dataset, which includes the Phase 2 data collected by SMAST.
- Phase 3 (since 2005) is ongoing and focuses on collecting genetic and movement information from spawning cod, using both conventional T-bar tags and data storage tags (DSTs).
  - Since 2005, spawning cod have been tagged in the WGOM, around Coxes Ledge, in the Great South Channel and on Georges Bank. Samples to date total: 4,814 (T-bar tags), 120 (Star-Oddi DSTs) and 200 genetic samples.
  - <u>T-bar tag recaptures:</u> Predominant movements for cod released in WGOM are to Ipswich Bay and Jeffries Ledge, with only 3 cod (10%) moving to the GSC/WGB area. Cod released on Coxes Ledge have shown predominantly localized movements, with a small number of fish moving to WGOM, Georges Bank. Most fish tagged in the WGB area have moved northwards into the inshore WGOM waters.

- DST recaptures to date suggest that cod may inhabit deeper waters in the spring, before moving to more shallow waters during the summer.
- Geolocation modelling: In 2007, SMAST published their geolocation model for application to temperature and depth data collected by LOTEK DSTs attached to cod (Groeger *et al.*, 2007). This approach is being expanded upon by Geoff Cowles (SMAST) who will apply a tidal model (FVCOM) to the temperature and depth information retrieved from both the LOTEK DSTs (n=100 releases) and the more recent Star-Oddi DSTs (n=120 releases) during Phase 3.
- 'Natural' tags: Ongoing otolith chemistry work is being undertaken to establish whether (1) the stable isotopic signature (δ18O and δ13C) of otoliths can be used to distinguish winter- and spring-spawned Atlantic cod in Massachusetts Bay/Ipswich Bay, and (2) whether temporal variation in spawning in this region is representative of discrete spawning contingents. [See Annex 2, p. 52 for an abstract on this work.]

- **Movements of cod spawning groups:** Jon Loehrke (MSc student, SMAST) is currently investigating the SMAST and NRCTP tagging data using a number of statistical techniques aimed at identifying temporal trends in spawning cod movement. His analyses have tested two hypotheses: (1) Do all cod have similar dispersal patterns? And (2) do all spawning groups behave in the same way? Loehrke concluded that:
  - Different spawning groups have significantly different temporal and spatial recapture distributions;
  - Pro-rating weighting observations greatly effects the apparent distribution of recaptures;
  - Cod groups appear to have unique home ranges: Western Gulf of Maine groups are constricted within Massachusetts and Ipswich Bays; Cape Cod fish reside in both shoal water from Stellwagen Bank to Nantucket Shoals and in deeper water towards Georges Bank; Georges Bank fish show a strong connection to the Bay of Fundy; and the fish on Coxes ledge appear to remain largely within Southern New England and are only available to the fishery during a restricted portion of the year;
  - Seasonal homing patterns are evident for some cod groups (e.g. WGOM and Coxes Ledge), but are less defined in others (e.g. Cape Cod and Georges Bank);
  - Many of the cod moving large distances are doing so only after a long time at liberty;
  - Natal homing has been identified in field studies, but may be difficult to document using the techniques currently applied.

Key findings summarized:

- The most efficient way to get a high volume of fish tagged in precise target locations is to charter vessels for specific tagging cruises;
- Using DSTs to geolocate cod is possible and offers exciting possibilities for improved understanding of DST-recorded cod movements in the future;

- There is evidence of persistent connectivity between Stellwagen Bank and the Nantucket Shoals/Western Georges Bank region;
- There is evidence that large cod travel further than small cod, and it seems feasible that long distance travel may be prompted by maturity;
- There is some indication of natal homing or spawning site fidelity;
- Contingents of cod may comprise both resident and highly migratory individuals, which may be associated with, e.g. stock mixing of promiscuous males; further analysis of genetic samples linked with the associated movements may elucidate this concept.

Key discussion points

- **Large cod movements:** Size-based differences in movement [referring to the NRCTP finding that medium sized cod (53-93 cm) move greater distances] may be more food-driven than related to spawning (Graham Sherwood, GMRI); small cod (<53 cm) should have a benthic diet (more sedentary), while medium cod have a pelagic diet (more mobile), but the diet of the largest cod (93 cm+) should become more benthic again (i.e. more sedentary). The SMAST finding generally supports that presented from the NRCTP dataset, i.e. increasing dispersal with increasing fish size (Shelly Tallack, GMRI). Where it differs is for the largest cod; the SMAST data do not show a reduction in distance travelled (Dave Martins, SMAST). This is likely because the largest cod in the SMAST analyses are ~85cm, and there are very few fish in excess of 93 cm, which was the largest category in the NRCTP dataset (Shelly Tallack, GMRI). In Canadian waters, the medium (~75 cm cod) travel inshore and offshore, but the extremely large fish don't go inshore, they stay deep in waters adjacent to the spawning areas (Don Clark, DFO).
- **Spawning cod analyses:** We need to distinguish between inshore and offshore when looking at spawning cod and the timing of spawning (Adrienne Kovach, UNH). More fine-scale work is necessary.
- **Spawning cod and closures:** Do closure areas protect spawning cod or not (Jim Churchill, WHOI)? Based on the dispersal shown by the bagplot analyses, current closure areas may not be large enough (David Goethel, FV Ellen Diane); they may protect the smaller fish but may not retain the larger fish. The WGOM closure area was initiated to protect juveniles and it may serve this purpose well, but CA I and CA II may not be as effective for cod as they seem to be for haddock.
- **Ipswich Bay:** Tagged cod are not recaptured in Ipswich Bay in the winter because they don't spend time there in the winter; cod movements are driven by water temperatures so large freshwater events from fall storms drive the cod offshore (David Goethel, FV Ellen Diane). If as a result, fishing effort is also reduced, this will impact the likelihood of recapturing a tagged cod (Steve Cadrin, NOAA/CMER). Low catches do not necessarily mean low exploitation rates, since exploitation is dependent on the concentration of fish in an area (i.e. low levels of catch on few cod may produce the same exploitation rate as high levels of catch on many cod); this is where using catch to prorate exploitation rates in the weighting factor for cod movements becomes problematic (Don Clark, DFO).

- **Limitations of conventional tags and/or bagplot visualization methods:** Outlier fish appear to impact the shape of the ellipse (bagplot) so maybe outliers need to be excluded from these analyses to avoid distorting the ellipses (David Goethel, FV Ellen Diane). We need to be careful about how we group and visualize conventional tagging data so that we don't project incorrect migration paths (Shelly Tallack, GMRI). For example, the Nantucket Shoals bagplot makes it *look* as if the two cod which were recaptured in the Bay of Fundy travelled there via the NH/ME coastline, when in fact these movements took place over the course of two years, and are probably evidence of cod migrating out to Georges Bank and joining the larger cod which travel along the corridor between eastern Georges Bank and the Bay of Fundy.

Project websites

- Cod tagging at SMAST: http://www.smast.umassd.edu/Fisheries/Tagging/index.php
- SMAST Stellwagen Bank tagging: http://www.smast.umassd.edu/Fisheries/Tagging/stellwagen_feb04.php

Technical reports

Cadrin, S.X., B.J. Rothschild and I. Wirgin. 2007. To Lump, or to Split? … maybe the wrong question for stock identification of fishery resources. ICES CM 2007/L:01.

Eagle, T.C., S.X. Cadrin, M.E. Caldwell, R.D. Methot and M.F. Nammack. 2008. Conservation units of managed fish, threatened or endangered species, and marine mammals. NOAA Technical Memorandum NMFS-OPR-37.

Loehrke, J. and S. Cadrin. 2007. A review of tagging information for stock identification of Cod off New England. 2007 Groundfish Assessment Review Meeting (GARM). Working Paper 3B, 21 pp.

Tallack, S., P. Rago, S. Cadrin and J. Hoey. 2005. Proceedings of a workshop to review and evaluate the design and utility of fish mark - recapture projects in the northeastern United States. Northeast Fish. Sci. Cent. Ref. Doc. 05-02; 141 p.

Unpublished presentations

Steve Cadrin, Dave Martins, Jon Loehrke & Greg DeCelles 2008. Observations of Spawning Cod and Yellowtail from Tagging Studies, etc. Groundfish Spawning Closure Workshop: An Initial Conversation, Danvers MA, 23 April 2008.

Jon Loehrke, Talia Bigelow, Dave Martins, and Steve Cadrin. 2007 Tagging Methodology applied to two New England Fishery Resources: Past, Present, and Future. EURING Technical Conference 2007, Dunedin New Zealand, 13-20 January 2007.

Jon Loehrke, Dave Martins and Steve Cadrin. 2007. Is Biocomplexity Important for New England Atlantic Cod (*Gadus morhua*) Resources? American Fisheries Society-Southern New England Chapter Summer Meeting, Rhode Island, 27 June 2007.

Jon Loehrke, Dave Martins and Steve Cadrin. 2008. Consideration of spatial patterns in modeling and managing spawning groups of cod. American Fisheries Society - Annual Meeting 2008, Ottawa, Canada, 18-22 August 2008.

Project publications

Groeger, J.P., Rountree, R.A., Thygesen, U.H., Jones, D., Martins, D., Xu, Q., Rothchild, B.J., 2007. Geolocation of Atlantic cod (*Gadus morhua*) movements in the Gulf of Maine using tidal information. Fishery Oceanography 16: 317–335.

3.3 *Vertical activity and fine-scale distribution of cod on the Ipswich Bay spawning ground*

Abstract(s) & collaborators

Presenter: Laughlin Siceloff

Collaborators: Laughlin Siceloff & Hunt Howell

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Abstract: We applied a combination of data storage tags (DSTs) and acoustic telemetry to examine cod spawning habitat utilization in Ipswich Bay and compare spawning and post-spawning activity patterns. We tagged 200 pre-spawning cod in April & May 2006 in Ipswich Bay with DSTs that recorded depth and temperature for six months. Twenty-six cod were also implanted with acoustic transmitters. These were located manually by hydrophone and with stationary receivers during May and June. Tracking data showed cod aggregated alongside particular bathymetric features, and most followed the same overall circuit across the spawning ground. Both tracking and DST data indicated departures from the spawning ground were staggered through May and June, and most had vacated Ipswich Bay by July. Twenty-five DSTs were returned and analyzed, and recaptures demonstrated that post-spawning cod dispersed in all directions into the western Gulf of Maine. Cod shared a distinctive low vertical activity pattern on the spawning ground, but after leaving adopted a wide variety of vertical behaviors associated with particular recapture areas.

Key presentation points

- Ipswich Bay is closed to fishing from April to June (the peak spawning period for the area). Original tagging work from 2001-2003 found pre-spawning cod assembling in the Scantum Basin area in April, moved inshore during April and May, and dispersed from the spawning area in June and July (Howell *et al.*, 2008). These data also provide evidence of spawning site fidelity.
- Additional tagging work by UNH in April-May 2006 investigated fine-scale movement and behavior of the cod spring spawning component in Ipswich Bay. Tag deployments included Starr-Oddi DST-milli data storage tags (n=200) and implanted VEMCO V13 tags (n=26) for acoustic tracking (manual and passive) of cod in the Whaleback area (northwestern edge of Scantum Basin). Specific questions included:
  - Can we characterize spawning behavior?
  - What is the fine scale movement of spawning individuals?
  - How do spawning cod interact with their habitat?
  - What temporal movement patterns exist in GOM cod?
- **Tracking findings:** A spawning 'hot-spot' was observed, where ~80% of cod were detected for several days around a small hump (known as Stacey's) at the west end of Whaleback.

- A southward movement of the majority of individuals coincided with intense May storms, and showed cod sought deeper waters in rough weather. They returned north, into shallower water after the storms.
- Overall, 90% volume kernel distribution contours showed the tracked Ipswich Bay cod have small home ranges or "activity centers" (~4 km^2) and their movements were largely contained within a "corridor" defined by vertically elevated features.
- Departure from the Whaleback area was staggered, with cod heading from west to east and then southwards from mid-May through mid-June; rapid departures were observed for 7 cod, and just 3 cod remained in the area by the end of tracking surveys.

- **DST findings:** The recapture rate for DST-tagged cod was 13% (n=26), across four primary recapture/fishing areas: Ipswich Bay, the north end of Stellwagen Bank, the south end of Jeffery's Basin and the northern slope of Jeffrey's Ledge.
  - Time at large ranged from 19-757 days, and most cod were recaptured <80 km from their release location; the maximum straight-line distance observed was 171 km. The depth profiles from these fish suggest that cod stayed largely inshore of Jeffrey's Ledge (the depths recorded were not sufficiently shallow to indicate cod moving over the top of Jeffreys).
  - Spawning site fidelity, as shown in an earlier study, was indicated by recaptures (n=2) from May 2007 (i.e. ~ 1 year post release).
  - Shallow depth profiles were recorded in May; deeper depth profiles were associated with post-spawning movement out of the area. The vertical range was more variable after departure.
  - Vertical movement was shown to be diel and site-specific. The narrowest diel variation (<15 m) occurred on the spawning grounds (65-75 m), compared with slopes on Jeffrey's and Stellwagen (~60 m daily vertical range, but sedentary behavior during the day) and Bigelow Bight where they were consistently deep during the day (~120 m) with a daily vertical range of >40 m.

- **Conclusions:** The findings from both studies has enabled Siceloff and Howell to draw the following conclusions:
  - Cod spawning occurs around small bathymetric features (e.g. Stacey's hump), and such features probably comprise one attribute of critical cod habitat. There is further need to identify additional small-scale features that are used by cod during spawning seasons. This knowledge is key to the successful siting of area closures that aim to protect spawning cod.
  - The tracking data show very small-scale movements (both vertical and spatial) during the spawning period. Vertical migration is minimal and shows a weak temporal pattern. The activity centers/home ranges for spawning cod are small; this picture changes dramatically post-spawning when fish move away from Ipswich Bay and the spawning location (by mid-July at the latest).

- Both DST and telemetry data indicated a staggered departure from the spawning ground, from mid-May through mid-June; the post-spawning dispersal is limited to the western GOM area.
- The vertical behaviours observed (both site-specific and those related to spawning) suggest that cod vulnerability to different groundfishing gears will vary both temporally and spatially.

Key discussion points

- **Spawning cod and feeding:** This may vary from fish to fish, cod may feed en route to the spawning grounds, and some may feed while spawning while others may not (Laughlin Siceloff, UNH); catches by recreational fishermen suggest that they are feeding, but this may just be opportunistic, i.e. when a piece of bait is dangling in front of them and there is little effort needed to forage. You can tell from how the cod are hooked as to whether they are feeding or not (David Goethel, FV Ellen Diane); often they are just snagged but have not been properly hooked in the mouth. Gut content data from the Industry Based trawl Survey may clarify this point (Laughlin Siceloff, UNH). Winter spawners in Ipswich Bay are traditionally thought to not feed, but spring spawners may be different (Steve Cadrin, NOAA/CMER); we need to be careful about drawing conclusions from just one spawning group. It is possible that bioenergetics play a role and that winter spawners 'bulk-up' on pelagic prey before entering into a fasting spawning stage (Graham Sherwood, GMRI). Water temperature probably influences feeding behavior also; winter spawners may not feed if they are less able to digest the food due to colder water temperatures (Don Clark, DFO).
- **Placement of receivers:** For studies which cannot afford to set up an expansive grid of receivers, both detection potential and sample numbers can be maximized (thus increasing our confidence in movement observed) by placing receivers in 'choke points', or locations where the fish are most likely to pass by (e.g. in old river beds). It was also noted that acoustic tags and receivers may be the solution for observing fish movements in the Downeast region where fishing effort and thus, recaptures are low (Shelly Tallack, GMRI).
- **Rolling closures:** It was noted that this study (the spawning-related vertical migration information in particular) may endorse the rolling closures as beneficial for spawning cod (Eric Hesse, FV Tenacious); though rolling closures may miss some spawning cod, they help reduce fishing pressure at a time when spawning is likely and fishing practices disrupt spawning behavior. There has been a noticeable change in diet for fish in Ipswich Bay since the rolling closures began (David Goethel, FV Ellen Diane); it was proposed that the rolling closures have led to concentrations of cod in the area and that they simply eat what is available to them in this area.

Project websites

- UNH Ipswich Bay cod tagging: http://www.biolsci.unh.edu/faculty/howell/ipswichbay.html

Project reports

Howell, W.H., Goethel, D., Bouchard, C., Felch, C., Stettner, M. & Pingguo, H., (2008). Northeast Consortium Project Annual Progress Report 2008: Activity and distribution of cod in the Ipswich Bay spawning area (Contract number: 111A22). 5 pp.

Project publications

Howell, W.H., Morin, M., Rennels, N. & Goethel, D., (2008). Residency of adult Atlantic cod (*Gadus morhua*) in the western Gulf of Maine. *Fisheries Research*, 91: 123-132.

3.4 Acoustic tagging of cod in the Stellwagen Bank National Marine Sanctuary

Abstract(s) & collaborators

Presenter: Shelly Tallack

Collaborators: James Lindholm[1,3,4,]*, Peter Auster[2] & Ashley Knight[4]

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1) Site Utilization by Atlantic Cod (*Gadus morhua*) in Off-Shore Gravel Habitat as Determined by Acoustic Telemetry: Implications for the Design of Marine Protected Areas

Collaborators: James Lindholm[1,2,]* & Peter Auster[2]

Abstract 1): We quantified the site utilization of offshore gravel habitat by Atlantic cod (Gadus morhua) using acoustic telemetry. An omni-directional receiver was deployed inside Stellwagen Bank National Marine Sanctuary during Summer 2001 in an area that excluded commercial fishing for demersal fishes. Fish were collected using hook and line, tagged externally with coded acoustic pingers, and released on the seafloor using an "elevator" within the range of the receiver. Observations were made over 120 days. The total number of days that individual fish were recorded was up to 120 days and a total of 37% of all tagged fish showed high site fidelity to the study area.

2) Site fidelity and movement of adult Atlantic cod *Gadus morhua* at deep boulder reefs in the western Gulf of Maine, USA

Collaborators: James Lindholm[1,2, 3,]*, Peter J. Auster[2], Ashley Knight[4]

Abstract 2): Little is known about the role that patterns of habitat selection play in mediating movement of Atlantic cod *Gadus morhua*, particularly in off-shore environments. We used acoustic telemetry to study the movement of adult cod tagged at deep boulder reefs (DBRs) in the western Gulf of Maine. The movement of 65 cod tagged with acoustic transmitters was monitored by acoustic receivers deployed on the seafloor at 4 DBRs from May to September 2002 and September 2004 to February 2005. Each receiver encompassed an area of the seafloor of approximately 0.5 km2, and data on each fish were recorded for up to 95 d post-release. Twenty-three cod (35.4% of tagged fish) exhibited high site fidelity to the DBR where they were caught and released (recorded in >82% of the 1 h time bins), while 33 cod (50.8% of tagged fish) appeared to depart the area rapidly following release (recorded in <20% of the 1 h time bins). Cod with high site fidelity exhibited no pattern of diel activity. Cod movement among DBRs was

recorded in both sampling periods (maximum linear distance of at least 24 km). Patterns of site fidelity and movement did not differ significantly with fish total length, among individual DBRs, or between sampling periods. Understanding the spatial dynamics of fish populations with both resident and transient components that are linked to particular habitats can aid in development of unique management strategies for both sustainable fisheries and conservation of biological diversity.

Key presentation points

Since this presentation was delivered by Shelly Tallack on behalf of James Lindholm and Peter Auster, the slides were essentially read without particular insight and Shelly urged people to follow up by reading the two publications which have resulted from this work. Project objectives and synopses are also captured by the abstracts presented above.

Key discussion points

- Fine-scale behavioral studies are important for understanding the ecological dynamics of Atlantic cod; they have the potential to inform a lot about what drives species movement patterns. Unfortunately, the equipment can make or break a project – gear loss due to weather, tides or fishing activity can severely impact the success of a study (Don Clark, DFO).
- Fine-scale movements at crucial times in the spawning cycle may indicate that closure areas do not need to be large so much as well-sited based on habitat and seasonality of the cod life-cycle (David Goethel, FV Ellen Diane).
- Fine-scale information is important when considering timing and placement of closed areas, particularly rolling closures; the need for closure areas is valid, but adjustments may be necessary.
- Fish size may make a big difference to the fine-scale movements observed; small fish may associate more with complex bottom, while larger fish seem to need this less. Small fish may also be more 'trackable' than larger fish which move further resulting in higher potential for 'missing' their movements (Don Clark, DFO).
- More long-term fine-scale studies are needed to learn more about the role of habitat in fish movements.

Project websites

- National Marine Sanctuary Program, Stellwagen Bank cod site fidelity study:
  - http://stellwagen.noaa.gov/science/site_fidelity.html
  - http://www.pier.org/cod.shtml
  - http://www.nurc.uconn.edu/research/mis/summary.asp?Project_No=NAGL-03-09

Project publications

Lindholm, J. & Auster, P., J., (2003). Site utilization by Atlantic cod (*Gadus morhua*) in off-shore gravel habitat as determined by acoustic telemetry: implications for the design of marine protected areas. Marine Technology Society Journal, 37: 27-34.

Lindholm, J., Auster, P., J. & Knight, A., (2007). Site fidelity and movement of adult Atlantic cod *Gadus morhua* at deep boulder reefs in the western Gulf of Maine, USA. Marine Ecology Progress Series, 342: 239-247.

3.5 Tag reporting rates

Abstract(s) & collaborators

Presenter: Tim Miller, Timothy.J.Miller@noaa.gov
Institution: National Marine Fisheries Service, Woods Hole, MA

Abstract: Tag reporting rates are generally not the primary focus of a tagging study, but they must be considered in tagging models to avoid biased estimation of parameters of interest such as fishing and natural mortality rates. Some general methods applicable to cod and commercial fisheries to estimate reporting rates for non-reward tagged fish are briefly presented. One appealing method releases tags at a range of values. In theory, this method allows estimation of the relationship of reward to reporting rate and avoids assumptions of full reporting for "high" reward tags, but there are, of course, associated difficulties.

Key presentation points

- Tag reporting rates are directly related to a combination of fishing effort distribution, tag detection and compliance to report tags.
- Accurate estimates of reporting rate are fundamental for:
  - Studies focused on obtaining estimates of fishing mortality (F) and natural mortality (M), since these estimates are directly impacted by the reporting rate;
  - Studies focused on movement/mixing questions, since a good understanding reporting rates is fundamental for accurately interpreting the relativity of cod movements.
- Potential reasons for non-reporting:
  - Lack of awareness that there is a reward;
  - The reward is too low;
  - The catch is so high that tags are hard to detect.
- Tag reporting rates can be quantified through study designs which offer incentives of different values - such a design facilitates the estimation of variation in reporting rates, as determined by how motivated fishermen are to return tags. Examples of tag incentives highlighted include:
  - Monetary rewards of differing values (e.g. $10, $20, $50, $100, etc.);
  - Low-reward/high-reward schemes;
  - Tag reward lotteries.
- Alternative methods of investigating tag reporting rates include:
  - Tag planting: tagged fish are “planted” within the catch during fishing trips such that a known quantity of tags are available for detection and reporting, and thus a non-reporting rate can be estimated;

  - Observer trips: on the assumption that observers will report 100% of the tags they detect, reporting rates from observed trips can provide a comparison for reporting rates from commercial vessels operating with the same gear type in the same fishery.

- Reporting rates may vary over time:
  - Waning interest in the study may affect reporting rates;
  - Inflation: Tag rewards (particularly dollar value rewards) should be adjusted/budgeted in line with inflation to ensure that the tag rewards are sufficiently high to be deemed desirable – this could even become an issue within a single multi-year study if, e.g. the cost of fishing increases during the course of the study (e.g. in association with increased fuel prices etc);
  - Fluctuations in markets and fishing regulations may affect handling practices and attitudes/compliance.

Key discussion points

- It was confirmed the NRCTP had utilized a two-tier tag incentive scheme: all tags reported were rewarded with either a Tshirt, hat or mug ('low-reward' incentives). High-reward tags (worth $100) were deployed in year 2 of the study only. In addition, a monthly lottery was held for the first 24 months of the program, with 5 regional winners each month receiving a check for $200 (Shelly Tallack, GMRI).
- It was reiterated that effective outreach methods are required to educate potential tag reporters on the rewards available (Shelly Tallack, GMRI).
- Budgeting for tag-reward schemes may be difficult, particularly for long-term studies (Tim Miller, NEFSC); however, tag incentives are a vital component of tagging study design and should be sufficiently budgeted for.

Select references of relevance

Nichols, J.D., Blohm, R.J., Reynolds, R.E., Hines, J.E. & Bladen, J.P., (1991). Band reporting rates for mallards with reward bands of different dollar values. *Journal of Wildlife Management*, 55: 119-126.

Murphy, M.D. & Taylor, R.G., (1976). Preliminary study of the effect of reward amount on tag-return rate for red drum in Tampa Bay, Florida. *North American Journal of Fisheries Management*, 11: 471-474.

Pollock, K.H., Hoenig, J.M., Hearn, W.S. & Calingaert, B., (2001). Tag Reporting Rate Estimation: 1. An Evaluation of the High-Reward Tagging Method. *North American Journal of Fisheries Management*, 21: 521–532.

Pollock, K.H., Hoenig, J.M., Hearn, W.S. & Calingaert, B., (2002). Tag Reporting Rate Estimation: 2. Use of High-Reward Tagging and Observers in Multiple-Component Fisheries. *North American Journal of Fisheries Management*, 22: 727–736.

Hearn, W.S., Hoenig, J.M., Pollock, K.H. & Hepworth, D.A., (2003). Tag Reporting Rate Estimation: 3. Use of Planted Tags in One Component of a Multiple-Component Fishery. *North American Journal of Fisheries Management*, 23: 66–77.

Taylor, R.G., Whittington, J.A., Pine, W.E. & Pollock, K.H., (2006). Effect of different reward levels on tag reporting rates and behavior of common snook anglers in Southeast Florida. *North American journal of fisheries management*, 26: 645-651.

3.6 Understanding tag reporting behavior – the NRCTP questionnaire findings

Abstract(s) & collaborators

Presenter: Shelly Tallack, stallack@gmri.org

Collaborators: Shelly Tallack, Sarah Whitford, Pat Foote

Institution: Gulf of Maine Research Institute, Portland, ME

Abstract: GMRI distributed questionnaires to the groundfish fishing community through its January 2008 results-oriented glossy mass-mailing. The aim of this questionnaire was to find out how the Northeast Regional Cod Tagging Program has been perceived by industry on a variety of facets, including: tag color used, findings presented, the tag rewarding system, reward quality, and distribution of tag recapture and other programmatic information. The questionnaire also directly asked what motivates individuals to report their tags; and if they do not report their tags, what needs to change programmatically for these individuals to support any tagging program.

Key presentation points

A total of ~5000 questionnaires were mailed in January 2008 to multi-species permit holders, tag reporters and processing plants throughout the region. Over the duration of 1 year, 112 questionnaires were completed and returned – thus, the information represents just a small sample of the potential pool of tag reporting stakeholders. As with the tag returns, a high response rate was observed from Canadian stakeholders, both fishermen and processors.

- **Exposure to tagging programs:** Of those who completed the questionnaire, 10% had tagged cod for the NRCTP, and 30% had tagged fish for other tagging programs. The vast majority of responses (87%) came from individuals who had recaptured tagged fish of some species (not just cod).
- **Tag visibility:** Tags were noted as sufficiently visible in 97% of all responses. When asked to choose their ideal tag color for cod, the predominant (49%) preference was for yellow tags (i.e. the color used for the NRCTP low-reward tags); other recommendations were orange (33%), blue (8%), green (6%) and other (4%).
- **Tag rewards:** 90% of individuals who completed the questionnaire were aware of the NRCTP rewards available if they returned a tagged cod. The rewards were 'liked' by 81% of individuals (3% did not like their reward) and 16% did not answer (they may not have received rewards since only 87% of responses came from people who had reported tagged species).
- **Information dissemination:** GMRI asked if people had been happy with the level of information provided in various outreach materials, including fish recapture reports (85% indicated yes), newsletters (81% indicated yes) and mass-mailings (75% indicated yes).
- **Why people return tags:** The questionnaire asked people to indicate what their motivation had been if they had returned tags (they could select more than one category). Of the responses, "helping science" (40%) and "interested in the fish" (34%) were the most common responses. The reward motivated 17%, the lottery 3% and "other" 5%. When

asked what would have to change in order to make someone report a tagged fish (if they never had), most people (55%) did not respond; of those who did, the responses were: more valuable reward (7%), trust in science (12%), anonymity (4%) or other (24%).

Key discussion points

- **Regulatory discards:** for many multi-species trips, non-target species are discarded straight from the net without being brought on deck. As such, these fish (which can include cod) are not handled and thus, tags will not be detected.
- **Bio-fouling of tags:** despite the deliberate purchase of Hallprint Pty T-bar tags which apply an anti-fouling coating, boil-fouling does occur and its greenish coloration means that tags can become difficult to detect (Eric Hesse, FV Tenacious).

Reports, publications and project websites

See page 12.

3.7 Potential ecotypes in cod: Implications for management and recovery

Abstract(s) & collaborators

Presenter: Graham Sherwood, gsherwood@gmri.org
Institution: Gulf of Maine Research Institute, Portland, ME.

Abstract: Previous tagging studies in cod have focused on describing contemporary stock structure and/or average movement behavior of individuals within putative stocks or populations. Within-population variations in movement have been largely ignored due likely to the absence of ancillary information (e.g., diet, growth, body morphology, color, and genetics) that could put tagging results into an evolutionary and ecological framework. At the same time, the existence of life-history variants (movement and feeding ecotypes/morphotypes) is being demonstrated in a large number of other fish species (primarily freshwater and diadromous) where the migrant form is usually the most productive. In this presentation, I will present early results from Newfoundland and the Gulf of Maine that suggest cod may also be adopting alternative life-history strategies. Specifically, in one spawning population from Newfoundland, the existence of nearshore, benthic residents versus offshore, pelagic migrants was established using acoustic telemetry and stable isotope (diet) analyses. In the Gulf of Maine, an ongoing study is showing that red coloration in cod is correlated to life-history traits consistent with a sedentary life style. Red cod may be an extreme expression of residency, but this is not to say that all resident cod should be red. Future cod tagging studies should consider within-population (fine-scale) variation in movement behavior, and if ecotypes do indeed exist, management should consider the possibility that poor recovery may be related to a change in the relative frequency of ecotypes with the fishery being dominated by the less productive (resident) form.

Key presentation points

This presentation was structured with the aim of addressing four key following areas:

- **Cod rebuilding:** Wroblewski et al. (2005) proposed that inshore and nearshore stocks of Atlantic cod are important for re-building the East Coast fisheries in both Newfoundland and the Gulf of Maine. Given the near total collapse of offshore stocks in Newfoundland, inshore cod may be the key to recolonizing offshore areas, although it's unclear whether these resident fish currently have the capacity or drive to undertake large-scale migrations. In eastern coastal Maine, migrant cod may be required to recolonize inshore spawning grounds which are for the most part completely abandoned.
- **"Migrants" versus "residents":** Fish that travel long distances are considered "migrants" while those with smaller home ranges are defined as "residents"; these two types of fish can be considered separate ecotypes of the same species. There is likely a bioenergetic reason (e.g. differing metabolism, foraging needs, etc.) for the difference in lifestyle within the same species. Species examples include:
  - The Lake Superior coaster brook trout: within the lake, the migrant populations have crashed, while the resident type remains ubiquitous;

- Eastern brook trout (Morinville & Rasmussen, 2003): Growth rates are similar during the first year of life, but by age two the migrants grow more slowly despite higher feeding levels. Migrants can only achieve growth by eating more, while residents appear to grow sufficiently even with a more limited prey resource. Given this energetic deficit, migrants head out into the ocean to capitalize on foraging opportunities beyond the stream; in doing so, they become significantly larger than the residents which limit themselves to fresh-water streams.
- Atlantic cod: Does a similar ecotype variation exist in cod?

- **Ecotype variation in cod:** Divergent life-history strategies have been evidenced for cod in Newfoundland (Bar Haven spawning ground, Placentia Bay) through a combination of stable-isotope and telemetry data.
  - Two different long-term feeding preferences (benthic versus pelagic) were identified through stable isotope analyses on samples from spawning cod; these are proposed as being associated with resident (benthic diet) versus migrant (pelagic diet) ecotypes of cod (Sherwood, in preparation);
  - Habitat preferences were observed for cod tagged in the nearshore waters of Bar Haven. Cod were differentiated based on historic feeding patterns and tag detections indicated that migrants utilize the more shallow waters around the islands for spawning while residents spawn in the deeper troughs between the islands.
  - Residency has been demonstrated through acoustic tag detections where benthic cod were detected year-round near the spawning grounds during 2002 and 2003, while detections of pelagic (migrant) cod dropped off shortly after spawning. Homing occurred more completely for benthic cod likely due their being in closer proximity (Sherwood, in preparation).
  - Maturation also differed between residents and migrants with residents maturing earlier than migrants; residents may reproduce early to avoid being unable to reproduce as a result of potential food limitation later in life, while migrants seek out alternative food sources and thus, are in less hurry to reproduce. Age at maturity for Newfoundland cod has reportedly decreased in recent years (theoretically due to fishing pressure (E.M. *et al.*, 2005)); this effect may actually be caused by a shift in the relative proportion of each ecotype remaining in the population, i.e. if the population remaining is dominated by resident cod, the earlier age at maturity is consistent with this ecotype dominating .
  - Breakdown of migration highways: Ecotype variation is evidenced in Newfoundland cod and if the balance between resident and migrant cod in Newfoundland is tipped towards resident cod, this may explain the recent breakdown in migration highways noted for the Newfoundland region.
  - Future tagging studies may help determine the relative frequency of migrants/residents, which may be a better index of resource recovery.

- **Red cod as an ecotype:** 'red' versus 'green' cod have been sampled on Cashes Ledge with a particular focus on diet, body shape and long-term diet preference (through stable isotopes).

- Digital imaging analysis has verified that the cod can be scientifically differentiated by color.
- Size versus color trend analysis confirms that color in cod is not ontogenetic, i.e. there is some overlap in size though red cod tend to be smaller, not exceeding ~60 cm (i.e. their growth is stunted).
- Morphometric analysis confirms that red cod are less stream-lined than green cod, which is fitting with a more benthic, less migrant ecotype.
- Stable isotope analyses produced a surprising result – red cod had a pelagic signal in their diet which appeared counter-intuitive to the benthic/resident ecotype theory; however, the red cod were sampled around Ammen Rock (a pinnacle on Cashes Ledge) which may be entirely bathed in pelagic productivity from surrounding waters. If there is a distinct carbon signature for this site, it may be possible to utilize this to trace red cod residency (further analysis is planned for summer 2009).
- Parasite loads of seal worm were lower in red cod than in green cod, indicating a distinct diet and possibly supporting the notion that they are resident, and as such, are cut off from contact with seal worm sources.
- Overall, red cod seem to be sufficiently distinct to represent a separate ecotype and tagging studies should be undertaken to verify what appears to be resident behaviour.
- It was reiterated that while red cod may be resident, not all resident cod will necessarily be red (e.g., Newfoundland cod); other distinguishing factors must be identified (e.g., timing of spawning, diet or morphometrics).
- Genetics may reveal highly complex meta-population structure for red cod.

- In conclusion, the **implications of ecotypes and a role for cod tagging** were summarized as follows:
  - Ecotypes differ in life-history strategies; residents budget well and migrants are "gluttons".
  - Given differences in feeding and movement strategies, changes in spatial fishing pressure and/or food web structure may affect ecotypes differently. Our current fishery/management strategy may favor the resident ecotype (e.g., protection of less mobile cod via closed areas) and changes in the food-web structure (particularly a lack of forage fish, e.g. capelin in Newfoundland) may be impeding the recovery of migrants.
  - If ecotype variation is important in cod, it is in our best interest to describe and quantify it so that strategies can be devised to manage both types.
  - Tagging (traditional, acoustic and DST) should be an integral part of this endeavor.

Key discussion points

- **Maturation and fecundity:** Larger cod are usually more fecund (David Goethel, FV Ellen Diane). Though this is the general trend, it is not the case for resident cod in Newfoundland

(Graham Sherwood, GMRI) and when the data are teased apart, (i.e. fecundity estimates from migrant versus resident cod), the differences in fecundity become more apparent.

- **Impact of fishing VS food web:** If there is a common pool of larvae, [fishing/management] conditions may favor the resident cod (Lisa Kerr, SMAST). It is necessary to determine if cod are most impacted by fishing pressure or the food web; once determined, it might be possible for migrant cod to re-colonize the inshore areas (Graham Sherwood, GMRI).
- **Cod feeding habits** might be better determined by looking at fatty acids over stable isotopes (Steve Cadrin, NOAA/CEMER). It would be interesting to know the pelagic signature of those areas to overlay the data collected and see if there are any patterns (Graham Sherwood, GMRI).
- **Seasonal vs. year-round residency:** Cod in New Hampshire waters seem to be seasonally resident, moving offshore every year; cod are abundant in June but are absent in winter (David Goethel, FV Ellen Diane). The red cod in Cashes Ledge closed area are on top of Ammen rock all year round, even in winter (Graham Sherwood, GMRI). Based on oceanographic conditions, Cashes Ledge should be able to support cod year-round; internal waves bring up nutrients necessary for primary production all year round (Jonathan Grabowski, GMRI).
- **Coloration and diet:** Red cod can lose their red coloration if they leave the shelf since coloration does seem to be affected by diet, though this has not yet been fully investigated and acoustic tagging might be one way to investigate this (Graham Sherwood, GMRI).
- **Parasite load:** It is surprising that the load of parasitic worms in red cod are so low, because cod are typically loaded with worms (Ted Ames, PERC). Cod on Cashes Ledge are their own entity and do not have many worms since they may be cut off from usual intermediate hosts (Graham Sherwood, GMRI).

Project websites

- http://www.gmri.org/science/research.asp?ID=106

Project reports

Pending.

Project publications

Pending.

3.8 A Review of recent juvenile cod research: closed areas & habitat associations

Abstract(s) & collaborators

Presenter: Jonathan Grabowski, jgrabowski@gmri.org

Institution: Gulf of Maine Research Institute, Portland, ME.

1) Evaluation of closed areas: Cashes Ledge as juvenile cod habitat?

Collaborators: Jonathan Grabowski*, Graham Sherwood, Julien Gaudette, Tom Weber, Chris McGonigle, Bob Steneck, Ray Grizzle, & Curt Brown

Abstract 1: The effectiveness of fisheries management is limited by the paucity of information on how management tools, such as marine protected areas, impact key fisheries species. In the Gulf of Maine, more information is needed to determine how marine protected areas including the Cashes Ledge Closure Area influence fish population dynamics and, subsequently, the status of fishery stocks. We conducted seasonal surveys in 2006 and 2007 on the kelp, barren cobble, and mud habitats in the vicinity of Cashes Ledge using video, trap, and gill net sampling to quantify how habitat influences the abundance and distribution of juvenile and adult Atlantic cod, *Gadus morhua*. Seasonal surveys identified that cod are still abundant on Cashes Ledge, and that their spatial and temporal distribution is influenced by habitat as well as by other species on Cashes Ledge such as spiny dogfish, *Squalus acanthius*. Juvenile cod were most abundant in kelp (Laminaria spp. and *Agarum cribrosum*) habitats. These results are being compared with historic cod datasets that were collected prior to the inception of the closure, and predate extensive harvesting on Cashes Ledge in the early 1990's, to determine if cod populations have recovered locally. Quantifying important ecosystem functions such as the provision of nursery habitat for commercially important fish species will assist managers in selecting the most appropriate areas for management action. This study will also provide baseline information that will be of value to ongoing efforts to monitor the impact of the Cashes Ledge Closure Area on rebuilding cod populations throughout the Gulf of Maine.

2) Identifying habitat associations of juvenile cod in nearshore Gulf of Maine waters

Collaborators: Jonathan H. Grabowski*, Julien Gaudette, Graham D. Sherwood, Sally Sherman, Gail Wippelhauser, and Joseph T. Kelley

Abstract 2: Young-of-year Atlantic cod (*Gadus morhua*) are typically found in shallow waters in complex habitats such as seagrass beds and cobble-rocky ledge habitats that provide refuge from predators. As cod mature, they are thought to slowly migrate into deeper water, yet whether these juvenile cod associate with specific habitat types remains unclear. We utilized seafloor mapping information and trawl survey data from 1992-2005 conducted in mid-coast Maine to examine cod habitat associations during early life-history phases. In 2006, we conducted video surveys and hook-and-line sampling to assess how cod relative abundances in these habitats compare to more structured habitats including rocky ledge and cobble bottom. Trawl surveys revealed that juvenile (10-25 cm) cod were far more abundant on gravel than on mud or sand bottom. Although depth was positively correlated with fish size ($r^2 = 0.35$), examination of tows conducted at similar depths demonstrated that juvenile cod densities on gravel were more

abundant than those on either sand (20-35 m) or mud (35-50 m). 89.9% of cod were found in water between 4 and 10 ºC. Juvenile cod densities were also consistently higher in gravel than either of the two soft-sediment habitats across this temperature range. Video surveys and hook-and-line sampling suggested that cod are most abundant in complex habitats such as rocky ledge and cobble habitats. Given that these habitats are incapable of being towed because nets are easily entangled on complex bottom, attempts to quantify the abundance of juvenile cod populations using only trawl surveys may be insufficient. Further investigation is merited to determine whether complex nearshore habitats influence juvenile cod survivorship and growth as well as if the availability of these habitats is affecting the recovery of cod populations and their fisheries in the Gulf of Maine.

Key presentation points

- **Cod habitat by life-stage:** Research to date has investigated the linkages between habitat and cod life-history stages. Young-of-the-year (YOY) cod use structured habitats such as sea grass and kelp as refuge from predators, but it is less clear what habitat is preferred by older juvenile life stages.
    - Cod size-frequency data from the Maine and New Hampshire inshore trawl surveys were investigated in parallel with high-resolution habitat maps for the Midcoast Maine area to investigate which habitat types (e.g. gravel, mud and sand) are used by YOY and larger juvenile cod. Rock was not sampled with trawl gear, but was sampled using video and hook-and-line gear.
    - YOY cod: Most YOY cod (0-10 cm) were captured at depths <20 m. Because only sand was sampled in this depth range, it is unclear if these cod prefer sand habitat or shallow depths. YOY cod that were captured at depths > 20m were more abundant in gravel than in sand or mud.
    - Larger juvenile cod: Larger juvenile cod (11-40 cm; 1+ years) were most abundant in gravel habitat, intermediate in sand, and least abundant in mud habitat (significant, $p<0.001$). After controlling for the effects of depth on the distribution of cod, larger juvenile cod were still more abundant in gravel than either sand or mud habitat.
    - Temperature: Approximately 90% of the juvenile (11-40 cm) cod caught/sampled were retrieved from waters ranging from 4-10 °C; however, cod abundance was highest at 8-10 °C and during the fall when water temperatures are warmest. Cod were consistently more abundant in gravel habitat regardless of temperature.
    - Rock habitat: Cobble/ledge rock habitat was sampled and compared to gravel, sand, and mud habitat using underwater video footage (frequency rates by size – coarse estimate) and hook and line sampling. Both video visitation rates and catch rates indicated that larger juvenile cod utilize cobble/ledge habitats.
    - Question remaining: How does habitat use of juveniles affect stock productivity?
- **Impact of closed areas on cod populations:** Earlier studies (e.g. Witman and Sebens 1992, Steneck 1997) found that abundances of large cod and Pollock located on offshore ledges and banks such as Cashes Ledge were greater than those in inshore areas. Intensification of the offshore fishery in the early 1990s led to Cashes Ledge being

designated as a closed area to mobile fishing gear. Thus, current research is focused on understanding whether cod are still abundant on Cashes Ledge? And if so, whether the closure is supporting this abundance and which habitats are most important?

- Habitat zonation: Habitat zones were classified on Cashes Ledge using video sampling and multibeam sonar in 2006. Laminaria kelp was common on the pinnacle (0-15 m), followed by shotgun kelp (16-30 m). Below 30 m, the habitat shifted to predominantly bare rock (35-50 m) and a mixture of bare rock and mud/sand habitats at depths > 50 m.
- Sampling juvenile cod habitat use on Cashes Ledge: In 2006 and 2007, Fish sampling was conducted in each of the four dominant habitats described above (Laminaria kelp, shotgun kelp, bare rock, and mud/sand) using seasonal video surveys, hook and line sampling, and gillnet surveys.
- Fish sampling methods indicated relatively low abundance of cod on Cashes Ledge in spring, increasing to a peak in the summer (particularly in the shotgun kelp zone) before tapering off again in the fall. Their disappearance in the fall may be associated with the higher abundance of dogfish sampled on Cashes Ledge in the fall months. As such, it begs the question of how effective a closed area can be when other factors (e.g. species interactions) may be a driving force for cod abundance.

- **Conclusions:**
  - Habitat maps have a role to play in tagging programs – they can be an essential tool to understanding cod population dynamics.
  - Preliminary findings from this study suggest that Cashes Ledge and the closed area offer prime habitat for groundfish generally, but the results for cod specifically are less clear because cod show seasonal variation in abundance.
  - It is possible that certain species interactions (e.g. spiny dogfish) will impinge on the effectiveness of area closures.

Key discussion points

- **Sampling methodologies:** It was asked if all the methods to estimate cod abundance were at the same level of magnitude (Hunt Howell, UNH). Grabowski reiterated that only relative abundances were used (i.e. not absolutes) but that the standardized results from gillnets and video footage were in alignment. Video visitation sampling was noted as having the potential to record one fish multiple times which may inflate abundance estimates (Hunt Howell, UNH) This potential limitation was acknowledged, but it was reiterated that video sampling is a standard method for surveying relative fish abundance (Jonathan Grabowski, GMRI). The sole sampling method used in winter was hook gear (Jonathan Grabowski, GMRI); hook gear was noted as not being an effective capture gear for cod if abundance, is low and particularly if dogfish are in the area, and thus this gear may not be ideal for estimating cod abundance (Eric Hesse, FV Tenacious). Grabowski agreed with this observation, stating that he didn't show abundance results from hook-and-line sampling for this and other reasons. For instance, Grabowski pointed out that the catch rates of other species may impact abundance rates from hook and line fishing.

- **Depth:** Was depth a factor in cod abundance rather than habitat (David Goethel, FV Ellen Diane)? Depth and habitat can't be teased apart in the field for the work at Cashes Ledge because the habitats exist within distinct depth zones, so the effect seen may be related to either habitat or depth, but we're not sure (Jonathan Grabowski, GMRI). In other areas where habitat is the same across depths, depth seems to be the primary factor influencing cod abundance, particularly juveniles (David Goethel, FV Ellen Diane); in the Western GOM, cod <12" are found in depths <27 fathoms and only larger cod are found deeper than 30 fathoms. However, in the inshore study, there was no effect of depth on habitat usage by juvenile cod; cod prefer structured habitats (i.e., gravel and cobble rock bottom) regardless of depth (Jonathan Grabowski, GMRI). Grabowski commented that this work was conducted at depths shallower than 30 fathoms because it was focused on juvenile cod for the very reason that David pointed out.

Project websites

- http://www.gmri.org/science/research.asp?ID=88

Project reports

Grabowski, J. H., J. Gaudette, P. Wells, and V. Balzano. 2007. Identifying habitat associations of early juvenile cod in nearshore Gulf of Maine waters. NOAA CRPP Final Report.

Project publications

Grabowski, J. H., J. Gaudette, G. D. Sherwood, S. Sherman, G. Wippelhauser, and J. Kelley. Identifying habitat associations of early juvenile cod in nearshore Gulf of Maine waters. *Transactions of the American Fisheries Society* (in review).

4. Afternoon discussion and research recommendations

During this afternoon session, the group re-visited the data gaps identified during/after each individual tagging study presentation. These data gaps, in combination with some statements on "lessons learned" were compiled (see 4.1).

Outstanding cod tagging-related research needs for the GOM region had been identified throughout the day. During this afternoon session, these discussion points were re-visited and expanded upon in order to compile a synthesis of cod tagging-related research needs for the GOM region (see 4.2).

Workshop attendees then undertook a research prioritization exercise (see 4.3).

4.1 Lessons learns and information gaps remaining after completion of the tagging studies presented in this workshop

- The identification of migration highways by the NRCTP is good, but the need remains for improving evaluations of movement/exchange rates between locations (using e.g. weighting and non-weighting methods).
- Cod movement information for eastern GOM waters is still vague, with few observations; a study designed to obtain more information in the Downeast waters is needed.
- **Reporting rates:** Future tagging projects will benefit from the deployment of high-reward tags from the outset of the study to ensure sufficient distribution of high-reward tags (both spatially and temporally). This will also ensure that sufficiently high quantities of high-reward are released to yield the most accurate estimates of reporting rates possible; this has important implications for the accuracy of subsequent movement estimates.
- **Rigorous experimental design:** Depending on the goals of the study, future tagging efforts could consider:
  - Releasing tags in proportion to biomass, e.g. for stock mixing investigations;
  - Targeting specific fish within the population (for e.g. spawning-related studies, or studies focused on specific life-history phases);
  - The need for a short-term versus a long-term, multi-year design (to detect inter-annual trends); and
- **Ancillary data:** The studies presented had all collected varying amounts of ancillary information, but it was acknowledged that when tagging studies are collaborative in nature and involve large numbers of industry participants, it is a challenge to train all fishermen in multiple forms of data collection, particularly those which might be more subjective (e.g. fish color or fish condition). That said, it was reiterated that future studies should consider routinely collecting ancillary data where possible. Examples include:
  - Genetic information;
  - More detailed/specific spawning condition classification (using e.g. cannulation techniques);

- Cod color and morphometric measurements;
- Stable isotope analysis to look at long term feeding patterns;
- Parasite loading;
- Environmental information (e.g. bottom temperature and CDT information), etc.

4.2 Cod tagging-related research needs for the Gulf of Maine and neighboring waters

Theme 1: Cod management

Recent and historical cod tagging data (and genetic data) suggest substantial movements across current stock boundaries and considerable heterogeneity within current management units. Best available science indicates the need to re-visit the stock management boundaries. Key recommendations from the group include:

- The management/stock assessment boundaries need to be re-analyzed and assessed; it may be easier to define new boundaries for certain areas than others (Don Clark, DFO), but the need to address this is high. This task will be best achieved by an interdisciplinary team (Steve Cadrin, NOAA/CMER).
- Investigate options for alternate management scales (e.g. large-scale/fine-scale) – it was noted that a workshop ("Exploring Fine-scale Ecology for Groundfish in the Gulf of Maine and Georges Bank") is scheduled for 2-3 April, 2009, and this venue is charged with specifically investigating management scales; thus, this recommendation is timely.
- It is likely that if management/assessment boundaries are re-drawn, this will direct future research directions (Jon Grabowski, GMRI).
- Currently, the majority of our movement data is for adult cod; more information is needed for cod throughout its life-history in order to understand how these life-stages and populations connect in time and space. (Hunt Howell, UNH).

Theme 2: Data mining, re-analysis, modeling

There is now a wealth of regional cod mark-recapture information available which could be mined and analyzed in concert with various other data types in order to improve our understanding of cod movements, dispersal, life-history, catchability, etc. Following are a list of examples of research which would not require further tagging, but could potentially yield more detailed understanding of cod biology in the GOM region.

- **Meta-analysis of historical mark-recapture datasets** (e.g. NRCTP, UNH, SMAST, DFO datasets for the period 2000-2009; older tagging datasets may also become available in future months/years through the Northeast Fisheries Science Center's multi-species mark-recapture database.
- **Stock assessment applications:** Compare estimates of stock assessment parameters derived through mark-recapture data with those derived through traditional methods.
    - Initial estimates of natural mortality and fishing mortality from the NRCTP data were prepared for the 2008 GARM (Miller & Tallack, 2007); further work is

needed to refine these estimates and consideration of the additional UNH, SMAST and DFO datasets may be of use for this.

  - Tagging data is particularly useful for assessing selectivity in an objective manner and this was also recognized and prepared from the NRCTP data for the 2008 GARM (Hart & Miller, 2008); refining these analyses by gear type could also be attempted.
  - Mark-recapture data provide an alternative source of growth information (Taylor & Tallack, in preparation; Tallack, in review); these data might also complement future stock assessment efforts, particularly if considered in combination with growth information from the UNH, SMAST and DFO cod tagging datasets.
  - Develop alternative stock assessment models which can better incorporate the region's non-traditional mark-recapture information as supplementary information on stock structure and status.

- Undertake analyses which contextualize cod movements and dispersal with environmental (physical and biological) data (e.g. temperature, current, salinity, substrate, depth) (Shelly Tallack, GMRI & Jim Churchill, WHOI).

Theme 3: Socio-economic aspects

Mark-recapture studies are ideal collaborative research opportunities with common research goals for fishermen and scientists; tagging studies (and cooperative research projects in general) trigger interest in industry "there would be more ostriches without these projects". High-level, region-wide collaboration was a primary objective for the NRCTP; it was attempted to involve stakeholders throughout the region across all facets of the fishery including harvesters, processors, markets, scientific organizations and management. With so much investment (financially, but also through outreach and tagging operations) it is recommended that an evaluation of the socio-economic objectives of the NRCTP (and potentially other cod tagging studies) be undertaken. Specifically, this research should consider addressing:

- The extent of collaboration undertaken, but also the nature of collaboration (e.g. during planning stages, experimental design, in the field, post-tagging, analyses, outreach, etc.);
- The economic impact through vessel charter/workshop stipends etc.;
- The efficacy and frequency of outreach methods used: mailings, presentations, recapture reports, communication, workshops, etc.

Theme 4: Reporting rates

Tag recapture rewards/incentives are crucial for the successful retrieval of tag recapture information (across tagging technologies); and rewards have a considerable impact on reporting rates for tagging studies (Pollock *et al.*, 2001, 2002; Hearn *et al.*, 2003). There is a need to investigate how rewards have affected the reporting rates in the NRCTP and other regional studies presented here, in order that region-specific variation and changes in reporting rates over the course of the study can be accounted for during movement analyses. This investigation should address the effects of reward schemes within new and existing studies, while also trying to quantify how reward systems in one study have impacted new and other ongoing studies in the region. Specific points to consider include:

- Efficacy of outreach advertising the rewards available;
- Dissemination efficacy of recapture information to individuals reporting tags;
- Effects of multiple tag rewards and values;
- Inter-program effects (on both cod and other species).

Theme 5: Additional deployment of tags on cod

Additional tagging initiatives are recommended to enable more focused investigations into dispersal, migration and habitat usage of specific life-history stages of cod in the GOM region. Cod tagging initiatives are also suggested for: the collection of non-traditional, long-term monitoring, the assessment of management measures (e.g. area closures) and investigations into management scale. For each tagging theme, core objectives/research questions are highlighted.

- **Juvenile cod:** A variety of questions surrounding juvenile cod are currently only partially answered and mark-recapture studies could be designed to address a number of these, including questions on:
  - Habitat usage by juveniles and identification of critical nursery grounds;
  - Juvenile movement patterns: is there seasonality in juvenile movements? Is connectivity with adult populations demonstrated through juvenile movements?
  - Dispersal and recruitment from nursery grounds to regional stocks – where do juveniles recruit to?
- **Spawning cod:** A number of recent and ongoing studies have incorporated spawning cod questions into their study design, to greater or lesser extent. However, it was reiterated that the need remains for undertaking additional studies which focus on spawning cod, in all primary spawning grounds. It was reiterated that the methods applied by Howell and Siceloff have significantly improved our understanding of spawning-related cod dynamics in the Ipswich Bay area and that these methods should be re-applied to other spawning areas throughout the region. Particular research recommendations include:
  - To maximize the efficiency of vessel time, investigate the use of acoustics/vocalization for improved detection and thus sampling of spawning cod?
  - Investigate how to study spawning 'migrants' in comparison with spawning 'residents' since this will likely impact the methodological design applied to monitor spawning generally.
  - Long-term monitoring of spawning cod behaviors could involve developing *in situ* arenas, by deploying hydrophones, videos and acoustic arrays on the seabed to detect spawning fish as they enter an area.
  - Investigate the potential correlation between spawning and feeding behavior and the environmental constraints which may determine movements of spawning fish.
  - Data collected from spawning studies should be considered in context with the overall oceanographic regime, including larval transport, time of arrival to and departure from the spawning grounds. Existing datasets should be mined for spawning records already available since it may be possible to compare the

movements observed with environmental data, but there is still a need for additional spawning-focused studies to be undertaken.

- **Fine-scale investigations:** All-encompassing standardized studies which incorporate genetics, environment, diet, stable isotope analyses are recommended for the following priority locations: Ipswich Bay, Downeast Maine, Northern edge of Georges Bank, Coxes Ledge, Cashes Ledge, Bay of Fundy and Massachusetts Bay.
- **Multi-year, long-term cod tagging initiatives:** Multi-year, long-term 'monitoring' tagging studies should deploy consistent numbers of tagged cod each year/season (e.g. 5000 cod per location, or as determined during planning stages based on the monitoring objectives). The following priority locations should be targeted: Eastern Georges Bank, Cape Cod waters, Inshore GOM, Bay of Fundy.
- **Advanced tagging technologies:** Through a combination of the studies summarized in this workshop, it is evident that considerable information on cod movements in the GOM region exists. The vast majority of mark-recapture records currently available for the 2000-2009 time-frame have been derived from conventional tags; with these data our understanding of cod movements is restricted to the start and end locations associated with tag release and tag recapture and recaptures are also skewed by fishing distribution and effort. These data have proven valuable for identifying core migration routes in the GOM, and thus, as a region we are now well positioned to design and undertake an effective region-wide study which incorporates advanced tagging technologies. As one example, acoustic arrays could be deployed in strategic locations along the migration routes to investigate cod movement and exchange between regions which cannot be detected using conventional tags. Such a tagging initiative will provide a more detailed picture on cod movements which is not readily captured by conventional tags, and is also less reliant on reporting accuracy and fishing effort. [It was proposed that closed areas provide the ideal location for deploying acoustic arrays since the waters are protected from trawling activity. Thus, providing the closed areas targeted are good cod habitat, they may yield high cod detection rates].
- **Closed area investigations:** Area closures in the GOM region have been introduced to meet a range of objectives, e.g. protection of spawning cod (rolling closures) and the reduction of cod fishing mortality and rebuilding of cod stocks (Western GOM closure), and the protection of juvenile cod (e.g. Nantucket Lightship closure). At this workshop, small-scale studies have been presented that begin to address the role of closure areas with respect to fine-scale cod movements and habitat use (see pages 20, 24 and 36). However, considerable uncertainty remains regarding the impact of these area closures on the Atlantic cod resource. Pressing questions which remain unanswered include:
  - What fraction of the cod population is protected by each closure area?
  - What life-history stages of the cod population are protected?
  - Are the closures promoting productivity and/or recruitment?
  - Is the closure area sited appropriately in terms of critical cod habitat (e.g. for juveniles, or spawning cod)?
  - Is the closure area sufficient in size to protect a mobile species like cod?

  - Are area closures causing concentrations of fishing effort in alternative, more valuable cod habitat?

- **Ecology and Biology:** Future regional tagging studies should incorporate additional biological and ecological data parameters within their study design. These types of information will aid in our interpretation of cod movements observed, and might address the following concepts:
  - Migrant and resident ecotypes, such as the red cod on Cashes Ledge, might be an important piece of the puzzle. Interdisciplinary collaborations (e.g. modelers with geneticists) will be important for teasing apart the movement patterns. There may be a genetic or morphometric reason why certain patterns occur, she said, and researchers can learn what is driving the phenotypic plasticity.
  - More information is necessary regarding species interactions, (e.g. cod and dogfish) to determine how these impact cod movements.
  - In the GOM, a forage driving force for cod movements (e.g. Capelin in Newfoundland) has not yet been identified; understanding this linkage is vital for understanding future fluctuations in cod abundance/migration in the region.
  - Cod preferences for habitat and food, along with feeding frequency, should be examined more closely.

4.3 Prioritization of cod tagging research needs

Prioritization of cod tagging research needs took place both during the workshop and via an online survey in subsequent weeks; 75% of attendees (n=18) completed the online survey. Table 2 summarizes the prioritization of over-arching research themes. In support of the highest ranking recommendation, the following statement was drafted by the group during the workshop:

> *"Recent and historical cod tagging data (and genetic data) suggest substantial movements across current stock boundaries and considerable heterogeneity within current management units. Best available science indicates the need to re-visit, re-analyze and re-assess the stock management boundaries; this task will be best achieved by an interdisciplinary team."*

The group also prioritized specific research recommendations within each research theme (Table 3). For greater detail on each research concept, see section 4.2.

Table 2: Prioritization of over-arching cod tagging research themes for the GOM region (prioritized partially during the workshop and subsequently during a subsequent online survey).

Please prioritize the general themes here. Note: 1=Lowest priority and 5=Highest priority.						
Theme options	**1**	**2**	**3**	**4**	**5**	**Average rating**
1) Cod management - best available science suggests a need to re-analyze and assess the cod management/stock boundaries	0%	0%	6%	17%	78%	4.7
2) Data mining, re-analysis and modeling using existing data	6%	6%	33%	44%	11%	3.5
3) Reporting rates and behaviours	17%	56%	22%	6%	0%	2.2
4) Socio-economic effects of tagging studies	61%	33%	6%	0%	0%	1.4
5) Additional deployment of tags	17%	6%	33%	33%	11%	3.2
					Additional comments	**4**

Table 3: Prioritization of more detailed research activities within each research theme (prioritized partially during the workshop and subsequently during a subsequent online survey).

Theme 1: Cod management: Best available science suggests a need to re-analyze and assess the cod management/stock boundaries.						
Answer Options	**Irrelevant**	**Somewhat relevant**	**Relevant**	**Important**	**Very important**	**Crucial**
- Re-visit the definitions of stock boundaries	0%	0%	0%	11%	17%	72%
- Investigate options for alternative management scales	0%	0%	0%	22%	44%	33%
- Need for more data across cod's life-history to educate this decision	0%	0%	6%	28%	39%	28%
- This should be tackled by an interdisciplinary group	0%	0%	11%	11%	33%	44%
					Additional comments	**5**

Theme 2: Data mining, re-analysis and modeling using existing data						
Answer Options	**Irrelevant**	**Somewhat relevant**	**Relevant**	**Important**	**Very important**	**Crucial**
- Meta-analysis of NRCTP data with historical mark-recapture datasets (e.g. UNH, SMAST, DFO, etc).	0%	0%	11%	50%	22%	17%
- Compare estimates of stock assessment parameters with those derived from tagging studies (e.g. F, M, selectivity, growth etc.)	0%	6%	6%	56%	28%	6%
- Develop alternative stock assessment models which can incorporate regional tagging information	0%	0%	11%	28%	50%	11%
- Analyze existing tagging data in the context of environmental (physical, biological) information	0%	0%	0%	28%	44%	28%
					Additional comments	**4**

Theme 3: Reporting rates and behaviours						
Answer Options	**Irrelevant**	**Somewhat relevant**	**Relevant**	**Important**	**Very important**	**Crucial**
- Investigate how rewards have affected reporting rates in the NRCTP and other regional studies (e.g. UNH, SMAST, DFO)	0%	0%	33%	33%	28%	6%
- Compare and investigate non-cod tagging study reward schemes for impact on the cod tagging reporting rates observed	0%	6%	44%	33%	17%	0%
- Investigate reporting behaviours in different fishing communities	0%	0%	33%	50%	17%	0%
					Additional comments	**6**

Theme 4: Socio-economic effects of tagging studies						
Answer Options	**Irrelevant**	**Somewhat relevant**	**Relevant**	**Important**	**Very important**	**Crucial**
- Extent, type and success of collaboration efforts	0%	6%	33%	17%	39%	6%
- Efficacy of methods used to disseminate findings	0%	6%	33%	39%	22%	0%
- Quantify the economic impact of tagging studies on participating fishermen	0%	6%	33%	39%	17%	6%
					Additional comments	**1**

Theme 5: Focus areas for additional deployment of tags						
Answer Options	**Irrelevant**	**Somewhat relevant**	**Relevant**	**Important**	**Very important**	**Crucial**
- Juvenile cod (movements; habitat; recruitment)	0%	0%	6%	17%	39%	39%
- Spawning cod (improve sampling efficiency; migrants vs. residents; long-term monitoring through in situ sampling methods; correlation between spawning/feeding; oceanographic context)	0%	0%	0%	6%	39%	56%
- Fine-scale investigations	0%	0%	11%	33%	39%	17%
- Multi-year, long-term monitoring tagging efforts	0%	0%	17%	33%	44%	6%
- Advanced tagging techniques (acoustic arrays, etc.)	0%	0%	0%	39%	28%	33%
- Closed area investigations (efficacy? all life stages? promotion of productivity? protection of spawning cod? sizing?)	0%	0%	6%	22%	50%	22%
- Ecology, biology (migrant/resident ecotypes, species interactions, forage driving force, habitat)	0%	0%	11%	33%	33%	22%
					Additional comments	**4**

5. Acknowledgements

This workshop was hosted and facilitated by Shelly Tallack and the Gulf of Maine Research Institute, with financial support from the NOAA fisheries Cooperative Research Program (under Award # NA07NMF4720278, Task 1). However, this workshop was essentially a synopsis of a number of past and ongoing research projects and as such, we acknowledge all individuals

(fishermen, scientists and managers) who have invested their skills and time into each of the presented research programs over the past decade.

For the success of the workshop in particular, we thank our presenters (in order of presentation: Shelly Tallack, David Martins, Jon Loehrke, Laughlin Siceloff, James Lindholm & Peter Auster, Timothy Miller, Graham Sherwood and Jonathan Grabowski) for preparing and sharing updates and findings from their respective research projects. We also thank all workshop participants (see page 51 for a full list of attendees) who offered constructive feedback, discussion and recommendations throughout the day.

We are also grateful to Rebecca Zeiber who provided rapporteur services during the workshop, and contributed to the compilation of these workshop proceedings. We also thank all workshop participants who provided feedback during the preparing of these proceedings.

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Annex 1: Workshop attendees

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Annex 2: Additional abstract for work underway at SMAST.

This work was not presented as the primary content during SMAST's presentation on cod tagging research completed, the abstract on this ongoing research has been included here to provide more detail.

Abstract(s) & collaborators

Title: Stock Composition of Atlantic Cod (*Gadus morhua*) Using Otolith Chemistry

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Abstract: Understanding the mechanism of stock separation among biological stocks of cod in the Gulf of Maine is critical to determining the dynamics of stocks and to developing effective harvest strategies. Despite management efforts, including time and area closures, rebuilding of Gulf of Maine cod has been slow. Failure of the regional cod population to recover in some areas may indicate a lack of understanding of how populations contribute to regional population productivity (i.e., source-sink dynamics) and persistence. Spawning groups of cod with unique spawning times (winter and spring) have been identified within the western Gulf of Maine and shown to be genetically distinct. We hypothesize that natal homing is the mechanism of stock-separating and that these populations contribute differentially to regional productivity across years because of differential responses to environmental changes. We use otolith chemistry to identify winter- and spring-spawned fish and test the hypothesis of natal homing in these populations. Preliminary results indicate that young-of-the-year winter and spring-spawned cod exhibit unique stable isotope signatures (δ18O and δ13C) due to the influence of temperature at the time of otolith formation. In assigning fish to their assumed spawning time (winter, spring), δ18O and δ13C provided high classification accuracy. Thus, otolith chemistry appears to be a useful tool in stock composition analysis of Gulf of Maine cod. Future work will include analysis of the core of otoliths from winter and spring spawning adult cod for stable isotope composition and based on these values fish will be assigned to their respective hatch-time (winter/spring). Depletion of historic spawning groups of Atlantic cod in heavily-fished populations has been cited as a contributor to the decline in population abundance from historic high levels. Identifying stocks and the roles they play in regional population persistence is pertinent to the goal of rebuilding and sustainably harvesting Gulf of Maine cod.

Annex 3: Meeting transcript.

Captured by Rebecca Zeiber (science writer); reviewed and corrected by workshop participants.

Disclaimer: These notes were transcribed simultaneously to the workshop presentations and dialogues. They have captured as much of the dialogue and discussion as possible and every attempt has been made to ensure these notes are accurate. Individual contributors are highlighted as underlined text.

I) Introduction and welcome: Shelly Tallack

This meeting was, in part, an intense one-day brainstorming effort to determine the future direction of tagging projects. Should future projects incorporate smart tagging? Should scientists focus more heavily on the modeling aspects to the data already collected? The information presented during the meeting was intended to update the attendees on the results from regional recent and ongoing cod tagging projects and to provide information to help the group make informed decisions about the future of cod tagging and management.

"We have some new faces to this group, and this is deliberate as I think they'll help us to look outside the tagging box to think about what we might be missing and how we can move forward as a region," said Shelly Tallack, program manager for the Northeast Regional Cod Tagging Program (NRCTP), at the Gulf of Maine Research Institute (GMRI).

The goals for the meeting included: (1) review the knowledge gained from current and recent cod tagging studies; (2) identify major gaps that currently remain in the information; (3) identify priority future tagging-related research that is still needed in the Gulf of Maine region; and (4) prepare and distribute a meeting summary for future reference.

II) Presentation: Shelly Tallack – The Northeast Regional Cod Tagging Program: What have we learned? Where do we go from here?

Tallack began her presentation by noting that this workshop would likely be the last for the Northeast Regional Cod Tagging Program (NRCTP). For that reason, she focused on summarizing the data collected from the NRCTP since 2003, but kept an eye towards the needs of future tagging projects.

The NRCTP had four original goals: (1) to develop a regional and international cod tagging infrastructure; (2) to involve industry, science and management partners; (3) to improve the understanding of cod movements; and (4) to make data accessible to the public through outreach efforts. The third goal dealing with cod movements was the only technical goal of the four, she noted.

To meet this objective, program managers set out to tag 100,000 cod in various areas of the Gulf of Maine, in both U.S. and Canadian waters. Numerous partners and organizations helped to tag cod using a standard technique to ensure consistency across all regions. A range of fishing vessels assisted in the tagging efforts, including those from the Cape Cod Commercial Hook Fishermen's Association (CCCHFA), Canada's Department of Fisheries and Ocean (DFO) research vessels, commercial draggers and recreational charter boats.

A total of 114,473 cod were tagged and released, mostly in the first two years of the program (March 2003 - July 2005). When the data are broken down by month, there was a peak in the number of fish tagged and released in the spring with another slight peak in the fall. Most of the recaptures occurred during the summer months, which coincides with the most active time of year for the recreational fishing fleet.

The low-reward and high-reward tags yielded different reporting rates; just over 5% of the low reward tags were reported, while the high return tags had a reporting rate of around 11%. "These reporting rates were about what we expected them to be," Tallack said. Of those individuals who reported the tags, approximately 57% were commercial fishermen (17% of those were Canadian fishermen); 21% were processors (mostly Canadian), 8.6% were fishery observers, and 9% were recreational fishermen. Although the reason for the high responsiveness from the Canadian processing sector is unclear, it is likely to be related to both accessibility to outreach materials informing them about the NRCTP (these are often small, family-run operations where communication within the processing plant is high), but also mindset, Tallack said.

As far as what types of gear were used for reported tags, approximately 56% of the reports came from fishermen using trawls, 19% were from the commercial hook fishery, 11% came from the recreational hook fishery and 14% were from gillnetting efforts.

New goals were set for 2007-09 for the NRCTP, including: (5) to maintain the tag return infrastructure and rewarding system; (6) to continue with public outreach efforts, including two workshops and a mass mailing that discusses the program's results thus far; (7) to archive the three historical cod tagging datasets; (8) to prepare the data and analyses for inclusion in the pre-GARM workshops, the 2008 GARM and (9) the 2009 TRAC workshop; and (10) to synthesize the region's findings to provide recommendations on future cod tagging research needs for the region.

Data compiled from all the organizations involved in regional cod tagging efforts, including from the NRCTP, DFO, SMAST and UNH, yielded approximately 182,000 tagged cod and approximately 10,000 recaptures. Tallack showed a map of the region with lines connecting the release and recapture locations for tagged cod between 2003-07 and noted that these results need to be used with caution. "One of the drawbacks of using a conventional method such as a T-bar tag is that the fish needs to be recaptured to obtain the movement data," she said. The movements in between release and recapture are not known, but "the point A and point B data still give us some idea; one particular strength of the NRCTP data is its sheer volume and the quantity of recaptures reported."

Another drawback to conventional tagging is that it is difficult to calculate the reporting rates accurately — it is highly influenced by when the fishing occurs, the timing and the location of the releases. Data from the closed areas are often underrepresented and the fish's time at large is highly variable as well. However, if the data are broken down into categories, some movement patterns start to emerge. Fish in the middle size categories (between 73-92 cm in length) tended to move the farthest from the release site (approximately 59 km), while the smallest (up to 53 cm) and largest (93 cm or larger) size categories of cod were recaptured closer to the release location. Georges Bank cod dispersed farther and more quickly than those from the inshore Gulf of Maine (GOM).

Many fish were recaptured in the same management area where they were released, and Tallack reiterated that she would refer to these fish as "residents" for the duration this presentation. In the GOM, approximately 83% of the tagged cod were residents, and their movements occurred on a

southwest axis along the coastline. For the cod recaptured in the GOM, some of them moved there from other management areas including Cape Cod.

There are ongoing analyses to determine the extent of cod homing patterns. When the data are broken down by season and release location, in autumn many of the cod moved back to the region where they were first caught and tagged. The middle size ranges of fish tended to display this homing behavior more strongly than other size classes. Tallack mentioned that there may not have been enough tagged fish in the larger size categories to show a pattern, and the smaller fish may not be mature enough to display homing behavior.

The data show certain "passages" of cod travel where the fish tend to concentrate their movements. For example, many of the fish tagged on Georges Bank moved across into the Bay of Fundy, indicating an interaction between stocks. GOM cod shuffled along the coast in a north-south movement, but mostly stayed within nearshore waters of the Gulf. Many fish tagged in Cape Cod waters stayed in that location for a number of months, though some fish moved southwards down the CT coastline during the colder months. Gradually these fish began to move with two distinct patterns: either northwards into the inshore GOM waters or eastwards into the offshore Georges Bank waters. "This divergence in movement patterns is probably this study's most surprising finding," Tallack said. What makes these cod decide which direction to take is unknown, but it could be due to geographic location or the timing of the tagging event.

These findings led to further questions about cod stocks. "Do cod movements support the current management boundaries?" Tallack asked. "There are two core assumptions when modeling stocks: (1) that the stocks existed in isolation and (2) that the stocks are self-sustaining. But this is obviously not the case for cod in the Gulf of Maine, which begs the question, if there is an exchange, how much is there and is it significant?" Determining the mixing rates was not one of the NRCTP's goals, but researchers are trying to address these questions by looking at the data in a different way.

In order to determine mixing rates, the relative biomass of cod in various areas needed to be examined in order to standardize or weight the tagging data relative to cod abundance by region. This was necessary since the NRCTP was not designed with the intention of quantifying and estimating mixing rates and if not weighted, the movements between regions may be over or under-represented by the actual data. As an extreme example, in the inshore Cape Cod region ~60,000 cod were released and yet the biomass estimates for this area are consistently low; thus, these cod might be considered "over-represented". In contrast, in other areas like Georges Bank, where abundance is fairly high, the relative number of tags released was much lower (~20,000). Another example is seen in the Canadian waters of eastern Georges Bank where cod abundance and fishing effort are reasonably high, and as such, there was a relatively high number of recaptures from other areas – however, because no tags were released in this area, the picture is not complete. "We need to take this imbalance in tag density between areas into account when we're determining the mixing rates," Tallack said. Overall, these imbalances required a data standardization process; so a weighting model was developed and applied to the NRCTP tagging data.

The goal was to apply a weighting model similar to one developed by Howell et al. that corrects for tag-induced mortality rate, tag shedding and catch/effort information. The model took the total number of tagged cod released, corrected for the number of lost tags (through an estimated tag-induced mortality rate and tag-shedding rate of 15%) and weighted the data by three indexes of biomass (survey, catch and VPA estimates) to estimate a weighted number of tag releases.

The number of recaptures was weighted first by a region-specific exploitation rate, then by a reporting rate to estimate the weighted number of tagged fish recaptures.

This weighting model was applied at various resolutions, including stock management areas (5Y, 5Z and 4X), the management areas with the transboundary area (Eastern Georges Bank) defined and at the Statistical Square resolution. However, since reporting rates were not achieved for all statistical squares (this requires both low-reward and high-reward tags being reported from all statistical squares) it was only possible to apply the weighting model to releases and recaptures in squares 513, 514, 521, 522, 467 and 466. "The study would have been improved if we had released more high reward tags," Tallack said, because that would have improved our estimates of reporting rates across more of the study region, in turn meaning that the mixing analysis would have been more successful when applied at the statistical square resolution.

Overall, there was a high rate of variation in the model results and it is still unclear which approach is best — i.e. which index of biomass to use between the survey, catch or VPA estimates. Since the amount of inter-annual variation was also high, it was decided that pooling the data for 2003-06 would be the best approach.

Tim Miller created a slightly different model – a finite-state continuous time approach to mixing analyses - in order to quantify movements between areas in a manner which does not require weighting. Miller's model provides probability estimates for movement, mortality (fishing and natural), reporting rate and tag shedding rate. "Tim's approach may help link tagging data to stock assessment models more readily through the calculation of an estimate of fishing mortality," Tallack said.

While the precise estimates of both models are not identical, both mixing model approaches indicate the core finding that for legal-sized fish (>53 cm/21") the strongest interaction is between Georges Bank (5Z) and the Bay of Fundy (4X), though some exchange is also seen between 5Z and 5Y. Very little exchange is seen between 4X and 5Y. When including the movements of sublegal-sized cod (released <53cm) the interaction between 5Z and 5Y is increased, which is in line with the divergent movement of small cod from the Cape Cod waters into the Gulf of Maine. Based on these results, she posed the question: "At what point is the estimate of cod movements significant enough to change the management regions?"

Moving on to a different portion of the program objectives, she discussed the growth analyses for tagged cod. The GROTAG technique has been used to date to analyze these data, but ongoing analysis with Nathan Taylor (University of British Columbia) takes the growth analyses a step further to incorporate gear selectivity and historical landings to minimize associated biases in the data. The growth estimates from the tagging data were also compared to estimates from non-linear methods on length-at-age data.

Tallack noted that the size structure and sample sizes of cod will impact the growth rates assessed; fish that are smaller at release will exhibit larger growth increments than larger fish. As such, it is important to represent the size-structure of the actual population as fully as possible. "This is not rocket science, and the results largely reflect what we anticipated," she said. For example, a fish 40 cm in length would likely exhibit a higher growth rate than a 100 cm fish that is closer to its maximum size.

Growth was assessed by management area. The 5Z management area indicated a faster growth rate than that for the 5Y and 4X areas. Cod in the 5Y (and inshore GOM) areas tend to grow slower but reach the largest sizes. One item to note is that the cod in Georges Bank and Cape Cod showed very different growth patterns to one another, probably due to the differences in fish

sizes sampled in each area, but both locations in combination represent 5Z. This may mean that the growth estimate for 5Z is less reliable, though the overall estimate is still closely aligned with length-at-age estimates from historical data. Similarly, the 5Y GROTAG estimates fall within the range of historical length-at-age estimates. Estimates for 5Y, 5Z and 4X are widely consistent with estimates from 2003-2006 length-at-age data.

The GROTAG model is also useful for projecting how growth rates may change as a function of migration and thus, exposure to different temperature and feeding environments. The young cod from the Cape Cod area were used as an example, with a hypothesized migration at size 60cm to either Georges Bank or inshore Gulf of Maine, where two dramatically different growth rates and asymptotic sizes were estimated. Split growth trajectories were then calculated based on a combination of growth estimates for the Cape Cod area, the inshore GOM area and the offshore GB area.

Ancillary growth studies were also presented. When comparing single-tagged with double-tagged cod, the double-tagged cod seem to have been affected by the extra tag, showing a lower asymptotic size and slightly fast rate of growth – this finding could also be due to slight differences in the size structure of single-tagged versus double-tagged fish. However, if the insertion of a tag does impact growth, it leads to some doubt about the impacts of even a single tag on cod growth, and thus whether tagging studies should be used to assess fish growth. It is possible the mean growth per year is altered by the presence of a tag.

It was also shown that measurements taken by fishermen tended to be significantly more variable than the measurements taken by scientists. However, this last point may not be a problem for all tagging-related questions (just growth) because the precise fish size may not be necessary for all study objectives, e.g. movement.

The data collected from the NRCTP have also been looked at as ancillary information on the effectiveness of areas impacted by permanent or rolling closures – it was however reiterated that this study was not designed to assess closed areas and thus, this is purely opportunistic analyses. Approximately 20,000 cod were released in closed areas and 94,000 were released in open areas. Some of the tagged fish were recaptured on the same tagging trip, so the residency estimates may be artificially inflated. Looking at the movements of both spawning and non-spawning cod recaptures pooled by month, Tallack has been able to demonstrate how the rolling closures correspond to the spawning cod observed in this study. Overall, spawning appears to be protracted, occurring in each month of the year and across many fishing grounds in the GOM; thus, while some closures apparently do offer a refuge for some spawning cod, they do not protect all spawning cod.

Looking at the overall program, Tallack noted that it has achieved its goal of obtaining a 'snapshot' of region-wide cod movement for an intensive two-year tagging effort. The program has far exceeded its planned achievements, but gaps in the data still exist. These might be partially filled by re-analyzing the combined datasets from 2000-2009 to see how the cod movements fit in with the long-term picture. Although funding for this program is drawing to a close, it is important to keep thoughts in mind for potential future studies. If more funding becomes available, would it be better to conduct tagging on a region-wide basis or focused on a specific area, targeting a specific question? Equally, would it be best to continue with conventional tagging efforts or use electronic technologies instead?

There is a need to continue with further analyses, including: cod movements and growth relative to the physical environment, such as bathymetry, water temperature and salinity; investigate

homing patterns; additional growth estimates; and analysis of historical datasets. Tallack suggested improvements such as: increasing the reporting rates by using more high-return tags; designing the program with more specific end goals in mind rather than trying to fit the data to unintended applications later; collecting genetic and ancillary data such as fish morphometrics; and collect bottom water temperatures at the time of tagged cod release.

Post-presentation discussion:

David Goethel: In the Eastern and WGOM seem to do different things, but those two areas are considered the same. The region encompassing the Bay of Fundy and Nova Scotia is way too large; some of these management areas need to be split into at least two separate stocks in order to be more effective.

David Goethel thinks that the smaller cod in Cape Cod are more stationary because their food source is stationary. Once the cod grow larger, they begin eating food that moves around a lot more and therefore the cod must move to chase their prey. He noted that inter-annual variation in cod movements is common. In most areas, their movement patterns seem to change each year, except for in the WGOM where the cod return almost the same time each year to spawn.

Steve Cadrin noted that GOM cod may have more variable growth rates than those in Georges Bank. Is this because GOM cod include several behavioral groups, some of which grow more slowly? Highly mobile groups often grow faster, and resident groups typically grow slower. Coincidentally, the GOM cod are currently more productive than those on Georges Bank. He does not believe it is as simple as cod in one area grow faster than in a different area.

Don Clark also noted that in the last 10 years, survey data from Georges Bank showed no cod above 100 cm, while fish from years ago were much larger. Does that mean the productivity in Georges Bank is lower now than it used to be?

David Goethel responded by saying that he and Hunt Howell have been working in the WGOM for years now. Originally, the fish they tagged were on average ~90 cm about 10 years ago. Each year, as they followed the fish, the average size kept getting bigger (up to ~150 cm) until two years ago. Last year, that trend dropped off dramatically, and Goethel thinks it is due to mortality that finally took its toll on the larger size classes.

Ted Ames added that the Eastern and WGOM have very different species dynamics. He believes the lack of spawning herring in mid-coast Maine had a dramatic impact on the cod populations there.

Eric Hesse noted that the climate and physical oceanographic components should be studied more closely to see if those issues are impacting the fishery. He said he has fished in Nantucket Shoals for years, and the cod fishery had been a staple there for the last 40 years. However, in the last five or six years, the fishery has almost disappeared. The time period during the NRCTP captured a snapshot in time just after the fishery disappeared, along with that of bluefin tuna. He believes there might be an environmental component involved in this change.

Shelly Tallack noted that the NRCTP study is indeed limited to a snapshot of 2003-2009, and so it will miss some of the trends and numbers that might occur in different time-frames and this limitation needs to be kept in mind when forming conclusions.

Jon Grabowski agreed with this, noting that the major fishery keeps changing and moving around in all the areas. The large management areas have several components that follow

different spawning routes, so the results from the program are only applicable for the time period that the study took place.

Ted Ames said there is a strong need for smaller management units in order to get fine-scale ecological detail. He said that there has been a recent recovery of the alewife runs in Penobscot Bay. About five years after this recovery, fishermen began catching juvenile cod. A few years after that, they began catching larger sized cod. He does not know for sure if there is a linkage for those trends, but believes the presence of cod might be due to the rebuilding of a forage base in that area.

Graham Sherwood also noted the importance of forage fish. A lack of nearshore forage for cod has left only remnant coastal populations in many areas. The cod migration rates may change based primarily on the availability of forage. If alewives come back, then the cod will likely come back.

Adrienne Kovach said there is a hole in the DNA samples for spawning cod in Downeast Maine. She also noted that growth rates might be interpreted more meaningfully in light of the genetic data. The WGOM fish are unique, particularly those that spawn in the spring, she said. Certain genetic markers might be linked to growth, salinity, temperature, but at this point it is not understood just how the physical environment influences the genetic structure. The timing of these different spawning groups should be examined in more detail once genetic data becomes available.

III) Presentation: David Martins and Jon Loehrke - "SMAST tagging review and update"

There were three phases to the cod tagging research conducted by SMAST from UMass-Dartmouth. Phase I ran from Aug. 2000 to 2003, and it was a voluntary tagging effort for cod in the Western Gulf of Maine (WGOM). Approximately 21,000 tagged cod were released in the inshore and offshore WGOM, Stellwagen Bank Marine Sanctuary and Ipswich Bay. Although this first phase was not considered to be as successful due to few fish tagged, Martins noted that it still resulted in important feedback — dedicated tagging trips using chartered boats tend to work out better than volunteers if the objective is to tag many fish in a short amount of time. In addition, fishermen who were paid $2 for each cod they tagged were more likely to help tag fish.

The recapture rate for Phase I was approximately 4%, which is consistent with other programs of this type. Of the cod that were tagged and released in Stellwagen Bank Marine Sanctuary, approximately 57% were recaptured in the sanctuary and 43% moved out of the sanctuary. Further analysis is required to examine if the fish that were recaptured within the sanctuary tended to be smaller in size, or if the cod that moved out of the sanctuary were generally larger.

Some of the cod were fitted with data storage tags (DSTs) to record water temperature and depth. The DSTs allowed researchers to get more information than just the locations of release and recapture. "A line between point A and B is not representative of the entire cod movements," Martins said. The FVCOM (Finite Volume Coastal Ocean Model) calculated tidal height and helped match the data to that recorded from the DSTs to determine where the fish were located.

Researchers wanted to test the hypothesis that large cod traveled further than small cod. The data were used to calculate a linear regression, which yielded a highly significant relationship. Although there was a low r-squared value, indicating that the points did not fit the line very well, the LOESS smoothing function helped dampen the data variability. Based on these calculations,

there was an increasing trend in distance traveled with increasing fish length. Cod that were less than 54 cm had a much smaller range of movement than those above 54 cm. This movement pattern may have been spurred on by the onset of sexual maturity or spawning, Martins speculated.

The data were presented as whisker plots and bag plots as well, each time showing the same results: as fish length increases, the distance traveled increased. "Think of this pattern in terms of closed areas," Martins said. "What would closed areas accomplish for cod if they are moving in and out of them easily?" Closed areas may be more effective at protecting juvenile cod that do not travel as far, he added.

Phase II of SMAST cod tagging was their contribution to the NRCTP, which occurred in 2003-04, complemented the Phase I tag and release efforts . Approximately 18 cruises were conducted to assist in these efforts. Based on the release and recapture data from the T-bar tags, cod moved back and forth in Georges Bank, although a small percentage moved into the Bay of Fundy. Fish released in Cape Cod moved up into the GOM, and those released in the GOM moved alongshore. Cod tagged in closed area I (CA I) seemed to have an affinity with the Stellwagen Bank Marine Sanctuary and Great South Channel, while cod recaptured in CA I mostly came from eastern Georges Bank. There was a large concentration of cod tagged in CA II in spawning condition, and their post-spawning dispersals showed movement in an easterly direction. Tony Wood will apply the release and recapture data to the Brownie model for further analyses.

Phase III of the project occurred in 2005-08 and took into account cod genetic stocks in addition to their movements. Approximately 4,000 tagged cod were released and 216 were recaptured. Similar to previous tagging efforts, most of the cod tagged in the WGOM were recaptured there. Martins focused on the data from spawning cod, and noted that a few moved out into Ipswich Bay and Jeffreys Ledge. When the movement data were broken down by year, there were slightly different patterns that emerged. In 2005-06, cod did not display much movement out of the area where they were released. In 2007, those that were released offshore moved towards Ipswich Bay, Cape Ann and out towards the northeast.

In 2007-08, researchers targeted a more southern group of cod near Cox's Ledge. Most of the tagged cod stayed there, although one was recaptured near Jeffreys Ledge. Cod tagged near Nantucket Shoals generally stayed there, but some moved into the GOM and Stellwagen Bank areas.

Martins noted that one male spawned in two locations: WGOM/Great South Channel and the Stellwagen Bank. The fish, he said, traveled four nautical miles/day in order to spawn in both locations. This highlights the connection between the Stellwagen Bank Marine Sanctuary and the WGOM/Great South Channel areas. Based on data from the DSTs, some spawning cod moved off into deeper waters in the spring and were recaptured back on Cox's Ledge in the fall. [David Goethel noted that cod exhibit diel movements in the water column, which may have been recorded on the DSTs].

The 2008-09 field season consisted of 15 days at sea. Approximately 500 conventional tags and 120 DSTs were deployed, and 200 genetic samples collected. Otolith samples were taken for future microchemistry analyses. Martins explained that otoliths can be used as a "natural" tag for fish. Using stable isotope signatures, researchers will be able to distinguish between winter and spring spawning cod in places like Ipswich Bay. This will help to determine the relative contribution of winter and spring spawners to the region, he said.

The DSTs released from this field season in Massachusetts Bay will be used to geolocate tagged cod. The previous data showed a low frequency but persistent connection between Stellwagen Bank Marine Sanctuary and Nantucket Shoals, as well as the western Georges Bank area. Data also showed the larger cod traveling much further and they exhibited natal homing and spawning site fidelity as well. Within the same group of cod there existed some residents and some highly migratory individuals. There was also some stock mixing of promiscuous males, he added.

Within-presentation discussion:

Graham Sherwood noted that data from his research, as well as that of Shelly Tallack, indicates that the largest sized cod actually do not travel very much. Cod start out eating benthic organisms, he said, and as they grow larger, they start to pursue forage fish that are highly migratory. At the point where they can consume these pelagic species, the cod are in the middle size category and exhibit highly migratory movement patterns. Once the cod grow to the largest sizes (>100 cm), they revert back to a more sedentary lifestyle. "I think that size-based difference in their movement patterns are based on food sources and energy budgets," Sherwood said, "not based on spawning habits." Tallack also noted that the SMAST study did not record many really large (>90 cm) cod, and as such, may not have observed the decline in dispersal seen in the NRCTP which recorded very large cod (mostly in the inshore WGOM area).

Don Clark noted that in his experience, 75 cm cod tend to migrate inshore and offshore, but the largest fish never go inshore; they simply move adjacent to offshore waters after spawning.

Adrienne Kovach said that it is important to relate the movements to the timing and specific location of spawning, because her research has found fine-scale temporal and spatial genetic differences. It would be useful to know if these genetic differences are related to different movement patterns as well.

David Goethel noted that the geographic boundaries of closed areas might be too small for most cod to remain inside. Smaller fish may benefit from the size of the closed areas, but they are not likely to retain the larger spawning cod. "The WGOM was established as a juvenile grow-out area, and it fit that bill very well," Goethel said. CA I and II helped to improve the haddock populations, but he said he does not think they have helped as much for cod populations.

Presentation resumes (Jon Loehrke):

Jon Loehrke continued with the presentation of his graduate research involving the movement patterns of cod spawning groups in New England. The goal of the project, he said, was to tease out the population processes occurring in the northeast. A paper by Templeman (1962) hypothesized that there are biological home ranges that separate cod into groups by areas based on fishermen's observations. "There is a diverse mix of cod populations but we don't know if it's driven by food, natal homing, or something else," Loehrke said.

The project's main hypothesis was to determine if there are patterns in the movements of individual spawning groups of cod. A few important aspects of cod behavior needed to be addressed first. Do all cod move to the same place, or is there random distribution in their movements? Do all spawning groups behave in the same way, or are there different preferences for habitat, food choices, and other similar items?

Although data from all three phases of SMAST cod tagging were used, the likelihood of observing a spawning cod was relatively low. Loehrke said he had to change techniques slightly

to account for this. He took the data and assigned the fish into designated spawning groups based on the area and month of their release. A pro-rated relative exploitation rate was applied to the recaptures and plotted in bag plots and bi-variate data ellipses to determine patterns of movement. A T-test using longitude and latitude and a Hotelling's two-sample test were also used to compare their spatial movements.

Loehrke broke the data down by recaptures of each designated spawning group. Winter and spring spawners from the WGOM shifted out to Jeffreys Ledge. Cod that are winter spawners in Mass Bay mostly stayed inshore and did not move very far. When a weighting factor was applied, the distribution of cod from Georges Bank shifted up to the Scotian Shelf. He noted that the weighted ellipses for the recaptures were not robust descriptions of the recaptures because outliers impact its shape. If one fish is recaptured much farther away than the other fish, the entire ellipse shape changes, and thus it may result in inaccurate predictions of cod movement.

Using plots called cyclic splines, observations of fish at large for one year indicated that many cod returned to the place they were tagged during spawning periods; however, it is unclear if this return was due to spawning or foraging behaviors. The various models predict that cod tagged in Ipswich Bay will move back into the bay during spawning periods but not many will do so the rest of the year. The spline for Georges Bank predicted a large number of cod recaptures right after the release event. "This is probably not a trend of homing so much as a trend due to the tagging event because fish didn't have time to distribute out of the area," Loehrke said. Using a weighting factor for the data indicates that fish distribution moved more towards the Scotian Shelf and Bay of Fundy regions, he added.

In general, all the designated spawning groups have significantly different recapture distributions. Pro-rated weighting factors applied to the data greatly impact the anticipated distribution of recaptures. However, each cod group appears to have unique homing patterns. Natal homing was noted in previous field studies, but it was difficult to document that behavior using the techniques from this project. Many cod moved long distances but only after a large amount of time after release. In addition, some fish exhibited seasonal movement patterns, although some did not. Loehrke reiterated the need for focused tagging efforts in the future, along with the importance of collecting environmental and oceanographic data to augment the study.

Post-presentation discussion continued:

David Goethel pointed out that the reason there were no tagged cod recaptured in Ipswich Bay in the winter is because fish don't spend time there during that season. Cod movements are often driven by water temperatures, he said, so large freshwater events from fall storms cause the cod to move offshore for the winter. Steve Cadrin wondered if the fishing effort was uniform among all seasons, because if there is lower effort in the winter, then it will impact the number of recaptured cod during that time period.

Goethel also addressed the problems with the use of weighted ellipses to determine a range of potential cod movements. If there is an outlier fish, perhaps one that moved down the coast to New Jersey, it will definitely impact the ellipse. He noted that data from outlier fish need to be excluded or filtered so there is less distortion in the ellipses estimates.

Don Clark noted that low fishing effort doesn't always mean low exploitation rates, but rather it depends on the concentration of fish in an area. "Not all effort is the same, that's the main problem with using a weighting factor," he said.

Some discussion was brought forth regarding the limitations of T-bar/conventional tags to provide only a start and end location with no detail in between. Shelly Tallack cautioned that the bagplots give a strong visual which may be misleading. For example, there were two cod which were tagged in Cape Cod and were recaptured two years later in the Bay of Fundy. It is likely that as these cod grew, they moved out onto Georges Bank (maybe ~1 year after being tagged), and then moved with the larger offshore cod up into the Bay of Fundy. There is no way of obtaining that detailed movement information using a traditional T-bar tag, but the bagplot visualization forces this movement into an ellipse which then makes it look as if these fish moved northwards along the inshore coastline, which seems less likely based on the primary migration routes discussed earlier.

It was mentioned that many of the conventional tags are reported by fish processors. He suggested that some of the data reporting might be incorrect. For example, if most of the fish coming in to the processing plant on one day were from Georges Bank, but a few fish came in from Digby, it's possible that the processor will group all the tagged fish as coming from Georges Bank and neglect other areas. Shelly Tallack responded that the accuracy of the recapture locations reported by Canadian processing plants is considered reasonable, since it has been possible for DFO (i.e. Don Clark) to verify/confirm the fishing location (i.e. statistical square) for each vessel which lands fish to the processors.

David Goethel noted that in the WGOM, numerous fish species utilize the same grounds at different times of year. Cod might use the habitat in the spring, while pollock might move on those grounds during the fall, and therefore it is possible that there is some level of interaction between stocks. It is also possible, he said, that cod from Ipswich Bay might move to Georges Bank and assimilate into that new cod stock. Steve Cadrin agreed and noted that some European studies have hypothesized that cod can be entrained behaviorally to a different stock of cod.

IV) Presentation: Laughlin Siceloff - "Vertical activity and fine-scale distribution of cod in the Ipswich Bay spawning ground."

This project was slightly different than the NRCTP in that it was a very localized tagging study. Researchers were interested specifically in Ipswich Bay, an area just south of the Isles of Shoals closed to commercial fishing during the spawning period (April – June). Hunt Howell previously conducted a mark-recapture study from 2001 – 2003. He began by describing the general findings of the mark-recapture tagging. Cod assembled in Scantum Bay in April, moved inshore to Ipswich Bay for the peak spawning period in May and dispersed in June. There was some evidence that cod were exhibiting homing behaviors for spawning purposes, but Siceloff wanted to examine the fish's fine-scale movements.

Using DSTs and acoustic telemetry, he wanted to characterize cod spawning behaviors, precisely track individual spawning movements, and to see if cod interact with different types of habitats. He tagged 200 post-spawning adults with DSTs to record water depth and temperature from April through October 2006. Of those fish, 26 were also implanted with acoustic transmitters which he tracked in May and June. Those fish were relocated using hand-held hydrophones on commercial fishing vessels for 47 tracking days. Passive relocation occurred using stationary Vemco VR2 receivers that had a 650 m detection range surrounding each one. The manual tracking located most of the cod within a 60 km^2 area in approximately 60-90 m depth.

The northern border of the study area is locally known as "Whaleback," a series of raised features or "humps" that raise up to 50 km in the water column. This was a focal region for

spawning cod, and they aggregated alongside Whaleback for spawning. Cod moved off into deeper waters south in early May during intense storms but assembled on Whaleback by mid-May. From mid-May through June, most of the cod moved east and west along Whaleback, and approximately 80% of them spent several days at a "hot spot" on the west end hump. Siceloff noted that the individual activity centers for cod seem to be ~ four km² in size and in the same general area while they were on the spawning grounds. They were contained within a corridor bounded by elevated bathymetric features, their activity was concentrated alongside vertical relief. The cod departures from the region were staggered in May and June, and some made a rapid movement off the spawning grounds towards the southeast. The DSTs were deployed on fish 19-757 days at large. Fish traveled up to 171 km from the release site, although most stayed within 80 km. The four major areas where cod were recaptured in 2007-08 were Ipswich Bay, east of Scantum Basin on Jeffreys Ledge, the slope of Stellwagen Bank Marine Sanctuary, and Bigelow Bight offshore from Saco Bay.

Depth profiles from the DSTs showed that cod stayed in the shallow waters of Ipswich Bay in late May and shifted into deeper water by June. They exhibited very little vertical movement and diel patterns during the spawning period in the bay, with their daily vertical range limited to the 15 m closest to the bottom. However, cod began strong diel vertical migrations once they moved into deeper waters. On the slopes of Jeffreys Ledge and Stellwagen Bank, many cod were sedentary and motionless during the day, and active during the night.

In summary, Siceloff noted that spawning cod aggregate around small bathymetric features, such as the humps of the whaleback, which may serve as critical habitat for cod. There seem to be small activity centers or hot spots during spawning, and the cod stay within a certain home range at that time. Their spawning behaviors were characterized by narrow vertical migrations and weak temporal patterns. Once fish move out of Ipswich Bay, there is an increase in their vertical migration patterns, although there are some sedentary periods as well. Data from telemetry and DSTs indicates that cod staggered their departures from the spawning grounds, although their post-spawning dispersal was mostly contained within the WGOM. Lastly, he noted that some site-specific vertical behaviors, such as foraging in the water column, may affect the cod's vulnerability to groundfishing gear.

Post-presentation discussion:

Steve Cadrin asked if the fish were feeding during the spawning period. Laughlin Siceloff said that party boat fishermen were pulling up a lot of spawning fish. He said he thinks some fish eat during spawning, while others do not, but some fish might eat on their way to the spawning grounds. He would like to examine stomach contents in the future to learn more about this issue. Cadrin said he thinks there is a lot of individual variability where some fish may be feeding opportunistically, or certain stock groups may feed while others do not. "Winter spawners in Ipswich Bay traditionally do not feed, but the spring spawners might," he said.

Graham Sherwood noted that seasonal bioenergetics may play a part in this issue. Winter spawners might bulk up on pelagic prey and then enter into a non-feeding stage. Don Clark said that very cold water, fish might not feed because they are unable to digest food as well.

Laughlin Siceloff reiterated that there was no evidence of fish located on top of the raised features of the whaleback, but fish were located next to it, and that he was confident in his estimate of their home range distribution.

David Goethel said there has been a noticeable change in diet for fish in Ipswich Bay since 20 years ago when the rolling closure began. He believes the closure helped to concentrate cod in that area, and they effectively ate everything else available to them because their numbers were so high. Regarding the cod caught from party boats, Goethel noted that many of those fishermen jig for cod and catch them by hooking the fish on the head or on their side rather than in their mouth. "The fish aren't actually feeding, they are just lashing out at the jig," he said.

With regards to determining where to place the stationary Vemco receivers, Goethel said when he worked with Hunt Howell that they placed the receivers at "choke points" where the fish were likely to move past, including up and down old river beds at the bottom. When there are not enough receivers to make an entire grid, it can still be an effective study if you place the few receivers you have at strategic locations to capture the movement data, he said. "That is a true testament to traditional ecological knowledge," said Steve Cadrin, "it shows the predictability of fish behavior."

Shelly Tallack noted that using Vemco receivers and acoustic technologies might be very beneficial for areas currently struggling to find the cod, such as Downeast Maine (due to significantly reduced fishing effort in recent years).

Eric Hesse said that this project was an endorsement for rolling closures and their benefit for spawning cod. "Fishing pressure disrupts their spawning behaviors, and the closure coincides with their spawning," he said. "The timing might be a little off from year to year, but it seems to catch most of them." He asked why fish might hang around the whaleback, are they trying to conserve energy during spawning by choosing that particular site? Siceloff said he is not sure; it could be an adaptive place to spawn because it is good for larval survival, or it might be an optimal location for feeding or something else entirely. Ted Ames followed up by saying that he was impressed by this information exchange. "Fishermen's knowledge seems to coincide well with scientific knowledge," he said.

v) Presentation: Shelly Tallack, presenting for James Lindholm, Peter Auster and Ashley Knight - "Habitat-mediated movement of Atlantic cod and other demersal fishes in the WGOM"

The goal of the first project was to understand how fish movement is mediated by topographic features and substrate types on the bottom of the ocean in the Western Gulf of Maine. The first substrate type was low-relief gravel, and 38 cod were fitted with acoustic tags. Four receivers were deployed in a 2x2 grid; each receiver had a range of 0.5 km^2, thus, the grid was capable of detecting fish over a ~1 km^2 area. The study was conducted for 95 days from May through September of 2001. Three of four receivers were lost: approximately 40% of all tagged cod were recorded at the one remaining receiver. Approximately 1/3 of the fish exhibited high site fidelity in the low relief gravel habitats, while 2/3 exhibited low site fidelity.

A second study examined the movements of cod in areas of deep boulder relief, and 65 cod were fitted with acoustic tags. The study was also conducted for 95 days in May through September 2004 using a four-receiver array, this time set individually on specific boulder outcrops. No clear patterns emerged from fish movements with regards to season, fish length, or boulder size, but 35% of all fish were recorded in more than 80% of each 1-hour time bin, suggesting high fidelity to boulder habitat in these fish.

The results from this study suggest that relatively small marine reserves, if sited appropriately relative to specific habitat features, could provide protection to 30-40% of cod in the study area.

This conclusion was drawn because there was strong evidence of habitat-mediated cod movements in both the low-relief gravel and deep boulder relief habitats. However, researchers also found significant variation in the movement behavior among conspecifics in the study area. Tallack urged the attendees to follow up on this research and learn more by reading the journal articles that accompany the project.

Post-presentation discussion:

Don Clark said that his graduate work involved some acoustic tagging of fish in New England waters, although the species he worked with did not move as far away as cod tend to move. However, through the use of acoustic technologies, he observed diel behavioral differences in smaller sized fish near the Bay of Fundy. The receivers were placed in a line across the bay to catch any fish that moved out after being tagged. Many of the tagged fish were juveniles that tended to stick close to the area so they were easy to track. However, without the large scale array he had access to at the time, it would have been unlikely to track their movements in the bay. "These studies are great if everything works out, but it's often just the luck of the draw," he said.

Jon Loehrke noted that additional long-term studies are needed to learn more about cod movement in different habitat types. David Goethel said that fish size makes a big difference in terms of habitat preference; small cod are more closely associated with complex habitat, while "big fish rule the world, so they don't care." He also said that there is a hump in that study region that is full of cod from April through June, but "it's just a rock the rest of the year."

Given all these data, Goethel said there is still a need for rolling closures, but they may need to be adjusted for a slightly different time period. "The fish need to be left alone to spawn," he said. Before government stepped in to regulate these closures, he said fishermen were often self-regulated because of their own social structure. Tightly knit fishing communities and families would not fish at night because if they did, there would be no fish to catch for a few years afterwards. Fishing for spawning cod at night would break up their spawning success. The fishermen might not have known why they shouldn't fish at night, but they knew it was detrimental to the future of the fishery, and they knew how to keep the fishery self-sustaining.

VI) Presentation: Tim Miller - "Tag Reporting Rates"

The tag reporting rate from a research study is an essential piece of information for models. If the reporting rates are assumed incorrectly or if they are not considered at all, it can lead to biased estimates of fishing mortality, natural mortality and migration rates. Tag shedding could occur or fishermen may accidentally overlook the tags, and either scenario adds to the inaccuracies in estimates. An accurate tag reporting rate will help provide more accurate model outputs, to the benefit of cod management.

Miller said there are a few different approaches to dealing with the problems involved with the tag reporting rate. First, the rate can be assumed to be 100%; however, this is never the case and essentially ignores the problem. The second option, using reward tags with some proportion of the releases, may be helpful to increase the number of tags reported. Tags are not always reported because fishermen may not know they have a reward, or perhaps the reward is not large enough to make it worth their while. Sometimes fishermen do not have time to search for tags if they haul up a net full of fish.

A slightly different approach to deal with tag reporting problems could be to plant a known number of tags in commercial catches to get a better estimate. "It might be difficult to plant tags without affecting the reporting behavior of the fishermen," Miller acknowledged. "You must ensure the component where tags are planted is representative of the rest of the effort."

An observer present on a commercial fleet might help to improve the reporting rate, but that is only if they observe all the catch — and this is not always the case. The observer component must also be representative of the rest of the fishing fleet, Miller said. One last approach he suggested would be to use reward tags with various values, although it is difficult to calculate how much money will be paid out. Previous data from reward values versus reporting rate can be plotted and fitted with a curve to determine the best reward values to use for the project purpose.

There are some aspects of the project design to consider when estimating the reporting rate, including: the number of reward value categories; the number of tags released in each category; the number of release groups; the length of time elapsed prior to analysis; and the fishing and natural mortality rates. It is possible that the reporting rate for non-reward tags may change during the time period when reward tags are used. It may be difficult to know what number of releases at each reward value will be sufficient to get a good reporting rate. Miller said the relationship of the reporting rate to tag value will change over time due to inflation, and some fisheries may have higher reporting rates due to their market value.

In summary, he said that previous analyses on cod tagging data assumed a 100% reporting rate for the high reward tags. This caused the mortality rates to be inaccurate, and he emphasized the importance of tag reporting rates in order to get reliable model outputs.

VII) Presentation: Shelly Tallack –" Results from the NRCTP questionnaire"

Participants at the 2004 Mark-Recapture Workshop spent a lot of time discussing tagging studies reward schemes, the drawbacks of different reward schemes and the types of incentives which should be considered when designing a tagging study. There was also much discussion on what factors influenced reporting rates and also the impact of individual tagging studies on each other, for example, if one tagging study does not respond to tag returners well, there can be a ripple-effect on other tagging studies in the region. As such, this study has remained conscientious about retaining an effective outreach infrastructure, particularly in light of how many tags were released for this program.

Shelly Tallack mentioned that a mini-questionnaire was sent out after the 2004 workshop to assess whether or not fishermen knew about the high reward tags and to determine if there was a difference in reporting rates between the low and high reward tags.

During the winter 2008 mass-mailing, GMRI included a second, more lengthy questionnaire to obtain feedback from industry participants about their general perception of the NRCTP, to learn what has worked and where this program could have performed better in terms of outreach and dissemination of information. The questionnaire also investigated reporting behaviors, tag visibility, people's preferences for reward schemes and what motivates people to report the tags.

Those who reported tags were mostly Canadian fish processors (no processors from the U.S. responded) and commercial and recreational fishermen. Many had previously reported tags and they noted that yellow is the tag color that is the easiest to see, followed closely by orange. Most respondents felt that the rewards made it worthwhile to report the tags. Responses indicated a

generally high level (75-85%) of satisfaction with the amount and type of information provided regarding the tagging efforts, through newsletters, mass-mailings and tag-recapture reports.

Regarding their motivation for reporting the tags, many respondents said it was to help science and the fishery, while others noted the reward was the main reason they reported tags. However, processors noted that a more valuable reward would increase their likelihood of tag reporting.

One interesting — albeit predictable — trend was that very few people answered the question asking for the locations of the respondent's predominant fishing areas. One individual specifically wrote "I don't want to show where I'm fishing," for a reason for the lack of response.

Tallack noted that it is often difficult to scientifically quantify human behavior, and this type of questionnaire was GMRI's attempt to do so.

VIII) Presentation: Graham Sherwood - "Potential ecotypes in cod: implications for management and recovery"

Migrant cod may be the key to rebuilding cod stocks in the northwest Atlantic, yet many traditional migration corridors may no longer be functioning as completely as they did prior to wide-scale cod stock collapses in the late 1980's and early 1990's. A study published in Nature (Rose 1993) noted a large-scale migration highway for Atlantic cod in Newfoundland; tagging and acoustic data indicated that these cod moved in a clockwise rotation around the northern Grand Banks. Cod overwintered offshore, moved inshore in the spring along the northeast coast of Newfoundland, and continued this circular motion over hundreds of kilometers, most likely following their preferred prey, capelin. This migration highway is largely non-existent today, perhaps as a result of overfishing and/or a decline in capelin. As a result, the majority of cod in Newfoundland are now more local to inshore areas and may in fact be considered residents. A similar breakdown in migration routes in the Gulf of Maine (inshore spawning migrations) may also be impeding the recovery of cod from inshore eastern Maine and this too may have a forage fish component with alewife and herring potentially limiting in the nearshore. Given the potential importance of migrants, it becomes imperative to examine this particular life-history strategy and how it may differ from another approach (i.e. the resident strategy).

Ecotype variation is common in fish. However, the majority of comparisons of migrant versus resident life-history variants are done on freshwater and diadromous fish which are easier to observe in their movements than fully marine fish. A good example of the migrant/resident dichotomy is Lake Superior coaster brook trout. This migrant form of brook trout historically left the rivers to get large in coastal Lake Superior, but due to a combination of habitat degradation, pollution, overfishing and introduction of exotic species, this ecotype is no longer represented in the majority of Lake Superior tributaries, whereas the resident stream dwelling form is still largely ubiquitous. In Maine, the sea run (migrant) and stream dwelling (resident) brook trout are examples of the same type of life-history variation. At spawning age, migrant sea run brook trout are much bigger than the resident stream dwelling brook trout; perhaps 1-3 lbs versus 0.5 lb, respectively.

Some have speculated that there is a bioenergetic basis for why some fish migrate and others do not (e.g., Morinville & Rasmussen 2003). Juvenile resident and migrant brook trout co-exist in the same streams, separated by habitat (migrants in the riffles and residents in the pools), thus there is indication of early differences in foraging. During their first year of life, both types grow at about the same rate. By the second year, the growth rate for migrants drops off even though

they feed at higher rates than residents. To continue growing the migrants need to leave the confines of the stream to search out areas with higher food availability (i.e., the ocean). Sherwood called them gluttons and noted that the resident types that stayed in the stream were able to budget their energy more efficiently and are thus better able to weather food shortages. From Morinville & Rasmussen (2003): "…a trade-off exists between the ability to efficiently exploit local environments (resident approach) and the capacity to capitalize from large-scale environmental heterogeneity (migrant approach)."

The Lake Superior brook trout and the northwest Atlantic cod populations are similar in that there are fewer migrants and this may explain the lack of rebuilding and low contemporary production from remaining residents which tend to grow less for brook trout. The question still remains, does similar ecotype variation exist in cod?

Following from this question, Sherwood then focused attention on previous studies from Newfoundland that found evidence for divergent life-history strategies in cod (i.e., ecotypes) based on stable isotope and telemetry data. During homing studies at Bar Haven, Placentia Bay on the south coast of Newfoundland (M. Windle & G. Rose, collaborators), tissue samples were taken at the time of acoustic tag insertion and analyzed for stable carbon isotopes which can differentiate between past feeding on pelagic versus benthic prey. Within the 50 cod that were tagged and released at Bar Haven, the entire range of feeding histories (strictly pelagic to strictly benthic), comparable to that seen throughout Newfoundland and Labrador, was represented. As such, cod were divided into two groups based on their feeding habits (pelagic versus benthic) and their movements were compared over the course of a year with the expectation that pelagic cod would vacate the spawning grounds after spawning and benthic cod would remain within close proximity to the spawning grounds year round. Interestingly, telemetry results indicated that the two types occupied different habitats on the spawning ground itself, with the migrants occupying more shoal waters next to the islands and the residents occupying a deeper trough in between the islands. Statistically, there was a significant difference in their depth preferences and geographic locations at the spawning site, Sherwood said. In addition, their evacuation rates were different; the migrants left the spawning site faster and sooner than the residents, as expected. Maturity rates for these cod were different as well — the residents matured earlier than the migrants. "The residents mature earlier in case there isn't enough prey to support their reproduction later; it's like a 'cash in your chips early' scenario" he said. "The migrants operate under the promise of food and growth later."

Studies have shown that a decrease in age at maturity for cod in Newfoundland (by ~ 1 year difference, Olsen et al. 2004) preceded fisheries collapse. This is thought to be a result of fishing induced selection for earlier maturing individuals (i.e., directional selection). The above results, particularly age at maturity being lower for residents, suggest that previous disruptive selection over evolutionary time scales may have set up a scenario where fishing could remove one type and precipitate what would look like very rapid evolution in cod. David Goethel noted that usually the larger cod are the more fecund ones, but this may not be the case for all Newfoundland cod. Sherwood said that a general trend of increasing fecundity with increasing size is accurate, but if the data are teased apart by ecotypes (e.g., by stable carbon isotope signatures as indicators of past feeding preferences) then differences become more apparent. "These two ecotypes may have diverged sometime in the past to take advantage of different food webs" he said. "It may well be that it's better to be at one extreme or the other [of the ecotype spectrum] and this could end up polarizing when, where and how much to mature."

Overall, the data from Newfoundland support the existence of feeding, movement and spawning ecotypes in cod. "Other than explaining recent changes in maturity for cod, this data may explain the recent breakdown in migration highways," Sherwood added since migrant cod may have been more vulnerable to offshore fishing fleets and inshore residents were likely never subject to overfishing. Future tagging studies may help to determine the relative frequency of migrants and residents which may be another indicator of cod stock recovery in addition to overall abundance.

From here, Sherwood turned his attention to the Gulf of Maine and red coloration as another possible example of ecotype variation in cod. Red cod are being sampled at Cashes Ledge Closed Area as part of a larger study to determine if Gulf of Maine and Georges Bank closed areas in general have the potential to alter life-histories in cod. Sherwood said that red cod may represent a separate [resident] ecotype of cod and thus provide the opportunity to study this topic in greater detail. Sherwood and colleague Jonathan Grabowski wanted to determine if the red color was due to a transient diet stage or if it was simply part of a different life history strategy. He ruled out the possibility that the color is ontogenetic, or part of a transient diet stage the cod go through, because there are red cod and normal-colored cod in the same size categories. It was hypothesized that red cod would have less streamlined body shapes and morphometric analysis indeed confirmed this; red cod have shorter heads and deeper bodies than normal colored cod. These differences are similar to those seen for resident brook trout (more robust) and their migrant counterparts (more streamlined).

It was hypothesized that red cod (assumed residents) would have more benthic diets. However, based on stable carbon isotope signatures, red cod appear to consume more pelagic prey. Sherwood explained that this probably has more to do with baseline carbon isotope differences than feeding differences. Ammen Rock, from where red cod were all sampled, represents a pinnacle or seamount in the Gulf of Maine (rising to within ~ 10 m depth 70 miles offshore) and may be bathed by pelagic productivity from surrounding waters such that all organisms (even benthic invertebrates) appear to be pelagic. Aside from being useful for diet determinations, if it can be shown that there is a distinct carbon signature at Ammen Rock, then this may be another means to trace residency in cod; in other words, cod would have to live and feed for extended periods of time on Ammen Rock to take on it's presumably distinct carbon signature. Sampling is planned for the summer of 2009 to determine to what degree carbon signatures are distinct at Ammen Rock and therefore useful for estimations of cod residency.

Parasite loads, specifically of the seal worm (per gram of cod filet), indicated that red cod have very few parasites as compared to normal cod. This could be further evidence of red cod residency at Cashes Ledge; as residents at this one offshore site, red cod may be cut off from the usual intermediate hosts for seal worm. In addition, red cod were found to exhibit a lower growth rate than normal cod with their maximum size not exceeding 60 cm. Given all these data, it is likely that red cod are indeed a distinct ecotype of cod with a very different life history strategy.

Overall, Sherwood noted that further tagging studies are needed to verify residency behavior of cod. In particular, red cod residency at Cashes Ledge could be determined by acoustic array technology. Further, red cod may be resident fish, but not all resident cod will be red in color. For example, resident cod in Newfoundland are not red. Thus, researchers must find other distinguishing factors to determine their residency status, such as the timing of spawning, diet or morphometrics. In addition, genetic studies may reveal that red cod (and other pockets of residents) have highly complex metapopulation structures since they may not intermingle as much as migrants.

There are certain implications for cod populations if there are two different ecotypes. Given the differences in feeding and movement strategies, any changes in spatial fishing pressure and food web structure may affect the ecotypes differently. This impact occurred in Lake Superior when the migrant coaster brook trout fishery was wiped out. It is possible, he added, that management regulations may be favoring resident ecotypes (with the creation of closed areas) and food web structures (due to the lack of forage fish) that then impedes the recovery of the migrant population. Further tagging studies should be an integral part of further scientific studies

Post-presentation discussion:

Lisa Kerr noted that if there is a common pool of larvae, then the conditions likely favor the resident type. "It might be more advantageous for the cod to be resident than migrant," she said. Sherwood said it is necessary to determine if the fish are impacted by fishing pressure or the food web. Once that is determined, it might be possible for the migrant cod to recolonize the inshore areas.

Steve Cadrin suggested that using fatty acids might be a better approach than stable isotopes to determine cod feeding habits. Sherwood said it would be interesting to know the pelagic signature of those areas to overlay the data collected and see if there are any patterns.

David Goethel said that in his experience in N.H., cod lose their residency and move offshore every year. Cod are abundant in June but there are no cod around in the winter. Sherwood said that for the red cod at Cashes Ledge, they remain right on top of Ammen Rock even in winter. He added that the cod can lose their red coloration if they leave the shelf, although it is still a relatively new research area. "There appears to be a resident lifestyle, but there is not tagging data to support that theory," he said, suggesting that an acoustic array on Cashes Ledge might be a good next step.

Jon Grabowski noted that based on oceanographic conditions, Cashes Ledge should be able to support cod year-round. The internal waves bring up nutrients necessary to primary production all year.

Ted Ames said he was surprised that the red cod parasitic worm loads were so low, because cod are traditionally loaded with them. Sherwood agreed and noted that cod on Cashes Ledge are their own entity and do not have many worms. He finished up by saying that there are other places to find red cod, such as on ledges just off Casco Bay, mid-coast Maine, and near Scituate, Mass.

IX) Presentation: Jon Grabowski - "Juvenile cod: closed areas and habitat"

It is known that young-of-the-year cod use seagrass as a refuge, but do larger juveniles use specific habitats? Grabowski's research used survey data from three trawls conducted between 1992-2006 by the Maine Department of Marine Resources (DMR) and other Maine-N.H. inshore trawl surveys near Cape Small. The habitat was delineated and classified as gravel, mud, cobble/ledge or sand. The gear used was a 20 m otter trawl with a 5 cm cod end. Tows were conducted for 20 minutes at a relatively slow speed of 2.4 knots. In general, the young-of-the-year cod were caught mostly in sand habitats and large juveniles (approximately one-year-old) were caught in gravel substrates. Very few adult cod were caught, and Grabowski said that might have been from trawl avoidance.

Most young-of-the-year cod were caught in water less than 20 m deep. The only habitat that was sampled in this depth range was sand substrates, so it was difficult to tell if the fish were in those areas because they chose sand substrates or the shallow water depths, he said. The young-of-the-year caught in water deeper than 20 m were more abundant in gravel substrates than in sand or mud.

Approximately 90% of the cod were caught in water with bottom temperatures between 4-10 degrees C, but were most abundant in 8-10 degree C water. There were no trawl surveys conducted in cobble/ledge habitat due to gear limitations.

Video footage and hook and line fishing efforts indicate that larger juveniles are found more often in cobble/edge habitat than the other three substrates. Based on the various sampling techniques, it appears that large juvenile cod do use specific habitats, Grabowski said, but it is unclear how that impacts overall cod productivity.

He then discussed the impact of closed areas on cod populations. Previous studies conducted on Cashes Ledge indicated a higher abundance of larger cod and pollock located there than closer inshore. The offshore fishery intensified in the early 1990s and Cashes Ledge was subsequently closed to mobile fishing gear. Grabowski's research questions included: Are cod still abundant on Cashes Ledge? Is the closure supporting a high abundance of cod? Which habitats are important to cod?

The first step was to build better habitat maps of the area. In 2006, multi-beam sonar was used to collect data on the substrates and habitat, and sampling efforts included video surveys to identify the habitat and fish abundance in those areas. Topography data were already available, so they collected multibeam data from the water column in order to classify habitats on Cashes Ledge such as kelp. Acoustic data showed that the kelp was abundant on the top and edges of Ammen Rock, but was almost non-existent at water depths greater than 30 m. The habitat zones on Cashes Ledge that were sampled with fishing gear include: Laminaria kelp, 5-15 m; shotgun kelp, 15-35 m; bare rock, 35-50 m; and mud/sand, 50-75 m.

Gill net surveys, hook and line fishing efforts and video footage indicated relatively low abundance of cod in Cashes Ledge in spring and fall, but there was a much higher abundance of spiny dogfish sharks instead during these seasons. Grabowski said there was a wave of cod that moved into the area in the summer, mostly caught in the shotgun kelp habitat. It is possible there are species interactions occurring between cod and dogfish, he said, with dogfish driving the cod out of Cashes Ledge at certain times of the year. "It begs the question, how effective is Cashes Ledge CA in light of these species interactions?" he said.

Overall, Grabowski noted that habitat maps are an essential tool for understanding cod population dynamics. The initial findings from this study indicate that groundfish are thriving on Cashes Ledge, but the results for cod populations are less clear. It is possible that dogfish may be impacting the effectiveness of the closure for cod. He noted that they established certain habitat zones for the research and have yet to take into account more fine-scale detail for substrates and habitat. However, even at this coarse level, certain patterns in cod abundance habitat preferences were obvious, as mentioned above.

Post-presentation discussion:

Hunt Howell asked if all the methods to estimate cod abundance were at the same level of magnitude. Grabowski said he did not work with absolute abundance, but that the abundance data from video footage and gill nets aligned closely with one another. Howell asked if

Grabowski could tell in the video if there were multiple fish or if it was the same fish swimming back and forth, and he answered that video data quantify visitation rates, so that one fish could make multiple passes.

Dave Martins wanted to know why sampling did not occur in the winter, and Grabowski said hook and line fishing did occur in the winter. Eric Hesse noted that using hook and line to estimate cod abundance is tricky because it has low effectiveness if the abundance is low. Grabowski agreed with this observation, stating that he didn't show abundance results from hook-and-line sampling for this and other reasons. For instance, Grabowski pointed out that the catch rates of other species may impact abundance rates from hook and line fishing.

David Goethel asked if Grabowski examined depth as a potential factor in cod abundance rather than simply habitat. "On Cashes Ledge, depth and habitat can't be teased apart," Grabowski answered, "so the effect we're seeing may be related to either habitat or depth, but we're not sure." Goethel noted that in other areas with the same habitat, depth seems to be the factor influencing cod abundance, particularly for juvenile cod. In the WGOM, cod that are less than one foot long are found in water less than 27 fathoms; only larger cod are found in water deeper than 27-30 fathoms. Grabowski noted that in the inshore study, when he did examine the effect of depth as a potential factor, it wasn't very important. In other words, when they were able to remove the biases of depth by comparing habitats sampled at similar depths, gravel habitat had consistently higher abundances of cod than mud or sand habitats. This work was conducted at depth shallower than 30 fathoms because it was focused on juvenile cod for the very reason that David pointed out.

x) Afternoon discussion on research recommendations

Shelly Tallack began the discussion by asking the attendees to identify where there are major gaps in tagging programs like the NRCTP and how they can be improved for subsequent studies.

The first issue discussed centered around reporting rates; rewards are still very important to maintain a good reporting rate. Don Clark noted that he had his own tag return study going using rewards and had a reporting rate of approximately 5%; when the NRCTP started, fishermen continued sending him the tags and the reporting rate increased to 15%. It is important to determine how to account for the reporting rate and the potential effects of reward schemes in new and existing studies.

Many attendees stressed the importance of outreach for tagging studies, particularly for education and outreach to occur prior to the beginning of the study. The presentations discussed in this workshop identified certain "highways" of cod movement, but researchers need to learn more about fish movement rates and the use of weighting models.

David Goethel noted that some areas would benefit from a second round of tagging efforts to learn more about the populations. He cited areas such as Mass Bay, Stellwagen Bank, Cashes Ledge, Cox's Ledge, northern Georges Bank and Ipswich Bay as potential places to retag cod. Tagging studies could also be improved by collecting genetic and oceanographic data to find out why certain areas are unique.

Methodology suggestions:

"We need to collect ancillary data as tagging is occurring," said Hunt Howell. Suggestions for additional information to collect included: genetics, isotope analysis, morphometrics/cod color,

bottom water temperatures, fish condition and parasite loading and identification. More rigorous testing for specific cod spawning condition is needed for future studies, and high reward tags should be used right from the beginning of future tagging studies to ensure higher reporting rates.

Juvenile cod studies:

Several suggestions were made with regards to future tagging studies that focus on juvenile cod. Don Clark said that tagging small fish will be very difficult because they will not be recaptured until they are 2-3 years old. This could impact reporting rates — for smaller cod tagged in Cape Cod, it took longer to get tagging returns because they needed to grow enough to be vulnerable to the gear. He also said it would be better to tag juveniles before they move for their spawning migrations. David Goethel said large juveniles could be caught if fishermen could use different gear; juveniles located in shallow water cannot be captured using traditional cod fishing gear. A few other issues need to be taken into account when designing a future study for juvenile cod, including habitat preferences, location where cod are recruiting to, and the seasonal and spatial distribution of tagging trips.

Spawning studies:

Future studies that focus on cod spawning could be improved in a variety of ways. Acoustic arrays and *in situ* "arenas" using hydrophones and video could be used to help detect spawning fish and to monitor their behaviors. There should be an investigation into how to best study spawning migrants versus spawning residents, as that may play a role during methodology design. There could be a correlation between spawning and feeding behaviors, along with the environmental constraints that determine the movements of spawning fish, so future studies should try to address these issues to tease apart the interactions. Any data collected from spawning studies should be put in the context of the overall oceanographic regime, including larval transport and the time of arrival to and departure from the spawning grounds. Shelly Tallack noted that it might be possible to mine the data already collected from some studies and compare it to the environmental cues for that area, but additional studies may need to be created that focus specifically on these questions.

Environmental data and cod movement:

Don Clark said that T-bar tagging studies represent a snapshot in time, so he is not sure that collecting environmental data would be very helpful. However, the rest of the group agreed there is a general need for improved collection of environmental data during tagging studies. Jim Churchill said there is a lot of oceanographic information out there that could help researchers understand cod movements and population dynamics. He pointed out that it might be helpful to work with a modeler to determine rates of larval transport and retention. Ted Ames noted that learning more about the environmental conditions of an area could help tease out the reasons why fish move in or out of an area. "This area of study is an incredible opportunity for fishery managers," he said.

Alternate technologies:

Discussion about using alternate technologies for future cod studies focused primarily on acoustic arrays. A large-scale array could be helpful in identifying more fine-scale movements. Now that some core migration routes have been identified, placing receivers near those areas

could be very useful. Jon Grabowski noted that if the goal is to refine knowledge about cod population structure, it might be beneficial to seek larger funding sources such as the Ocean Tracking Network. Eric Hesse said that there is a proposal to create a closed area near Cape Cod within a year. Graham Sherwood said that could be beneficial for tracking studies. "Closed areas are the best place to put acoustic receivers because they won't be constantly dragged up by fishing gear," he explained.

Socio-economic aspects:

Sometimes, the biggest benefits from a scientific study may come in the form of socio-economics. Studies such as the NRCTP have improved collaboration, where tagging fish enables fishermen and scientists to work together towards a common goal. The economic impact of tagging studies should not be overlooked; the funds used to charter vessels, hold workshops and pay for stipends are an important aspect of future tagging studies. If possible, quantification of the project successes should be measured at various stages, including during tagging, after tagging, outreach and educational events and workshops. It was noted that tagging studies help to trigger interest in the fishing industry and cooperative research in general. David Goethel noted that when people see a tag on a fish, it sometimes causes them to rethink their activities or to learn more about the management of the species. "This may be the biggest benefit we've gotten so far from this project," he said.

Multi-year tagging studies:

Shelly Tallack reiterated that the studies presented during this workshop have occurred between 2000-2009 and thus, just give a snap-shot of cod movements in this time-frame. If we were to tag in different decades when the fishery and stock looked different, we might come up with very different conclusions. As such, long-term tagging studies are necessary to fully understand cod movements and fluctuations in the population over time. Certain primary areas may be targeted for future multi-year studies, including eastern Georges Bank.

Ecological/biological studies:

Various ecological and biological data should be included in the design of future tagging studies. Migrant and resident ecotypes, such as the red cod in Cashes Ledge, might be an important piece of the puzzle. Cod preferences for habitat and food, along with feeding frequency, should be examined more closely. More information is necessary regarding species interactions, like those of cod and dogfish, to determine if that could be impacting cod movements. Lisa Kerr noted that it is important to collaborate with people, such as modelers and geneticists, to help tease apart the movement patterns. There may be a genetic or morphometric reason why certain patterns occur, she said, and researchers can learn what is driving the phenotypic plasticity.

Reporting rates:

It was agreed that improved reporting rates are necessary for future tagging studies. Suggestions included multiple tag reward values and additional outreach efforts as ways to increase the tag reporting rate.

Data mining/re-analysis/modeling:

There were numerous suggestions for improvements with regards to data mining, re-analysis of the data and modeling applications. Weighting models should be improved if they are to be applied to the data and a meta-analysis of historical data sets may help to fill in the gaps from current studies. It would be helpful to incorporate environmental information into current movement data as well. There should be a comparison of tagging-based estimates of stock assessment parameters with traditional estimates from the GARM. "We need to compare the calculations of mortality and fishing effort from the tagging data to see how it compares with traditional surveys and alter the stock assessment boundaries if necessary," said David Goethel. Tagging data are a good source for understanding gear selectivity in an objective manner, so improved selectivity analysis was recommended. Lisa Kerr also suggested more collaborations to improve the understanding of the mechanisms that drive migration movements.

During the discussion about re-analysis for tagging projects, Steve Cadrin asked the group whether the movement information collected across the presented studies suggested a need to alter the cod management boundaries. Shelly Tallack said that fish are certainly moving across management boundaries. "It's not just a handful of fish, but a large number of fish that are doing this," she said. The group agreed that the best available science indicates the need to revisit stock management boundaries.

David Goethel said that current management units for cod are too large to be effective. Dividing an area like the GOM in half could lead to improved management, but "if we're stuck doing things the way we've always done them, then we're going nowhere," he said. Steve Cadrin agreed and said that stock assessment scientists should not be the only ones making decisions on management boundaries. "I think we have strong enough evidence for cod to advise that the current management boundaries should be redesigned," he said.

The group drafted a statement: "Recent and historical cod tagging data (and genetic data) suggest substantial movement across current stock boundaries and considerable heterogeneity within current management units."

David Goethel said that all the data presented during this meeting indicates that cod are moving across boundaries. "We don't have all the answers, but we have enough evidence to show that the current structure is not working," he said. Jon Grabowski asked the group if they were ready to redraw the management lines. "We could redraw at least some of the lines right now much better than the boundaries we currently have," said Don Clark. He noted that in Cape Bretton, cod are managed as separate stocks for summer and winter based on different otolith chemistry of the fish. The management system is very complex but it has been in place since the 1980s and it works very well, he added.

Jon Grabowski pointed out that the recommendation for re-drawing management lines may help direct future research to fill in the gaps in knowledge.

Ted Ames noted that re-examining stock boundaries allows for another look at energy transport as well. Hunt Howell said that the data necessary to alter management boundaries is only available for adult cod. "We need more information throughout their life history and we need to know how all the life stages connect in time and space," he said.

"We don't have all the evidence, but it's time to have that discussion," David Goethel said. "We can't ignore it any more."

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