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Summary of Yellowtail flounder Tagging Study (2003-2006)

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ABSTRACT

This working paper provides a general summary of the 2003-2006 yellowtail flounder tagging study in the three U.S. stocks. Over 45,000 yellowtail flounder were tagged with conventional disc tags and archival data tags in all three New England stocks with the objectives of estimating movement among stock areas and mortality as well as providing growth observations. The pattern of release and recapture locations reveals frequent movements within stock areas and less frequent movement among stocks. Data storage tags show distinct periods of on-bottom and off-bottom movement behavior associated with movement to different habitats. Simulation of yellowtail flounder life history, stock status, fishery dynamics and the pattern of releases suggest that fishing mortality and movement estimates are confounded and cannot be independently estimated alone. Survival analyses for New England as a whole supported the general magnitude of mortality from the age-based assessment. Comparison of scale samples collected during the release and recovery confirm the current interpretation of one annulus per year. Overall, this study furthered our understanding of yellowtail flounder dynamics, particularly relative to movement behavior of the species that was considered previously 'sedentary.'

Introduction

This working paper (WP) provides a synopsis of the results of the yellowtail flounder tagging study based on the Cadrin et al. (2009). The contents of this paper are direct excerpts taken from the Cadrin et al. (2009) report and highlight some of the main conclusions from both conventional and archival tagging results. First, we provide an historical overview of previous tagging studies relative to movement of yellowtail flounder, followed by the study design and results of the 2003-2006 tagging study in three U.S. stock areas. While this paper focuses mostly on movement of yellowtail flounder, other aspects of the tagging study briefly considered in this WP include results of yellowtail growth confirmation based on scale samples from released and recaptured fish and a summary of the holding experiments used to assess tag mortality and tag shedding rates. The results from the holding experiments provide empirical support for the analytical framework of the tagging study (i.e. movement-mortality model), while the growth confirmation results further validates the current aging of yellowtail used for assessment purposes as well as in the simulation of the movement-mortality model. For an expanded version of this WP and list of collaborators involved, additional details can be found in the final Northeast Consortium (NEC) final report provided as background literature to this summary working paper.

Movement of yellowtail flounder from previous tagging studies

Movement of yellowtail flounder off New England has been addressed by several historical and more recent tagging studies. Royce et al. (1959) tagged and released yellowtail on U.S. fishing grounds from 1942 to 1949 and concluded that groups of yellowtail are relatively localized (e.g., most tagged fish were recovered within 80 km of the release site), short seasonal migrations occur, and little mixing occurs among fishing grounds (except for frequent movement from the Mid Atlantic Bight to Southern New England waters). Lux (1963a) also tagged yellowtail off U.S. fishing grounds and concluded that groups of yellowtail moved seasonally within fishing grounds, with a small amount of seasonal mixing among groups.

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

From 1999 to 2002, yellowtail were tagged and released on eastern Georges Bank (Stone and Nelson, 2003); none of the recaptured fish moved off the Bank, and all but one were recaptured on the eastern portion of the Bank.

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

Although data from historical tag recaptures suggest some mixing with the southern New England and Georges Bank stocks, these data were up to 50 year old and may not represent current environmental or stock conditions. Hence, a comprehensive study was initiated in 2003 with following objectives:

Study Objectives

There are several objectives of the yellowtail flounder tagging study:

1) Estimate movement rates among yellowtail fishing grounds
2) Provide independent estimates of mortality
3) Confirm age determination
4) Foster cooperative relationships between fishermen and scientist

The study was designed to help address some of the sources of uncertainty in the yellowtail flounder assessments by complimenting the current stock assessment methods to enhance scientific advice for effective fishery management.

Methodology

General Field design

The general approach was based on an experimental design that represents the entire population abundance of yellowtail flounder and an analytical design that models movement and mortality simultaneously. All phases of the study, from field protocol to public outreach, were developed cooperatively between New England fishermen, the Northeast Fisheries Science Center and other research agencies. The project contracted commercial fishermen and their vessels to work with scientist to tag and release yellowtail flounder on all fishing grounds, proportional to geographic patterns of abundance. The geographic design was based on statistical fishing areas (Figure 1), with releases in each area proportional to the relative abundance of yellowtail (Table 1 and Figure2). Such a design allowed for estimation of movement and mortality among the stock areas. The field protocol was peer reviewed at a “workshop to review and evaluate the design and utility of fish mark-recapture projects in the northeastern United States” and considered to be a valid approach to address the project objectives (Tallack et al, eds. 2005).

Yellowtail was captured using commercial otter trawls with large mesh (6.5”) and relatively short tows (30 min). All legal-sized fish (>33cm) in viable condition, and some sublegal sized-fish from low density tows in southern New England-Mid Atlantic were tagged with either Peterson discs or data-storage tags. Releases were during the spawning season (May-August; with the exception of 1% of releases in autumn of 2003). A summary of total numbers of releases by tag category can be found in Table 2.

Tag specifications were:

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

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

Tag recapture and outreach system

Tag recaptures are from a year-round commercial fishery with some seasonal geographic closures. The reward system for reporting recaptures involves $1000 lottery tags, 280 high-value ($100) rewards, and $100 rewards for returning data-storage tags. The outreach system includes reward posters, brochures, website (cooperative-tagging.org), annual letters to yellowtail fishermen, press releases, and a toll free number. Every fisherman who reports a recapture is contacted via a phone call and 'thank you' letter with a map detailing movements of the tagged fish. Fishermen who return data storage tags, also receive a graph of the temperature and pressure data from that tag. Mailings and posters about the program have also been distributed to fish processors, fishing associations; NMFS port agents, NMFS Observer Program and research institutions from Nova Scotia to New Jersey. Outreach materials were also translated in Portuguese, French and Spanish to foster better communication between scientist and fishermen. In addition to the standard "thank you" letters and maps, the project initiated an Outstanding Partner" Award to the vessel with the most tag returns. A framed certificate and "thank you" letter signed by the Director of the NEFSC is mailed to the partner and posters announcing the merit are distributed for display in fishing supply houses and around the waterfront.

Analytical Design

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

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

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

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

where,

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

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

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

M is the natural mortality rate

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

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

The parameter β_i^t can be calculated as the ratio of lottery tag returns to high value ($100) tag returns, assuming that all recaptures if $100 tags are reported. The parameters $\alpha_{i,j}^t$ (movement) and F_i^t (fishing mortality) can be estimated to fit model predictions to the observed frequency of seasonal returns by area.
The number of tag returns and the duration of the study will dictate how many parameters can be reliably estimated. The model has flexible spatiotemporal resolution, so that stock areas can be analyzed by statistical areas, and movements can be analyzed by season, if the number of tag returns supports such detail.

Simulations

Performance of the movement-mortality model on the number and pattern of tag releases was evaluated by simulation. Details of the analysis are reported in Alade (2008). An age-structured model of a single cohort was simulated for each stock, using the using data from groundfish assessments (GARM 2005) relative to the period of the tagging study. Forward projections for 2006-2008 abundances were generated by randomly sampling 2004 VPA fishing mortality estimates, assuming a lognormal distribution with a calculated measurement error (i.e. estimated CV's from the time series of VPA estimates) for each stock (Georges Bank 33% CV; Cape Cod-Gulf of Maine 35% CV and Southern New England-Mid Atlantic 44% CV). Using the movement-mortality model, predicted recaptures were generated assuming a fixed natural mortality rate of 0.2 and a global reporting rate of 0.57 (based on observed ratio of high-value and lottery recovery rates). Measurement errors and process errors were simulated around true recaptures, assuming a lognormal distribution at various levels of precisions (10%, 25%, 50% and

75%CV). Model simulations were repeated 100 times for several scenarios, with mortality and movement parameters estimated by comparing the randomly generated recapture datasets to the "true" recaptures using a least square estimator. Relative performance of the model for each simulated case scenario was evaluated by calculating the relative bias and the 80th percentile confidence limits between the mean of 100 estimates and the "true" reference value in the model. Covariance analyses were also conducted to evaluate independence among parameter estimates from the simulations.

Growth

Scale samples of released and recaptured yellowtail were pressed by placing them onto a hard plastic slide, placing a laminate slide on top of the scale samples and a second plastic slide on top of the laminate slide, and running the slide through a scale press. The final product was a scale impression that could then be viewed on the light projector. Scale images were processed for marginal increment analysis. Age was determined from digitizing scale images. The light projector was used to eliminate regenerated scale samples and identify the focus of the scale as well as the consecutive annuli or growth checks. Once the scale impressions were aged distances from the focus to the edge of individual annuli were measured using Image Pro-Plus software. By measuring the individual annuli and comparing the measurements between the mark and the recapture events, growth during time at large was determined (Figure 3).

Holding study Experiment

In 2004-2005, holding experiments were performed to assess tag retention and tag-induced mortality. Experiments were conducted both in holding tanks in the Woods Hole aquarium and in cages deployed in Ipswich Bay following tagging protocols. For the tank experiments, 30 fish were kept on the last tow of four inshore tagging trips and transported via flow-through tanks on board and oxygenated shipping bags via vehicle transportation maintained at 10˚C. One experiment observed 20 tagged fish and 10 untagged controls for 35 days. They were also held for up to a year to observe tag retention. A second experiment acclimated 30 untagged fish for 2 weeks, after which 20 were tagged. Subsamples were removed from the holding tank at durations of 0, 24 and 168 hrs. Tissue samples around the tag site were preserved and analyzed for histological reaction at the University of Maryland Eastern Shore Fish Pathology Lab. For the cage experiments, a total of 30 fish were caught of which 15 were tagged and deployed for three to four days to observe survival of tagged and control fish. Tissue samples were also collected from tagged fish for histological evaluation. A total of 12 deployments were conducted for a total of 360 fish in June of 2005.

Results and Conclusions

Overall, 3,853 recaptured fish were reported. Results indicate frequent movements within Cape Cod and Georges Bank stock areas with less frequent movement among stock areas. Recapture data with known recapture location indicates 96% residence in Cape

Cod-Gulf of Maine with 3% movement to Georges Bank and 1% movement to southern New England-Mid Atlantic), 98% residence on Georges Bank (with 1% movement to Cape Cod-Gulf of Maine and <1% movement to southern New England-Mid Atlantic), and 48% residence in southern New England-Mid Atlantic (with 37% movement to Georges Bank and 15% movement to southern Cape Cod-Gulf of Maine; Table3). However, most movement from southern New England to Georges Bank was from the Nabtucket Shoals area (Figure 4).

Eight percent of all lottery tags have been returned; 14% of $100 reward tags and 11% of data tags were returned. The relative return rate of lottery tags to high-value tags indicates a 59% reporting rate, which is exceptional for a commercial fishery. An analysis of recapture rate by sex, size, condition code and damage code (Table 4) indicates that females had a greater recapture rate than males (particularly small males), fish categorized as 'good' had the same recapture rates as those that were 'excellent,' and all damage codes had similar recapture rates (except 'net marks' which may be excluded from mortality analyses and 'lymphocystis' which is a natural condition).

Results from all simulated scenarios are reported in detail by Alade (2008). In summary, the simulations of moderate movement rates (10-25% per year) and moderate precision of input data (10% to 25% CV) show that fishing mortality and movement were well estimated (<10% bias). Conversely, for scenarios that simulate no movement, low movement (5%) or high movement (45%), model estimates tend to be confounded, indicating that movement rates and fishing mortality could not be effectively differentiated in the model. The implication these results indicate that there is a substantial penalty for imprecise input data, and parameter correlation may be a problem for some applications. Based on initial applications of the movement-mortality model and simulation results, movement and mortality were not simultaneous estimated using solely tagging data. Survival was estimated for the entire New England resource, and integrated modeling with fishery catch at age and survey data was initiated (Wood and Cadrin 2013).

Eighty-three data-storage tags were returned, indicating distinct off-bottom movements (Cadrin and Moser 2006). All tags at large more than one month indicated distinct off-bottom movements. Off-bottom movements were typically in evening hours, between 18:00 and 22:00, lasting an average of four hours, ascending to an average of 15m off-bottom (Figure 5; Cadrin and Westwood 2004). The frequency of off-bottom movements varied geographically, an average of once every ten days off Cape Cod, and once every three days on Georges Bank. Tidal geolocation has been tested (Cadrin et al. 2007), and geolocation of tag deployments continues in partnership with SMAST oceanographers.

These results illustrate how archival tags enhance the interpretability and power of tagging studies. Until recently, the well-studied yellowtail flounder was thought to be a "sedentary" fish, feeding on epibenthic fauna and limited to relatively shallow, sandy habitats. This strict habitat preference and the discontinuous distributions of such habitats were considered to limit movement among offshore banks and shelves, thereby maintaining geographic stock structure. The movement patterns indicated by disc tags likely involves passive drift in midwater currents, similar to patterns observed for other flatfish species. Therefore, the use of electronic tags reveals an important aspect of yellowtail behavior that was not apparent after decades of intense research.

Approximately 4,000 scale samples were taken during tag release, but only 131 scale samples were taken at the recapture event. Most (53%) of the recapture sample came from George's Banks, 44% came from the Cape Cod Gulf of Maine, and only 4% came from Southern New England-Mid Atlantic Stock. There were 113 females and 114 males in the paired release-recapture samples. The average time at liberty was approximately 188 days (0.5years). Average age was 3.6 years with minimum and maximum age of one and 6 years respectively. Evaluation of scale recapture samples supported the current knowledge that one annulus is formed per year (Figure 6)

Results of the tank experiments indicated variable patterns of mortality suggesting that tag mortality may be high. However, histological evaluation of tagged tissue showed no reaction at the tag sites, suggesting minimal impact of tagging on fish survival. The long-term tank holding study observed no tag lost with fish held for over a year.

Results from the cage experiments indicated low overall mortality of tagged and control fish. Of the 360 fish in the experiment, only 15 died, and more control fish died than tagged fish. Six fish died in the second deployment, which was associated with poor weather conditions and cage movement. Therefore, it appears that the trawl-capture and caging system impose more mortality than tagging. Analysis indicates no tag-induced mortality, because more control fish died than tagged fish, and approximately 3% mortality from the capture and cage system. Removal of data from a cage where sandfleas were observed eating live fish, suggests 1% mortality from the trawl-capture system. Although, deployment of cages offshore on Georges Bank was more difficult, result also suggest negligible tag induced mortality. Evidence from this holding study provided an empirical basis of tag mortality and tag shedding as priors in the movement mortality model, indicating low to negligible tag related mortality and 100% tag retention rate.

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Tables

Table 1: Distribution of Tag releases by Statistical Areas in Comparison to Survey Biomass

	Tag Releases					2003-2006
area	2003	2004	2005	2006	Grand Total	survey
513	3	1392	247	943	2585	13%
514	2025	1192	480	1616	5313	19%
521	2129	43	378	393	2943	4%
522	710	784	84	686	2264	5%
525	118	3978	817	459	5372	4%
526	117	524	32	1202	1875	3%
537	199	269	284	283	1035	4%
539	170	30	0	101	301	1%
561	423	476	57	534	1490	5%
562	2906	9096	3387	3072	18461	40%
613	292	331	231	205	1059	3%
Total	9092	18292	6242	9494	43120	100%

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562	2906	9096	3387	3072	18461	43%	40%
613	292	331	231	205	1059	2%	3%
	9092	18115	5997	9494	42698	100%	100%

Table 2: Total releases and recaptures by tag type

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

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

	Recapture Stock				
Release Stock	CCGOM	GB	SNEMA	UNK	Total
CCGOM	1054	39	11	82	1186
GB	33	2374	12	148	2567
SNEMA	14	47	36	3	100
Total	1101	2460	59	233	3853

	Percent Recapture Stock				
Release Stock	CCGOM	GB	SNEMA	UNK	Total
CCGOM	89%	3%	1%	7%	100%
GB	1%	92%	0%	6%	100%
SNEMA	14%	47%	36%	3%	100%

Table 4: Recapture rate (recaptures/release) by category

Sex	recap/rel
female	8%
male	6%

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

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

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

Condition	Recap/Rel
excellent	8%
good	8%

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

Figures

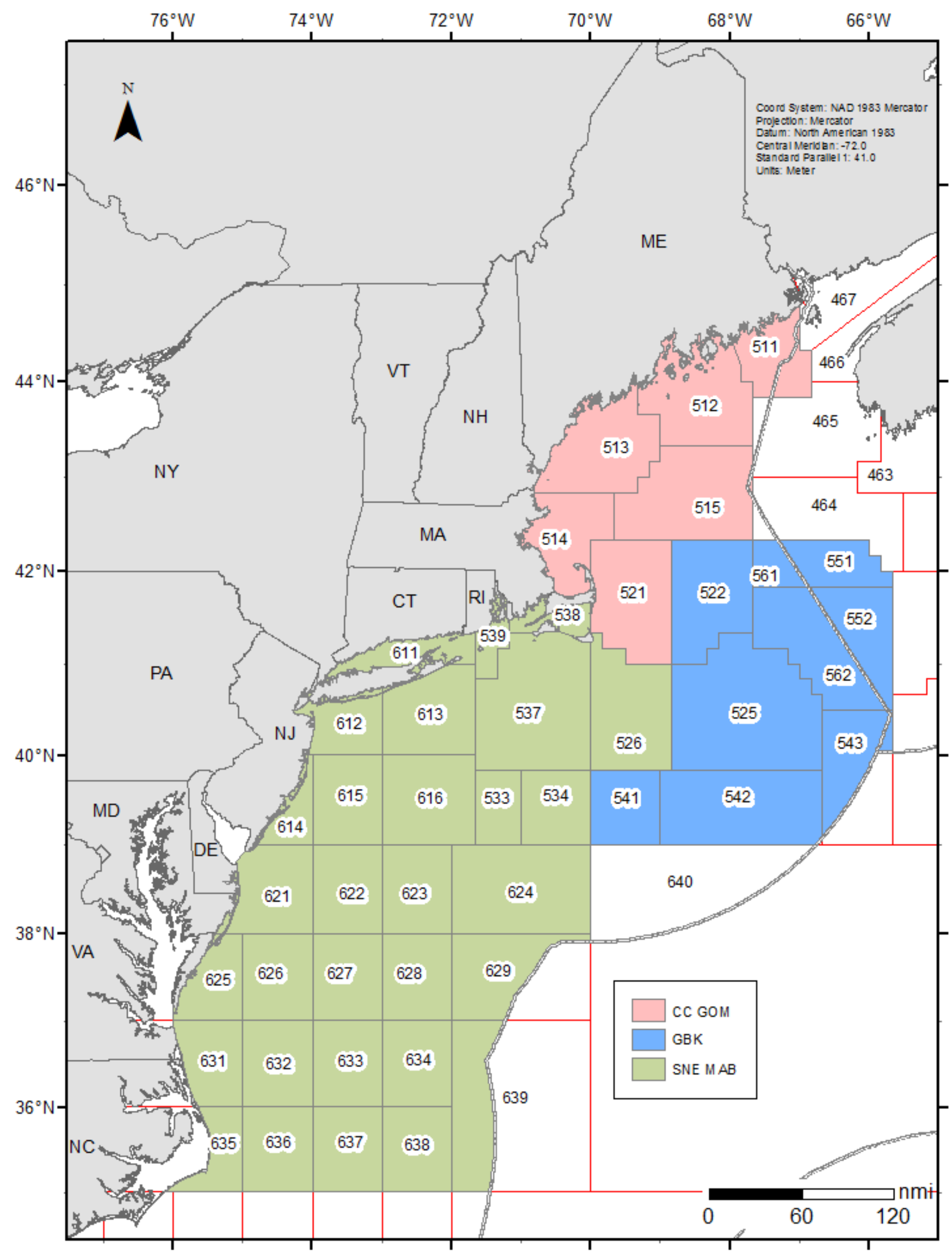

Figure 1: Map of Statistical area for the three yellowtail flounder stocks. CCGOM = Cape Cod Gulf of Maine; GBK = Georges Bank; SNE MAB = Southern New England Mid Atlantic Bight.

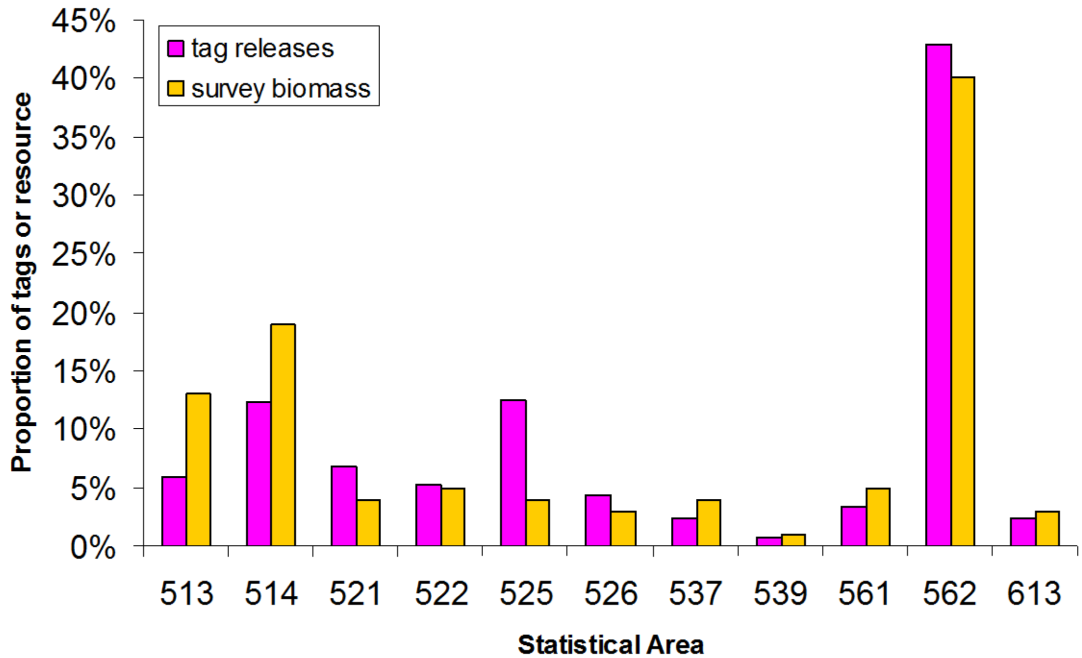

Figure 2: Distribution of Tag releases by Statistical area in comparison to survey biomass

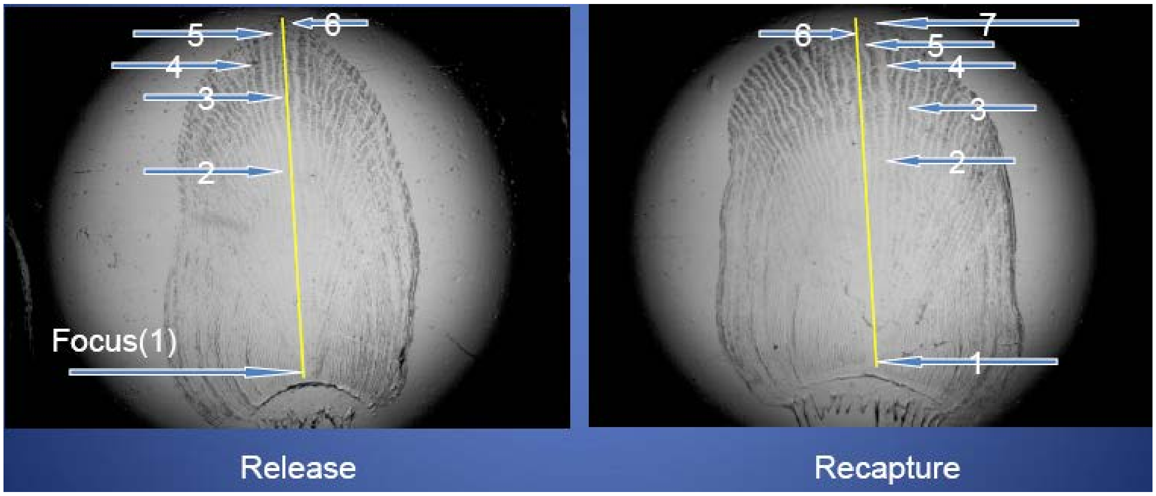

Figure 3: Example scale samples at release (left) and recapture (right) with annuli indicated

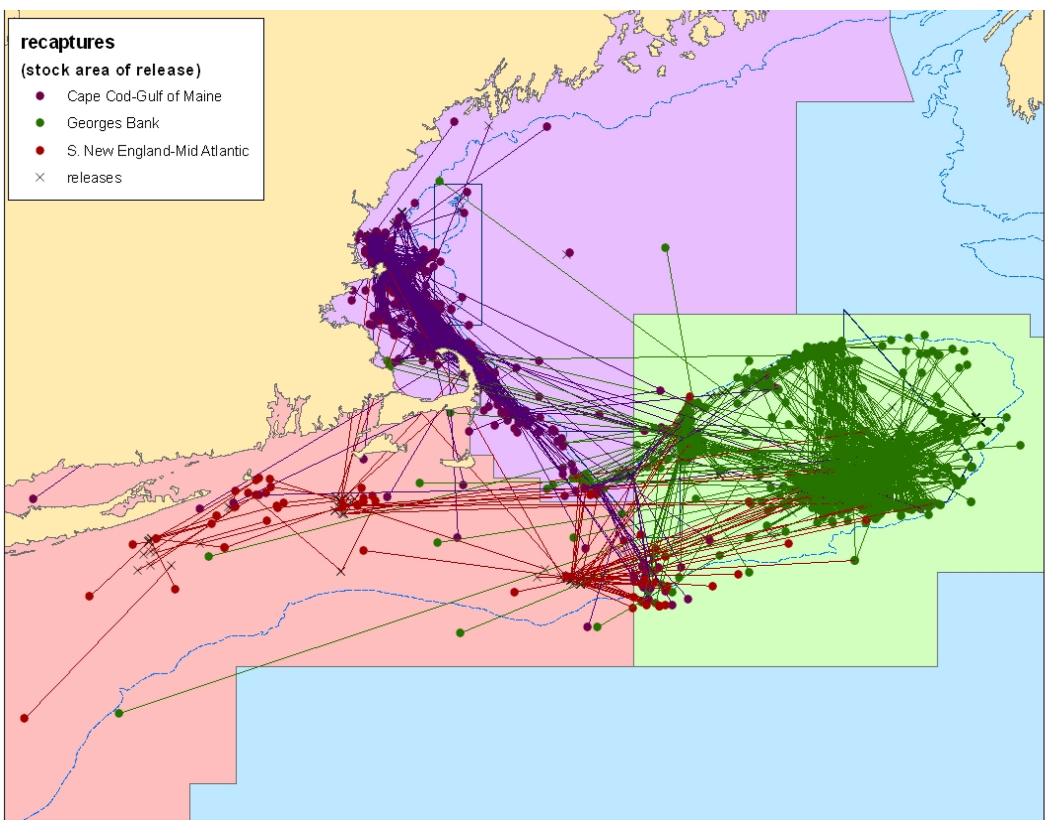

Figure 4: Residence and movement of tagged yellowtail flounder with respect to management areas. Symbols ("x") indicate releases and ("·") recapture positions.

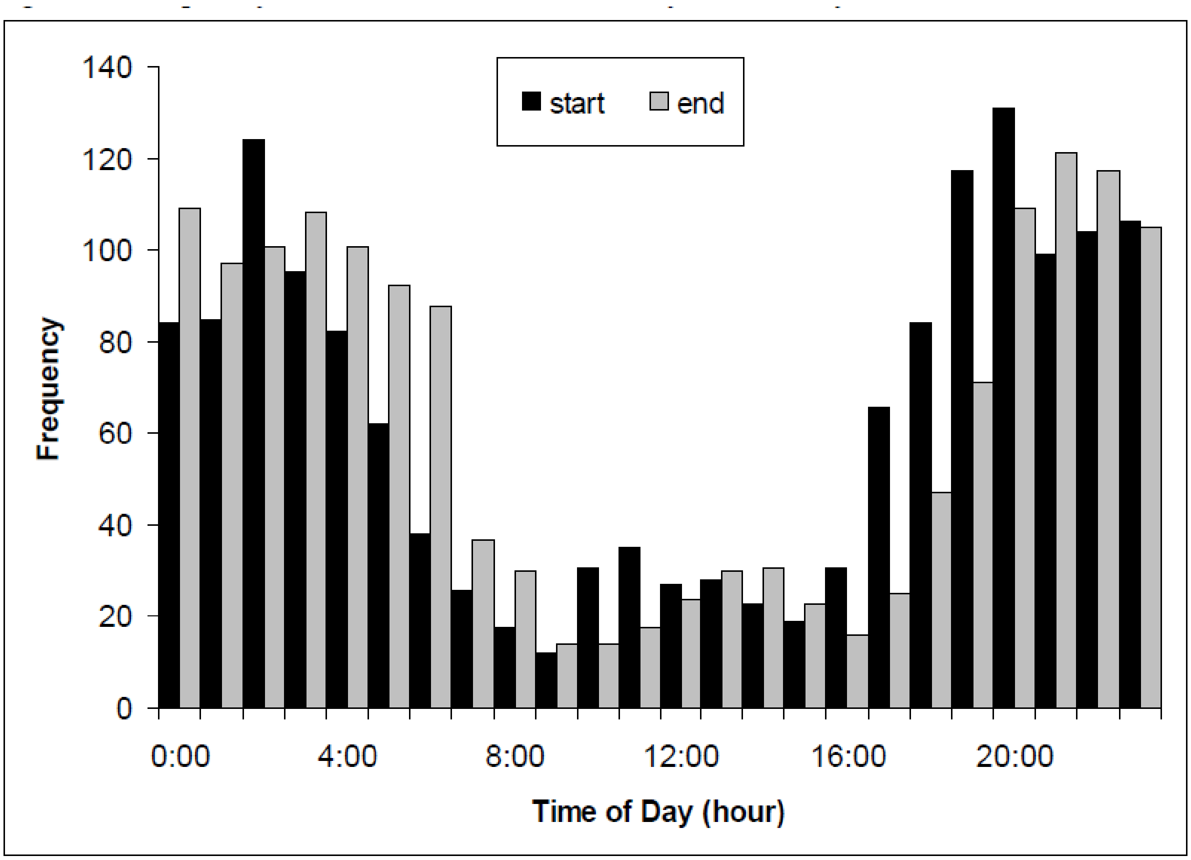

Figure 5: Frequency of yellowtail flounder off-bottom movement

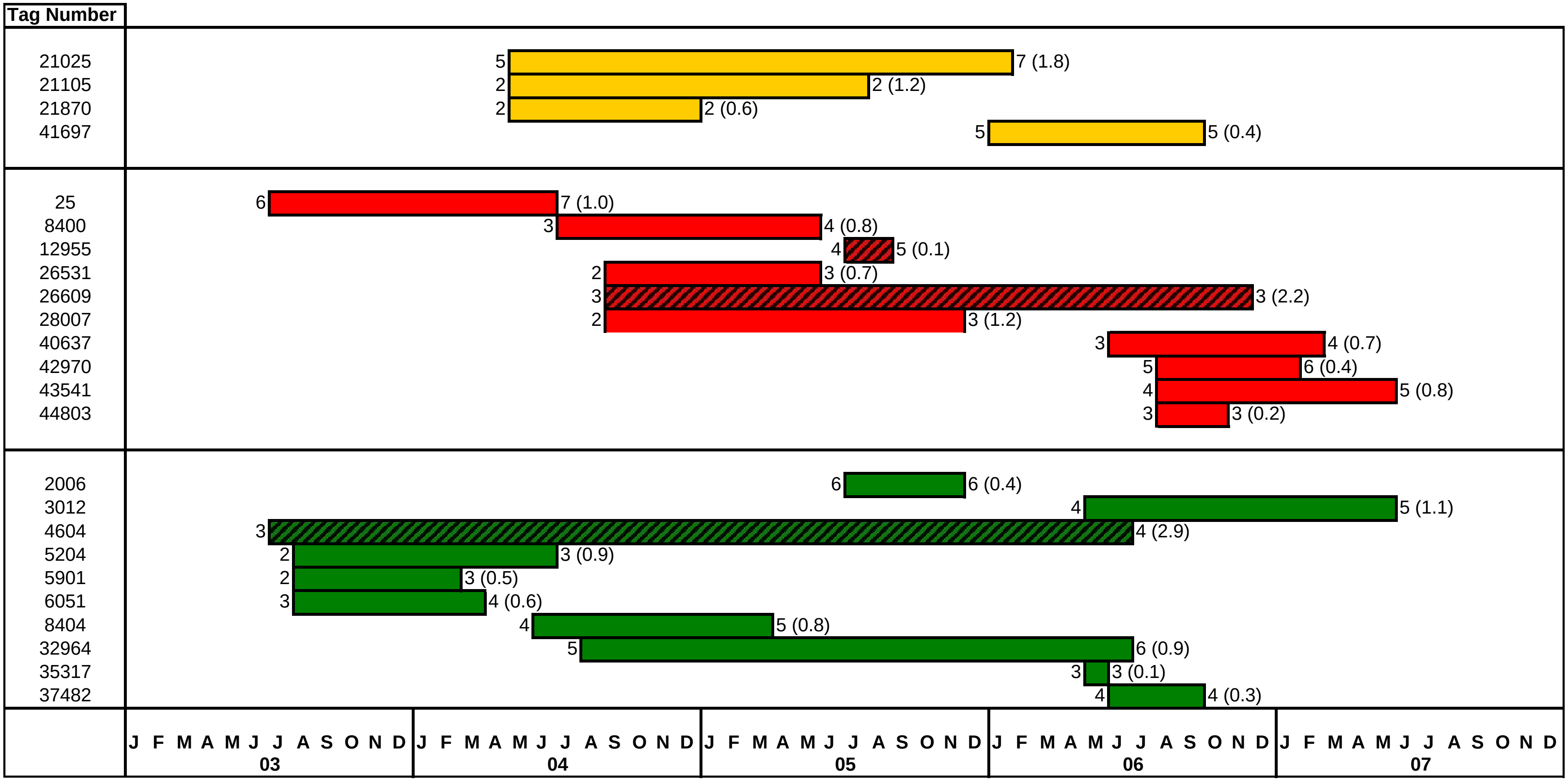

Figure 6: Time of release and recapture for a subsample of 24 tagged yellowtail flounder with number of growth checks (annuli) present on scales removed at release (to the left of the bar) and recapture (to the right of the bar) with values in parenthesis indicating the time at liberty in years. Orange bars are fish from SNEMA, red bar are fish from GB and the green bar represents fish from CCGOM. Diagonal patterns in bar indicate scales checks at recapture that do not correspond with the time at liberty.