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Abundance of Yellowtail Flounder in the Access Area of Closed Area 2 on Georges Bank in June 2008 from a Large-Scale Petersen Tagging Study

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ABSTRACT

Abundance of yellowtail flounder in the access area of Closed Area II on Georges Bank was estimated using a large-scale Petersen tagging experiment. In June 2008, a ten-day mark-recapture experiment was conducted in which nearly 73,000 yellowtail flounder were tagged, with nearly 44,000 yellowtail collected in the second sample, including 177 recaptured with tags. Abundance in the study area was estimated to be approximately 18 million for ages 2+ using a variety of conventional and modified models. The Petersen estimates of abundance are significantly greater than contemporary estimates of age-2+ abundance of yellowtail in the entire Georges Bank stock area from the 2013 stock assessment. Sensitivity analyses indicate that the discrepancy in abundance estimates from the tagging study and the stock assessment are robust to a wide range of assumptions. Therefore, the tagging estimates suggest that the stock assessment is substantially underestimating abundance. A mark-recapture experiment using conventional external tags has never been attempted at this large a scale. The ability of this cooperative study to estimate abundance in an area closed to fishing demonstrates the capability of the method for evaluating marine protected areas and complementing conventional stock assessments.

Introduction

Yellowtail flounder (*Limanda ferruginea*) inhabit a depth range of 10-100 m in the Northwest Atlantic from Newfoundland to Chesapeake Bay (Bigelow and Schroeder, 1953), but are found most often at depths of 30-70 m from the Mid-Atlantic Bight to Georges Bank (Overholtz and Cadrin, 1998). Yellowtail flounder do not typically exhibit large-scale migrations, but seasonal and off-bottom movements have been observed via long-term tagging studies using conventional tags and data storage tags (Walsh and Morgan, 2004; Cadrin and Westwood, 2004; Cadrin and Moser, 2006).

The Georges Bank yellowtail flounder resource is an important component of a multispecies groundfish fishery and is a bycatch species in other fisheries. The New England groundfish fishery was one of the most economically important fisheries in the Northwest Atlantic, but many stocks have been depleted since the prosperous days of the fishery's origin (Boreman et al., 1997). This collapse has been attributed to a combination of factors including overfishing, environmental conditions, biological considerations, and species interactions (Sinclair and Murawski, 1997).

Permanent and semi-permanent area closures have been implemented in marine ecosystems worldwide in order to achieve fishery management goals by reducing fishing mortality and bycatch, and protecting habitat (Gell and Roberts, 2003; Murawski et al., 2000). Marine Protected Areas (MPAs) have been regarded as one tool toward achieving fishery management goals, but have been shown to be of limited efficacy for conserving highly mobile fish stocks and those managed under a catch limit (Hilborn et al., 2006; Boersma and Parrish, 1999).

Three closed areas have been established in the vicinity of Georges Bank to limit fishing as part of stock rebuilding plans: the Nantucket Lightship Closed Area in the Southern New England-Mid-Atlantic stock area for yellowtail flounder, Closed Area 1 just east of the Great South Channel, and Closed Area 2 on the US-Canada border (Murawski et al., 2000) (Figure 1). These areas have been closed to all mobile fishing gear capable of catching groundfish since December of 1994. Exceptions to this closure have allowed limited dredge fishing for sea scallops in designated access areas on a rotational basis (Murawski et al., 2000) and a yellowtail flounder Special Access Program in 2004 (TRAC 2005). Access to Closed Area 2 for the scallop fishery has occurred in 1999, 2000, 2004-2006, 2009, and 2011-2014. Access to these closed areas has been granted to harvest large and economically valuable sea scallops where their populations have had the chance to grow due to the closures (Hart, 2003, 2006; Hart and Rago, 2006; Stokesbury, 2002). Scallop vessels participating in special access fisheries are limited by fleet-wide yellowtail bycatch so that the scallop fishery does not jeopardize rebuilding of yellowtail flounder. The yellowtail flounder bycatch allocated is a portion of the US Annual Catch Limit, which is determined by projections from the stock assessment. Exceeding yellowtail flounder bycatch limits has resulted in early closures for sea scallop access fisheries, leading to foregone economic yield for the scallop fleet. For example, the 1999 access fishery in Closed Area 2 harvested only 6 million of the 9.4 million pounds of scallops allocated due to reaching the bycatch limit for yellowtail bycatch (Gedamke et al., 2005).

Foregone revenue from exceeding or approaching yellowtail bycatch limits and not achieving target scallop catch in Closed Area 2 access fisheries was approximately $19 million in 2006 and $14 million in 2009 (O'Keefe and DeCelles 2013).

The Georges Bank yellowtail flounder fishery is assessed through the Transboundary Resources Assessment Committee (e.g., Legault et al., 2013). For the last two decades, the stock size of yellowtail flounder has been estimated by a calibrated Virtual Population Analysis (VPA), which reconstructs historical abundance at age using information on fishery catch and an assumed rate of natural mortality. Abundance of yearclasses in the last year of the stock assessment are calibrated with data from the Canadian Department of Fisheries and Oceans (DFO) trawl survey, and Northeast Fisheries Science Center (NEFSC) spring and fall bottom otter trawl surveys and summer dredge survey. The VPA exhibits a strong retrospective pattern, in which estimates of abundance in a specific year are revised downward each year as a new year of data are included in the stock assessment. National Marine Fisheries Service (NMFS) bottom trawl survey data have suggested that a large amount of the Georges Bank yellowtail flounder stock is concentrated in and near the sea scallop access area of Closed Area 2, but survey estimates are uncertain for this small area due to small sample size. Cooperative research surveys also document high densities of yellowtail flounder in the Closed Area 2 Access Area (e.g., Rago et al., 2000; Glass et al., 2004; DeCelles et al. 2014).

An independent estimate of yellowtail flounder abundance in the Closed Area 2 Access Area would provide valuable information for stock assessment and fishery management. A short-term mark-recapture study can provide this information by producing an absolute abundance estimate that complements the relative abundance indices from programmatic fishery-independent surveys. Mark-recapture techniques have been widely used in terrestrial, aquatic and marine systems to determine movement patterns, mortality estimates, and population estimates (Ricker, 1975; Krebs, 1989; Seber, 1992; Pine et al., 2003). By capturing and marking animals from a population, releasing them, and taking a second sample, the fraction of the population containing marks in the second sample can be used to estimate population size.

Mark-recapture studies fall into two categories: open and closed population models. When estimation of population size is the primary objective, and time and funding necessitate a single sample (i.e. one episode of marking and recapturing animals instead of a long-term project), a closed model is most appropriate (Pine et al., 2003). The simplest of these experiments can be carried out using the Petersen method, sometimes referred to as the Lincoln-Petersen method (Lincoln, 1930). Petersen (1896) first used this method of population estimation when he tagged plaice in the North Sea to study their movement and discovered that he could also estimate population size after a large amount of his marked fish were harvested by fishermen. The Petersen method is based upon a single marking event and the ratio of marked and unmarked fish in a subsequent sampling event.

The Petersen model has been used to estimate population sizes of wildlife in terrestrial systems and in lakes, ponds, streams, rivers and reservoirs (Gresswell et al., 1997;

Cooper, 1952; Isely and Tomasso, 1998). In these studies, the closure assumption is generally valid as long as the study is conducted over a sufficiently short period of time to prevent recruitment and removals. Short-term Petersen experiments have also been applied to a wide range of species in estuaries and shallow coastal areas (Iversen and Moffett, 1962; Barr, 1977; Castro and Rosa, 2005; Zeller and Russ, 1998; Crossland, 1980), and deeper-water open ocean environments (Scheidat et al., 2000; Cerchio, 1998; Tuck et al., 2003; McDermott et al., 2005; Siira et al., 2006; Svaasand et al., 1990).

The primary objective of this study was to estimate abundance and the associated uncertainty of yellowtail flounder in the access area of Closed Area 2 on Georges Bank using a Petersen mark-recapture experiment. A secondary objective is to analyze the results of the Petersen experiment in regards to its assumptions, and adjust the model estimate to account for violations of model assumptions. Further details are provided by Melgey (2010).

Methods and Results

Field Study – The experiment was conducted in the Closed Area 2 access area, which is 3129 km^2 with a depth range of 30-45 fathoms (64-73 m; Figure 1). The bottom substrate is mostly sand, with sand waves, some gravel and few boulders.

The experiment took place over a ten-day period in early June 2008. Data from previous tagging trips in the area (Cadrin et al., 2008; Wood and Cadrin, 2013) suggested that an average of approximately 200 yellowtail flounder per tow would be caught in this area if using standard flatfish trawl with 6.5 inch (16.51 cm) codend mesh to conduct 30-minute tows. A smaller mesh size codend liner of 4 inches (10.16 cm) was used to retain yellowtail flounder age-2 and older (approximately 24 cm and larger).

Using an assumed average of 200 yellowtail flounder per tow and fishing with half-hour tows (Cadrin, 2006) expanded to an average of 2 hours to include set, haul, and steam time between stations, it was determined that twelve tows could be conducted by each vessel per day if working around the clock. With five vessels sampling over seven days, approximately 60 000 yellowtail flounder could be tagged if five of the eight sampling days were spent tagging, and the remaining three were spent resampling. This planned schedule optimized sample sizes to minimize variance (Krebs, 1989).

Five commercial otter trawlers with crews experienced in the yellowtail flounder fishery were contracted to conduct the short-term experiment. Fishing vessels ranged in size from 70-85 feet, and fished with their own commercial nets modified with codend liners, changing gear as needed to suit the bottom type. Each vessel was staffed with three scientists in addition to the fishing crew. Permits for fishing in the closed area were obtained and no fish were retained for sale.

To meet the assumptions of the Petersen model, tagging locations were chosen randomly, then divided into five sub-areas (one for each vessel, Figure 2). Each station was defined as a one-nautical mile square grid cell and chosen using a random point generator. An adaptive sampling plan was employed through communication between vessels to avoid excessive recaptures during the first phase and to reduce bycatch of other commercially important species.

Phase 1 samples took place inside pre-selected one-nautical mile square grids and lasted approximately 30 minutes. Start and end times and positions were recorded for each haul, and the midpoint of the trawl was used as capture position. The catch was sorted immediately by scientists and crew. All live yellowtail flounder were placed in holding tanks filled with flow-through seawater. Determination of yellowtail condition (suitability for tagging) took place according to the protocol developed for the ongoing Cooperative Yellowtail Tagging project to maintain negligible tagging-induced mortality (Cadrin, 2006; Cadrin and Wood, 2013).

Modified t-bar anchor tags manufactured by Hallprint Technologies were used to expedite the tagging process (Figure 3). Each tag was marked with an individual identifier and a phone number. Tags were applied using a Dennison Mark II tag pistol by puncturing the animal through the musculature from the dorsal (eyed) side through to the ventral (blind) side. Each vessel used a different color tag, so that movement between sub-areas could be easily detected during the experiment. Each scientist tagged fish, recording the start and end tag numbers on each clip of tags and any misfires in each tag clip. One scientist per vessel subsampled the tagged fish to determine condition, sex and size distribution for the catch when conditions allowed. Fish were kept in holding tanks with circulating seawater after tagging and released in batches away from the next tagging station. Release locations were recorded in latitude and longitude. Tagged yellowtail that were recaptured during Phase 1 were recorded and sacrificed for maturity observations.

A new set of random stations was selected for recapture sampling during Phase 2 of the experiment (Figure 2). Recapture locations were sampled by starting in the general area where tagging began at the inner boundary of each sub-area, giving tagged fish time to disperse back into the population before recapture sampling. Trawls were 30 minutes long, and the catch was sorted and counted by fishermen and scientists. Any recaptured fish were sacrificed and sampled for maturity. Locations of recaptured fish were recorded by scientists, and all fish examined for tags were counted. All recaptures were sampled for length, condition, sex, and maturity stage. All untagged fish were marked with a fin clip before release to avoid counting the same animals multiple times.

Fifty data storage tags (DST, model LTD 1100, 32K memory, 8mm x 16mm x 27mm; Lotek, St. Johns, Newfoundland) were applied during Phase 2 to fish in excellent condition following the methods used by Cadrin and Westwood (2004).

Data from the Petersen experiment was entered into Excel spreadsheets in the months following the experiment. These spreadsheets were uploaded to the Northeast Fisheries Science Center Mark Recapture Database (MRDBS). Each vessel/trip was assigned an identification number ranging from YT200801 to YT200805. Audits were run on the data to correct any mistakes made during collection or entry, and corrections were made in the Excel spreadsheets which were then re-uploaded. Database queries linked release and recapture data for all recaptured tags. Summary statistics for length and sex data were computed.

Conventional Petersen Estimate - The conventional two-stage Petersen estimate of abundance (N_t) is based on the number of marked fish in a first sampling (M_t), the total number of fish in a second sample (C_{t+x}) and the number of tagged fish caught in the second sample (R_{t+x}):

$$\hat{N}_t = \frac{M_t C_{t+x}}{R_{t+x}}$$

The Petersen model assumes that the population is closed, all animals have the same chance of being captured in the first sample, marked animals have the same catchability as unmarked animals, marks are not lost during the experiment, and all recaptures are reported. Confidence limits (95%) were based on the large sample-size normal approximation:

$$\hat{N}_t = \frac{M_t}{\frac{R_{t+x}}{C_{t+x}} \pm 1.96\sqrt{\frac{(R_{t+x}/C_{t+x})(1-R_{t+x}/C_{t+x})}{C-1}}}$$

The number tagged (M_t) was 72,938; the number of fish observed in the second sample (C_{t+x}) was 43,588; and the number of recaptured fish in the second sample (R_{t+x}) was 177. The conventional two-stage Petersen estimate of age-2+ abundance in June 2008 was 17.962 million (confidence limits of 15.656 to 21.056 million).

Adjusted Estimate for Phase 1 Recaptures - The estimate was adjusted to account for tagged fish that were recaptured during the first stage (M_2):

$$\hat{N}_t = \frac{(M_t - M_2)C_{t+x}}{R_{t+x}}$$

The number of tagged fish that were recaptured in the first stage (M_2) was 100, and the adjusted estimate of abundance was 17.937 million (15.638 to 21.028 million) age-2+ in June 2008.

Adjusted Estimates for Phase 1 Recaptures and Immigration - For a Petersen tagging experiment conducted in the open ocean, population closure is impossible. While yellowtail flounder may not be highly migratory, evidence of prolonged off-bottom movements exists (Cadrin and Westwood, 2004) and immigration and emigration will have an effect on the closed population estimate. Therefore, the number of yellowtail flounder immigrating to the study area during the experiment was approximated to provide an abundance estimate that accounts for immigration. The conventional Petersen model was adjusted to account for immigration during the 10-day experiment ($I_{t,t+x}$):

$$\hat{N}_t = \frac{(M_t - M_2)C_{t+x}}{R_{t+x}} - I_{t,t+x}$$

Skellam (1951) modeled animal movement as a random-walk problem. Beverton and Holt (1957) extended the model to evaluate small-scale, local movements. Beverton and Holt's partial differential equation has been applied to model movement of marine invertebrate larvae (Hill, 1990) and movement patterns of large pelagic species (Sibert and Fournier, 1994; Porch, 1995).

Immigration was modeled based on spring 2008 survey data and movement data from the Petersen experiment (Figure 4). The mean time at large for fish captured during the experiment was 67.74 hours (2.82 days), and mean distance traveled used in the model analysis (n = 271) was 12.30 km. The mean speed was 0.26 km/hr. A plot of distance traveled versus time at large in hours shows that distance traveled increases with increasing time at large, with variation around the mean slope forced through the origin (Figure 5). A diffusion model used mean speed as the dispersion coeffcient to predict immigration from the open area into the access area during the experiment. An example of the dispersion from the survey data is given in Figure 6. The point source releases are obvious during the first day after release, and then the fish disperse to a fairly constant gradient as expected. The mean time at large for all fish of 2.82 days (67.74 hours) elapsed time was used to report the mean immigration during the experiment. With mean speed (0.26 km/hr), the model predicted a net immigration of approximately 200,000 fish at the end of the time step. The estimate of immigration reduces the estimate of age-2+ in June 2008 to 17.737 million (15.439 to 20.823 million). When the an extreme estimate of emigration (325,000 fish; Melgey, 2010) was assumed, the abundance estimate decreased to 17.612 million (15.313 to 20.703 million).

Sensitivity Analysis for Tag Loss and Tagging-Induced Mortality – Tag loss during the 10-day study was assumed to be negligible based on similar tagging studies and a holding experiment. Tagging-induced mortality was estimated to be negligible for a tagging study of yellowtail flounder with similar field protocol (Alade 2008). However, a range of aggregate tagging-induced mortality (expressed as a proportion, $P_{t,t+x}$) was assumed for sensitivity analyses:

$$\hat{N}_t = \frac{(M_t - M_2)(1 - P_{t,t+x})C_{t+x}}{R_{t+x}} - I_{t,t+x}$$

The estimates adjusted for stage-1 recaptures, immigration and tag-loss/tagging-induced-mortality suggest that the tagging estimates are robust to all these assumptions. With this knowledge, the Petersen estimate was compared to the time-adjusted VPA estimate. The results of this comparison suggest that aggregate estimates of tagging mortality and tag loss during the 10-day experiment would have to be greater than 45% to produce an adjusted Petersen estimate that is less than the VPA estimates (Figure 7) but 45% tag loss is unreasonably high in comparison to previous applications with t-bar tags and considering the increased retention expected from the double t-bar tag, and duration of the experiement. Revised estimates assuming a 45% loss would indicate that the entire stock was in the access area (according to the split-series VPA) or approximately 80% of the stock was in the access area (single-series VPA).

Test for Under-Dispersion – The Petersen model assumes that tagged fish disperse randomly into the untagged population. Recaptures should not be expected to be randomly distributed, because the population is not randomly distributed. Therefore random dispersal was tested using the statistical distribution of recapture rate (the ratio of recaptured fish to the total number of fish in each trawl), with a comparison to an expected random distribution of recapture rate.

The statistical distribution of recapture rates (Figure 8) suggests that the observed data approximately conformed to a log-normal distribution and showed no evidence of under-dispersion or patchiness. The pattern of deviations from the expected lognormal (P=0.2) indicate slight over-dispersion, or more evenly distributed recapture rates than random (i.e., more frequent low recapture rates and less frequent high recapture rates than expected). Therefore, the recapture data were not significantly patchy.

For comparison to Petersen estimates of abundance, VPA estimates were used to derive abundance of ages 2+ yellowtail flounder on June 1 ($N_{2\text{-}6+,June1}$) from starting year abundance, and a half-year of fishing mortality at age (F_a) and natural mortality (M) from Legault et al. (2013):

$$N_{2-6+,June1} = \sum_{a=2}^{a=6+} N_{a,January1} e^{-(F_a+M)/2}$$

VPA estimates of age-2+ abundance at the start of 2008 were 12.866 million (split-series) and 15.767 million (single-series). Decremented for a half-year of mortality estimates of age-2+ abundance in June of 2008 were 9.770 million (split-series) and 12.437 million (single-series).

The size structure of the sampled population is presented in Figure 9. Seventy-five percent of yellowtail flounder sampled during the Petersen experiment (n = 179) were either developing, ripe, or ripe and running, consistent with peak spawning time for the species (Bigelow and Schroeder, 1953).

Discussion and Conclusions

The 2010 TRAC reviewed a working paper with results from the Petersen Experiment (Legault et al. 2010). The TRAC concluded that the study could not be used to reliably estimate the abundance of yellowtail on all of Georges Bank, but that the Petersen estimate for the study area would be relevant as a point of comparison to the scale of the assessment estimates of total abundance (TRAC 2010). At that time, the Petersen estimate of age-2+ abundance in June 2008 was a large portion of the VPA estimate of abundance. However, with the retrospective inconsistency of the VPA, the tagging estimate is now greater than the updated VPA estimate of age 2+ yellowtail on all of Georges Bank in June 2008 (Legault et al. 2013). This apparent discrepancy was further explored to investigate properties of the tagging estimate and the robustness of the discrepancy to alternative assumptions. We conclude that the discrepancy between tagging-based estimates of abundance and VPA estimates are not the result of violated tagging model assumptions.

The Petersen method remains one of the simplest and most often used techniques for estimating animal abundance. Results of such experiments are often reported without much attention paid to violations of the model's strict assumptions and the sometimes severe effects of these violations on the population estimate. A population of mobile vertebrates in the open ocean is not expected to remain closed during even a short, ten-day experiment. Mortality and recruitment were not expected to be a substantial problem based on the short timeframe and the fact that the area is closed to fishing. In such a short period of time, the birth and death requirements of demographic closure can be approximately met. The major issue facing this model estimate was the lack of geographic closure and potential for immigration. Observed movement of tagged fish during the experiment offered evidence that the closed population assumption was not valid and also provided the dispersal information needed to account for this lack of closure (immigration estimates).

The major implications of this work are threefold. First, the research offers an experimental design and results that can inform a practical management decision (i.e., access to a closed area and sustainable catch in the area). Although the Petersen results are only a snapshot of the population in time, the results of the experiment demonstrate the potential impact of using an absolute abundance estimate to inform management decisions.

The second implication is related in that the approach offers a more general tool for monitoring and managing areas closed to fishing. Marine Protected Areas must be surveyed in order to analyze their efficacy and improve design and implementation, and in some cases determine suitability for rotational opening. A large-scale Petersen experiment should perform well for species that are easily captured and tagged and have low to moderate movement rates.

Finally, the field work demonstrates proof-of-concept that a short-term, large-scale Petersen experiment can be successfully conducted. The Petersen technique has been used extensively in the literature, but this study exceeds all similar studies by having a larger sample size, shorter duration, larger area, and dedicated sample and re-sample trips. Open ocean Petersen experiments are rare in the literature, and those that exist are largely dependent on commercial recaptures over long periods of time. None have tagged more than 10,000 animals in the first sample using conventional, external tags. An example is provided by McDermott et al. (2005), who tagged just under 9,000 Atka mackerel, recaptured just over 100 individuals, and had a large second sample of over 4 million fish because of the large volume of the commercial fishery. Population estimates for this study ranged from 80 to 105 million fish per area, but the confidence limits around these estimates were larger due to the low number of marks in the first sample.

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Literature Cited

Alade, L. 2008. A simulation-based approach for evaluating the performance of a Yellowtail Flounder (*Limanda ferruginea*) movement-mortality model. University of Maryland Eastern Shore Ph.D. dissertation.

Barr, L. 1977. Methods of Estimating the Abundance of Juvenile Spot Shrimp in a Shallow Nursery Area. Trans. AFS 4: 781-787.

Beverton, RJH, and SJ Holt. 1957. On the dynamics of exploited fish populations. London: Chapman and Hall, 1957.

Bigelow, H.B., and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. Fisheries Bulletin 53: 1-577.

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

Cadrin, SX and J Moser. 2006. Partitioning on-bottom and off-bottom Behavior: a case study with yellowtail flounder off New England. ICES C.M. 2006/Q:14.

Castro, ALF, and RS Rosa. 2005. Use of natural marks on population estimates of the nurse shark,*Ginglymostoma cirratum*, at Atol das Rocas Biological Reserve, Brazil. Env. Biol. Fishes 72: 213-221.

Cerchio, S. 1998. Estimates of humpback whale abundance off Kauai, 1989 to 1993: evaluating biases associated with sampling the Hawaiian Islands. breeding assemblage." Mar. Ecol. Prog. Ser. 175: 23-34.

Cooper, G. 1952. Estimation of Fish Populations in Michigan Lakes. American Fisheries Society Publication No. 81.

Crossland, J. 1980. Population size and exploitation rate of snapper, *Chrysophrys auratus*, in the Hauraki Gulf from tagging experiments. NZ J. Mar. Freshwater Res. 14: 255-261.

DeCelles G, K Thompson, and S Cadrin. 2014. Estimates of Yellowtail Flounder Biomass on Georges Bank Derived From a Seasonal Dredge Survey. TRAC WP 2014/x.

Gedamke, T, WD DuPaul, and JM Hoenig. 2005. Index-removal estimates of dredge effciency for sea scallops on Georges Bank. N. Am. J. Fish. Management 25: 1122-1129.

Gell, FR and CM Roberts. 2003. Benefits beyond boundaries: the fishery effects of marine reserves." Trends in Ecology and Evolution 18: 448-455.

Gresswell, RE, WJ Liss, GA Lomnicky, EK Deimling, RL Hoffman and T Tyler. 1997. Using mark-recapture methods to estimate fish abundance in small mountain lakes. Northwest Science 71: 39-44.

Hart, DR. 2003. Yield and biomass-per-recruit analysis for rotational fisheries, with an application to Atlantic Sea Scallops, *Placopecten magellanicus*." Fish. Bull. 101: 44-57.

Hart, DR. 2006. When do marine reserves increase fishery yield? Can. J. Fish. Aquat. Sci. 63, 7: 1445-1449.

Hart, DR and P Rago. 2006. Long-Term Dynamics of U.S. Atlantic Sea Scallop *Placopecten magellanicus* Populations. N. Am. J. Fish. Management 26: 490-501.

Hilborn R, F Micheli and GA De Leo. 2006. Integrating marine protected areas with catch regulation. Can. J. Fish. Aquat. Sci. 63: 642-649.

Hill, AE. 1990. Pelagic dispersal of Norway lobster Nephrops norvegicus larvae examined using an advection-diffusion-mortality model. Mar. Ecol. Prog. Ser. 64: 217-226.

Isely, JJ and JR Tomasso. 1998. Estimating fish abundance in a large reservoir by mark-recapture. N. Am. J. Fish. Management 18: 269-273.

Iversen, ES and AW Moffett. 1962. Estimation of Abundance and Mortality of a Spotted Seatrout Population. Trans. AFS 91: 395-398.

Krebs, CJ. 1989. Ecological Methodology. Harper and Row Publishers, New York. 654 pp.

Legault, CM, L Alade, WE Gross and HH Stone. 2013. Assessment of Georges Bank Yellowtail Flounder for 2013. TRAC Ref Doc. DRAFT

Legault, CM, SX Cadrin, and JH Melgey. 2010. What Percent of the Yellowtail Flounder Population is in the Petersen Tag Experiment Study Area? TRAC Working Paper 2010/10.

Lincoln, FC. 1930. Calculating waterfowl abundance on the basis of banding returns. US Dept. Agric. Circ. 118: 1-4.

McDermott, SF, LW Fritz, and V Haist. 2005. Estimating movement and abundance of Atka mackerel (*Pleurogrammus monopterygius*) with tag-release recapture data. Fisheries Oceanography 14, Suppl. 1: 113-130.

Melgey, J.H. 2010. A Petersen tagging experiment to estimate population size of yellowtail flounder in a closed area on Georges Bank. Master of Science Thesis. University of Massachusetts Dartmouth School for Marine Science and Technology.

Murawski, SA, R Brown, HL Lai, PJ Rago and L Hendrickson. 2000. Large-scale closed areas as a fishery-management tool in temperate marine systems: The Georges Bank experience. Bulletin of Marine Science 66: 775-798.

O'Keefe CE and GR DeCelles. 2013. Forming a Partnership to Avoid Bycatch. Fisheries 38(10): 434-444.

Overholtz W and SX Cadrin. 1998. Yellowtail Flounder: Status of Fisheries Resources off the Northeastern US for 1998. NOAA Tech. Mem. NMFS NE 115: 70-74.

Petersen, CGJ. 1896. The yearly immigration of young plaice into the Limfjiord from the German Sea. Report of the Danish Biological Station 6: 1-48.

Pine, WE, KH Pollock, JE Hightower, TJ Kwak, and JA Rice. 2003. A review of tagging methods for estimating fish population size and components of mortality. Fisheries 28 (10): 10-23.

Porch, CE. 1995. Trajectory-based approaches to estimating velocity and diffusion from tagging data. Fish. Bull. 93: 694-709.

Rago, P, S Murawski, K Stokesbury, W DuPaul, and M McSherry, editors. 2000. Integrated management of the sea scallop fishery in the northeast USA: Research and commercial vessel surveys, observers, and vessel monitoring systems. Copenhagen (Denmark): ICES.

Ricker, WE. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Bd. Can. Bull. 191.

Scheidat, M, C Castro, J Denkinger, J Gonzalez and D Adelung. 2000. A breeding area for humpback whales (*Megaptera novaeangliae*) off Ecuador. Journal of Cetacean Research and Management 2: 165-171.

Seber, GAF. 1992. A Review of Estimating Animal Abundance II. International Statistical Review 60: 129-166.

Sibert, JR, and DA Fournier. 1994. Evaluation of advection-diffusion equations for estimation of movement patterns from tag recapture data. Technical Report 336/1, FAO Fisheries, 1994.

Siira, A, P Suuronen, P Kreivi and J Erkinaro. 2006. Size of wild and hatchery reared Atlantic salmon populations in the northern Baltic Sea estimated by a stratified mark-recapture method. ICES Journal of Marine Science 63: 1477-1487.

Sinclair, A.F., and S.A. Murawski. 1997. Northwest Atlantic Groundfish: Perspectives on a Fishery Collapse, American Fisheries Society, 1997, 71-93.

Skellam, JG. 1951. Random Dispersal in Theoretical Populations. Biometrika 38: 196-218.

Stokesbury, KDE. 2002. Estimation of sea scallop abundance in closed areas of Georges Bank, USA." Trans AFS 131: 1081-1092.

Svaasand, T, KE Joerstad and TS Kristiansen. 1990. Enhancement studies of coastal cod in western Norway. Part 1. Recruitment of wild and reared cod to a local spawning stock. ICES J. Mar. Sci. 47: 5-12.

Tuck, GN, WK de la Mare, WS Hearn, R Williams, ADM Smith, X He and A Constable. An exact time of release and recapture stock assessment model with an application to Macquarie Island Patagonian toothfish (*Dissostichus eleginoides*). Fisheries Research 63: 179-191.

TRAC 2010. Proceedings of the Transboundary Resources Assessment Committee for Eastern Georges Bank Cod and Haddock, and Georges Bank Yellowtail Flounder. TRAC Proceedings 2010/02.

Walsh, SJ and MJ Morgan. 2004. Observations of natural behaviour of yellowtail flounder derived from data storage tags." ICES J. Mar. Science 61: 1151.

Wood AD and SX Cadrin. 2013. Mortality and movement of Yellowtail Flounder, Limanda ferruginea, tagged off New England. Fishery Bulletin 111:279–287.

Zeller, DC and GR Russ. 1998. Marine reserves: patterns of adult movement of the coral trout (*Plectropomus leopardus* (Serranidae)). Can. J. Fish. Aquat. Sci. 55: 917-924.

Figures

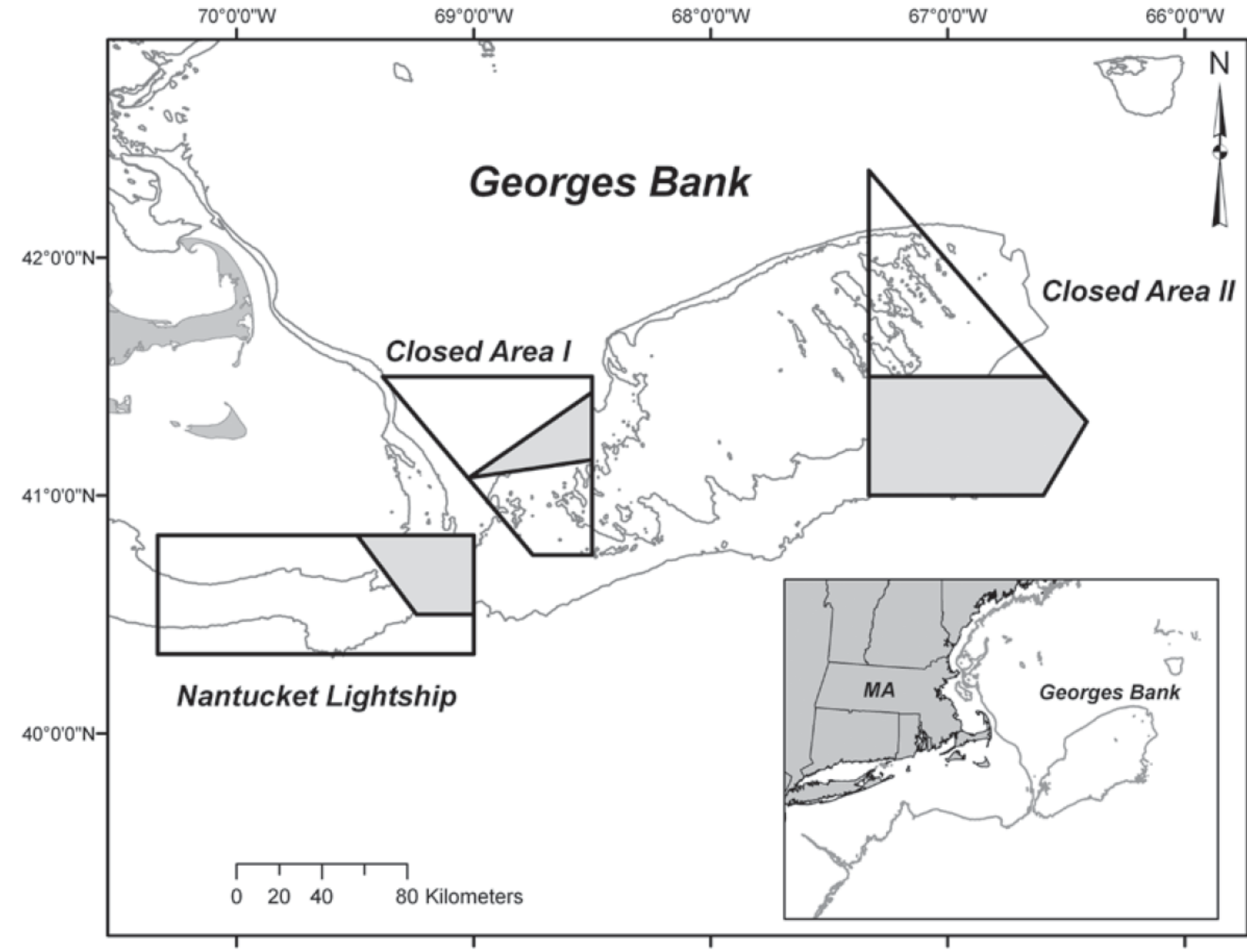
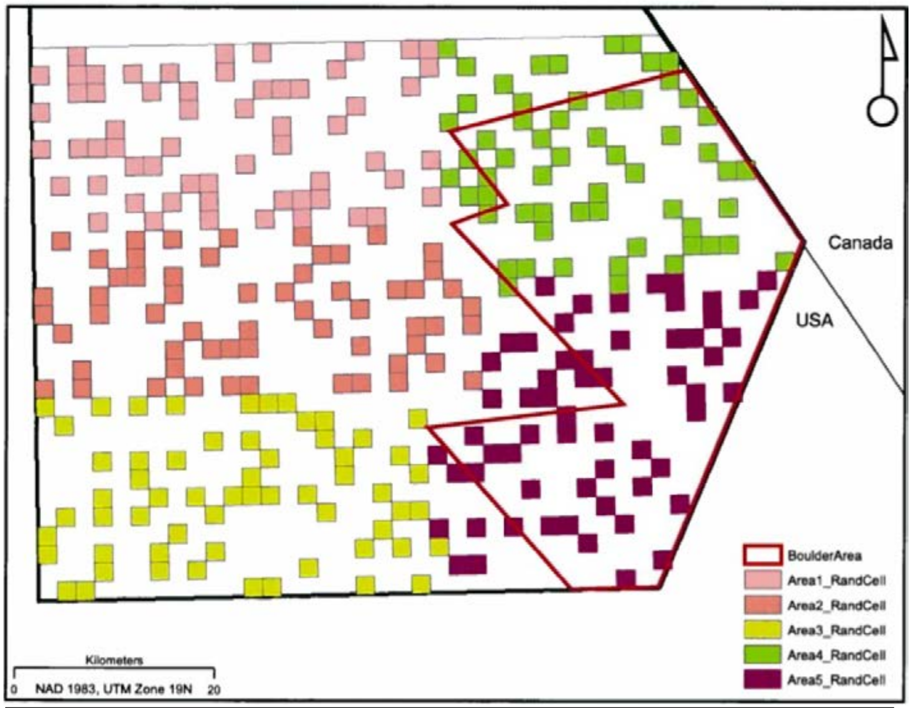


Figure 1. Georges Bank with closed areas outlined in black, scallop fishery access areas shaded in gray, and 50- to 70-m depth range where Yellowtail aggregate in the Nantucket Lightship region. Inset depicts U.S. East Coast with the 70-m isobath shown in gray (from O'Keefe and DeCelles, 2013).



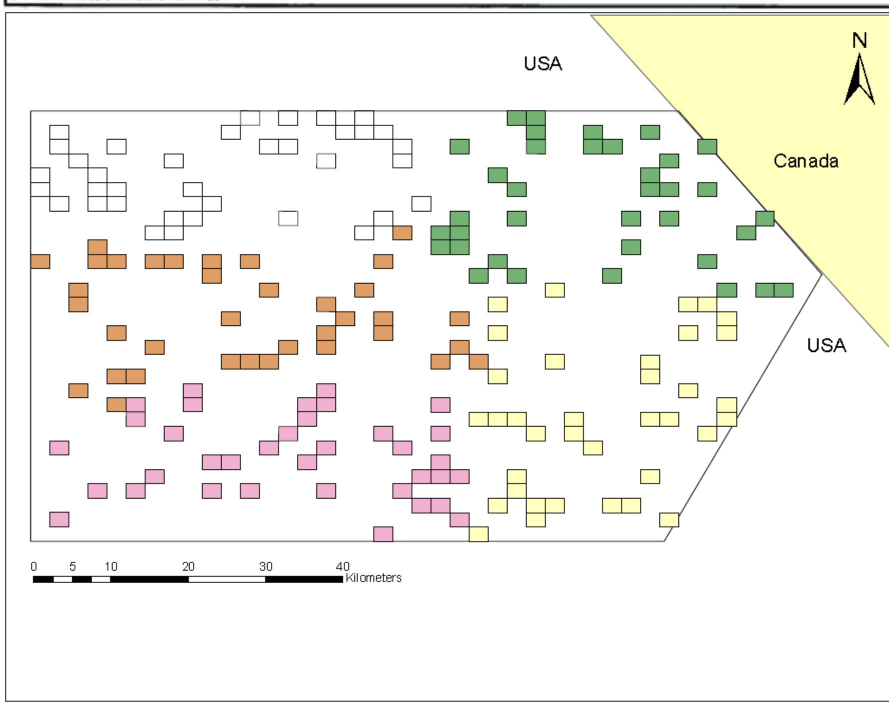


Figure 2. Sampling locations for the tagging phase (above) and recovery phase (below). Boxes are 1 nautical mile square and color coded by vessel.

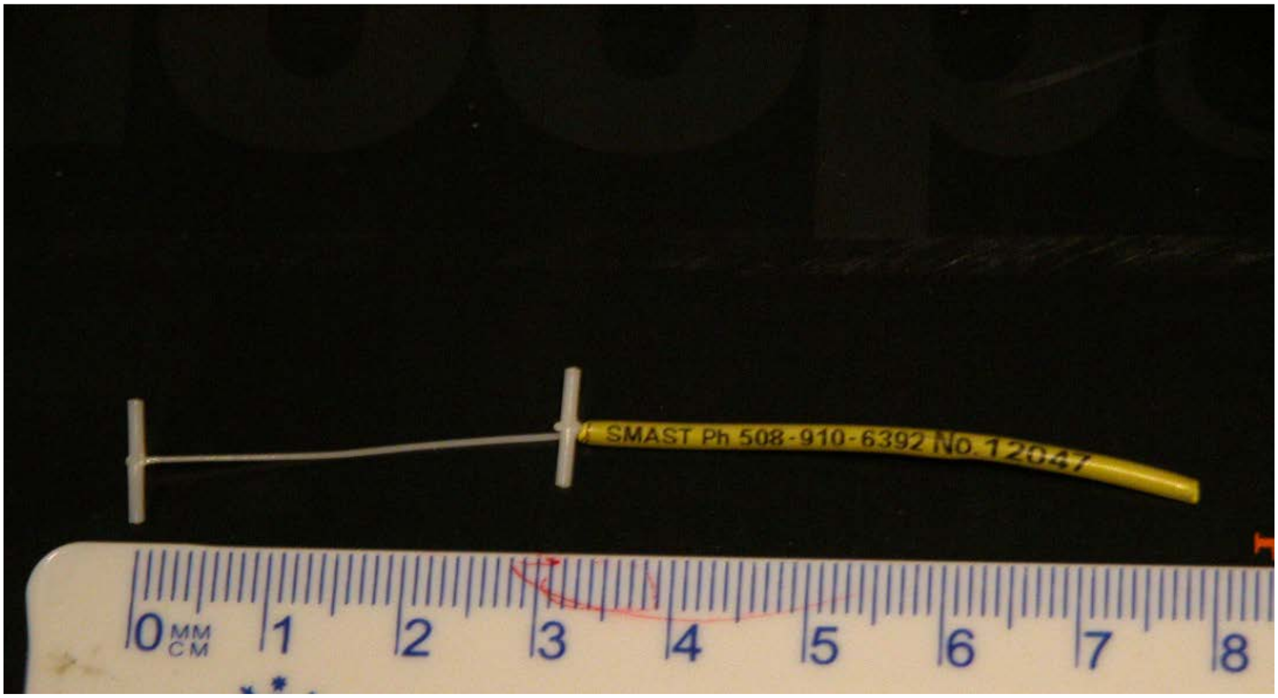


Figure 3. Example of double anchor t-bar tag used in Petersen experiment. The tag label is “SMAST Ph 508-910-6392 No. 12047”.

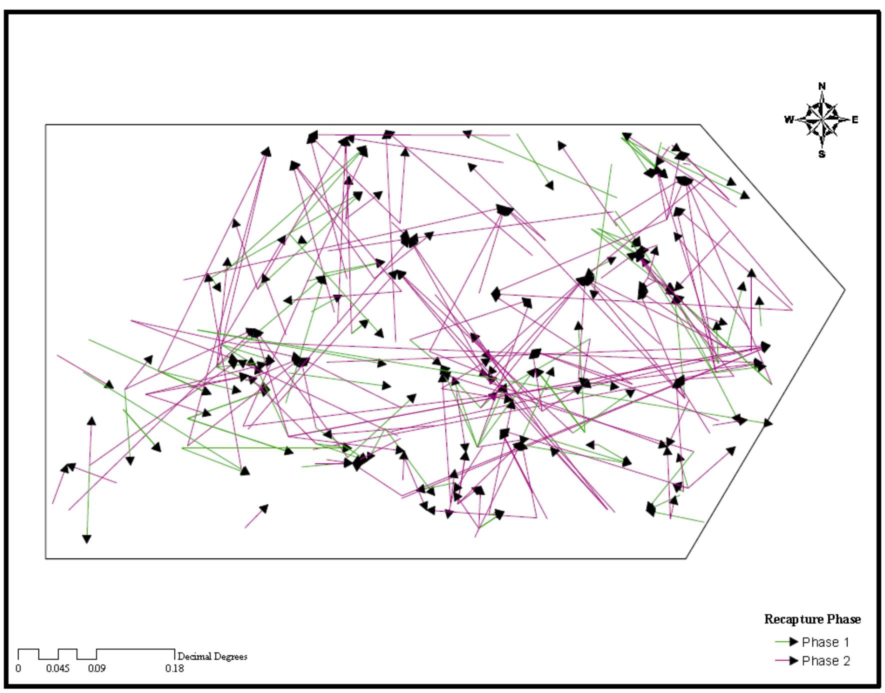


Figure 4. Release and recapture positions for all recaptured yellowtail. Phase 1 recaptures (from the tagging stage of the experiment) are shown in green, and Phase 2 (the recovery stage) in purple.

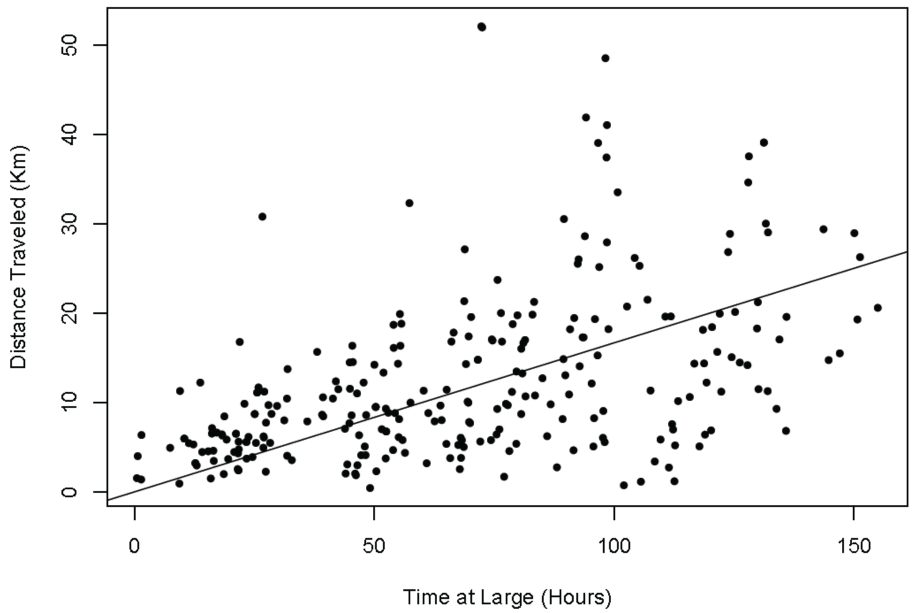


Figure 5. Regression through the origin of distance traveled versus time at large.

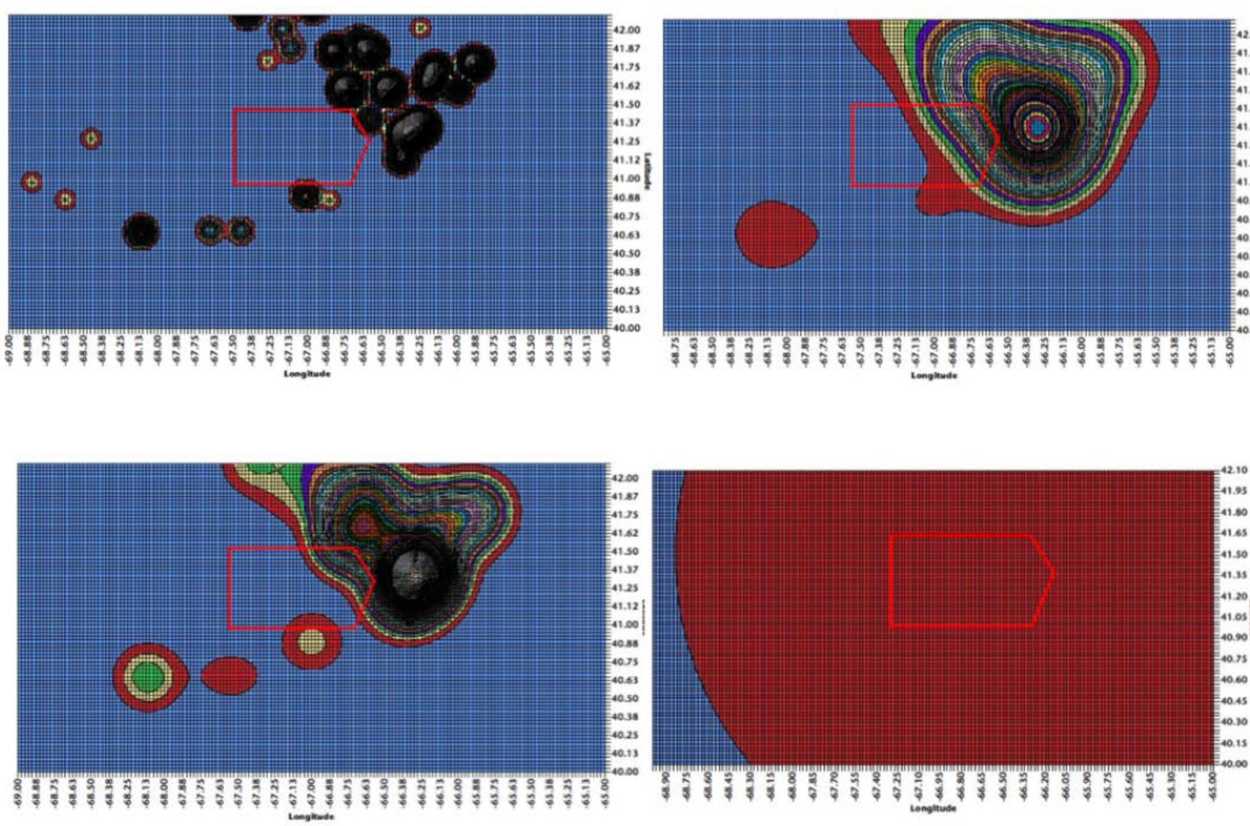


Figure 6. Model results of yellowtail flounder survey biomass dispersion at 1, 10, 24 and 192 hours. The red box marks the study area.

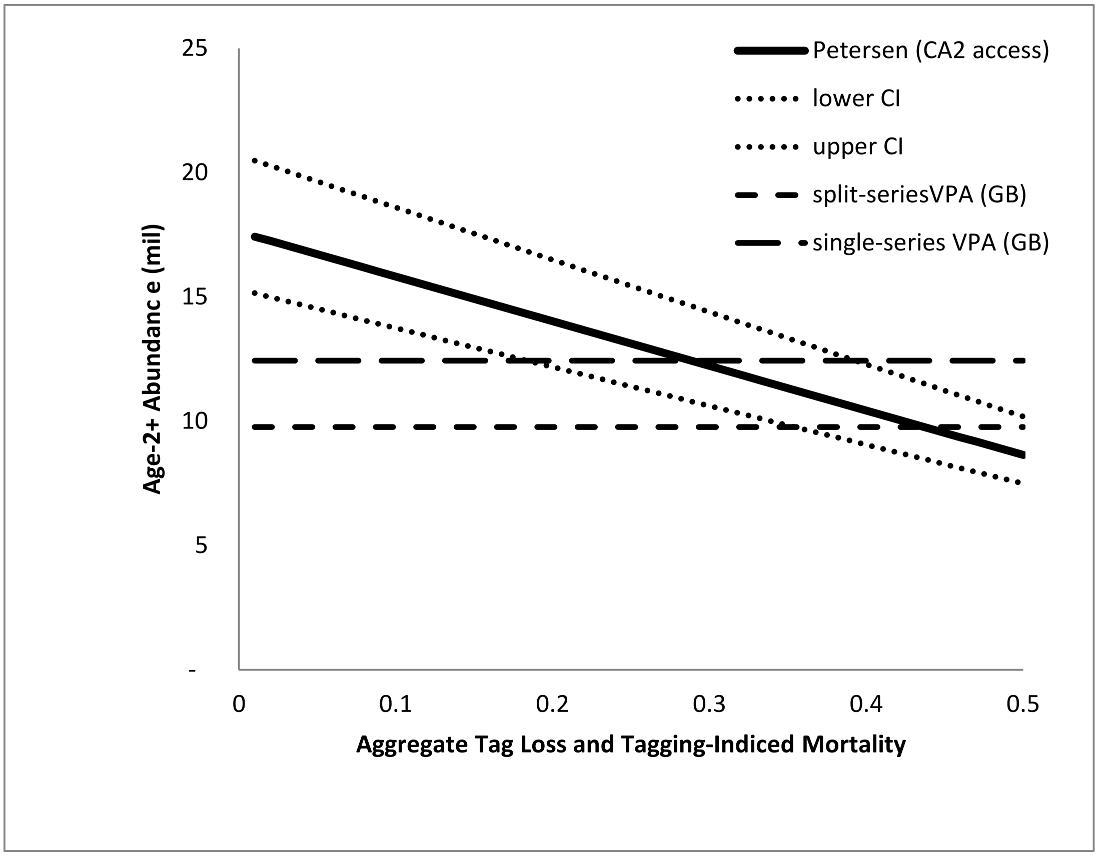


Figure 7. Sensitivity of abundance estimates from the Petersen model (with 95% confidence limits) to tag loss and tagging-induced mortality, compared to contemporary estimates from VPAs.

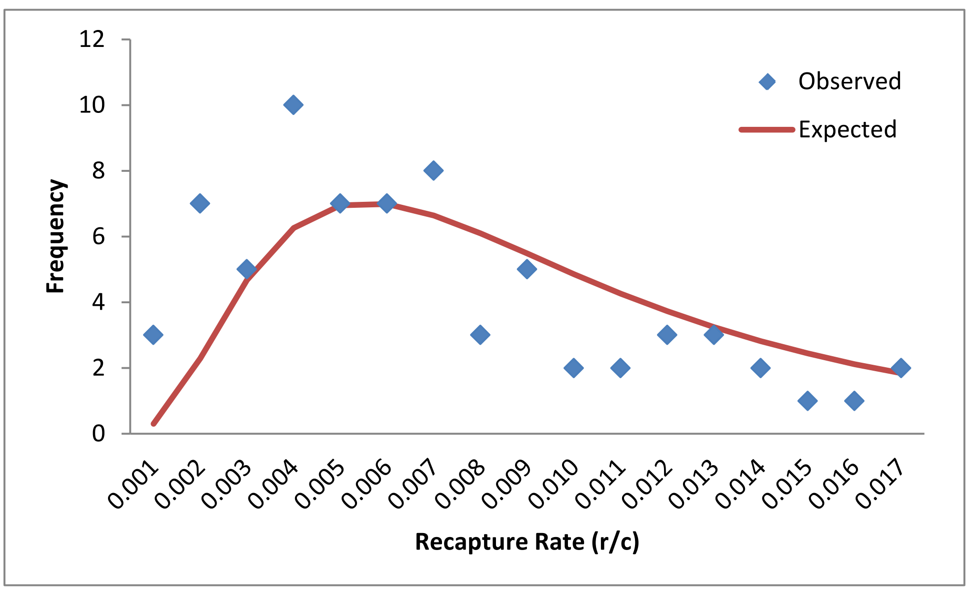


Figure 8. Statistical distribution of recapture rate of tagged yellowtail compared to an expected lognormal distribution.

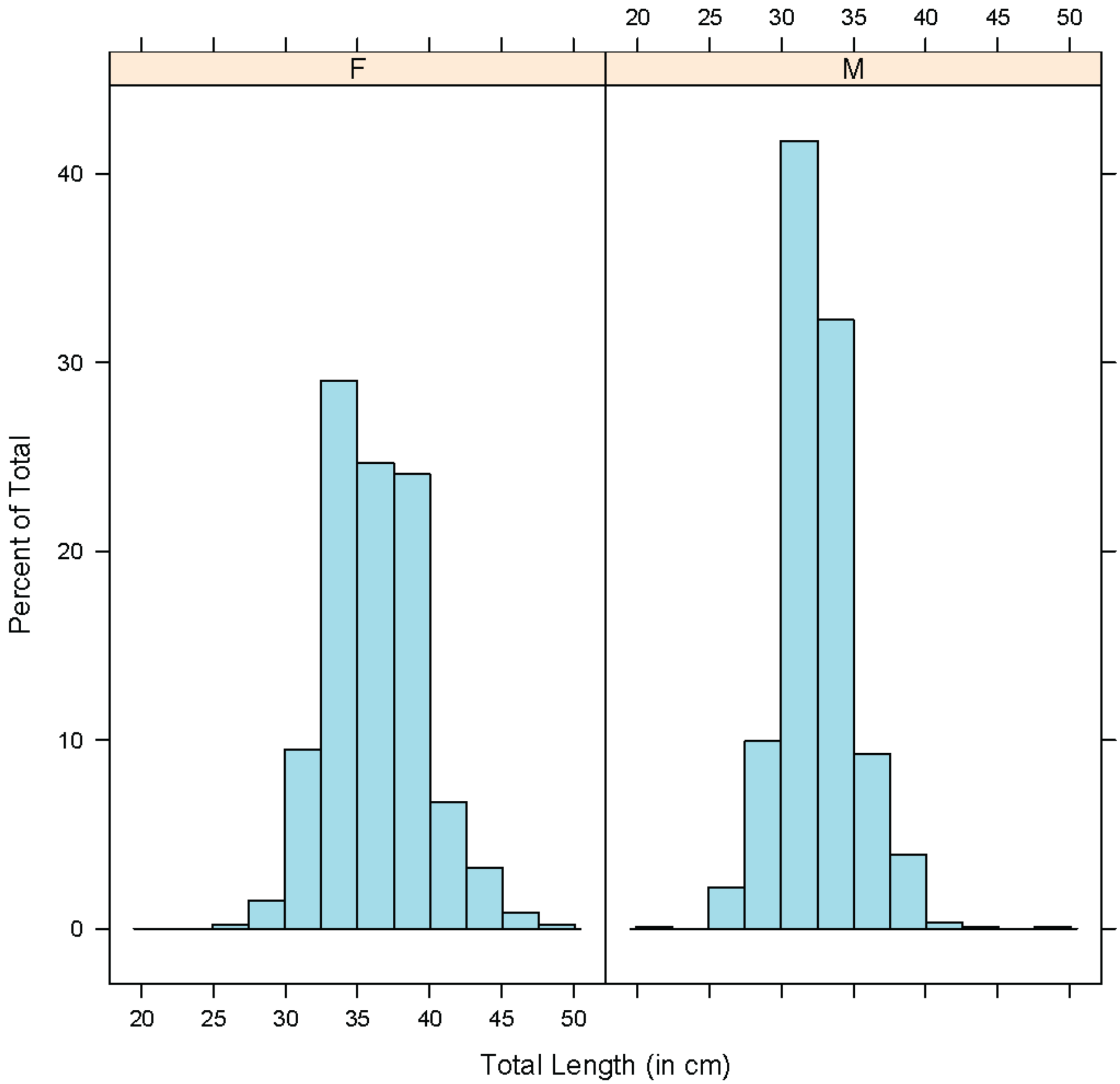


Figure 9. Histogram of length samples by sex (n = 2607).