Tagging 2008:
A Report on the Northeast Regional Tagging Symposium
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Tags have been used throughout much of the past century to learn about fish movements and populations. From simple metal or plastic tags to highly advanced acoustic and satellite popup tags that record detailed behavioral patterns and environmental data, researchers now have a variety of choices when it comes to the equipment used in fish tagging studies. Science is now less limited by technological options, but more by financial constraints that may require reformulating hypotheses and outside-the-box thinking to achieve scientific goals. The budget balancing act has led to innovation.

Tagging programs are often discrete studies that address specific objectives (e.g., mortality, movement, growth), but with careful project design and data analysis, tagging data can be integrated with other data sources to provide unique perspectives on challenging issues. Now, research often involves multiple stakeholders over wide geographic areas; collaboration between scientists, managers and fishermen has become more common in recent years to the benefit of everyone involved.

Sharing results and data is a cornerstone in the process of improving fishery management. On Oct. 17, “Tagging 2008: The Northeast Regional Tagging Symposium” was convened at the University of New Hampshire to summarize several tagging studies, collect stakeholder feedback to enhance data interpretation, and discuss fishery management applications of the data. The ways in which tagging enhances stock assessments and our understanding of the impact of closed areas were highlighted.

The day focused on the following questions:

- How are data being used in fishery assessments and/or management?
- How could data be used more extensively?
- What obstacles are involved in data usage?
- How could studies be improved for assessment and/or management?
- What are additional data needs?

Over 130 marine fisheries stakeholders attended the one-day symposium. There were representatives of a broad range of commercial and recreational fisheries and industry organizations, as well as academic and government scientists, fishery managers, students and tag vendors. Attendees traveled from as far away as Newfoundland and Maryland.

Although oral and poster presentations focused on fish species that reside in the Northwest Atlantic, keynote speakers provided perspectives from further afield and on the use of more advanced technologies. The first, David Welch, president of Kintama Research Corporation, spoke about the Pacific Ocean Tracking Array, a fixed acoustic array that monitors fish movements in riverine and coastal systems. Molly Lutcavage, director of the Large Pelagics Research Center at the University of New Hampshire, shared how satellite tagging of Atlantic bluefin tuna is challenging long-held management assumptions of east-west stock definitions. Overall, the symposium showed that with careful study design and data analysis, tagging data can indeed be integrated with other data to provide unique perspectives on challenging fishery issues.
The Pacific Ocean Shelf Tracking (POST) system is “so good that researchers can get a quantifiable knowledge of exactly how many fish from a given release move from one location to another,” according to Welch. This technologically advanced fish tracking system utilizes top of the line acoustic tags and receivers, allowing scientists to conduct research directly in the ocean and make quantitative statements based on the results. That is what moves science forward the fastest, Welch said.

The POST array is located on the continental shelf and slope waters near British Columbia, Alaska and parts of Washington state, but will eventually extend out to the Aleutian Islands and down to California and Mexico. It began in 2001 at Dalhousie University as part of a $45 million effort to globalize the concept of precise fish tracking systems. POST is the model, Welch explained, but more will follow in locations like New England, the Arctic, South America and Australia.

“The POST system is like a fish ‘EZ pass’ where an animal can go through and the receivers accurately record which individual fish it is,” he said. The receivers sit on the sea bed and must work to a very high standard. They need to log the time and date of each fish movement and they must reliably pick up each fish that moves in the receiver’s vicinity.

“Remember, the quality of a tagging system is measured by what we get operationally, not theoretically, out of these systems,” Welch said. “You have to have all the equipment in place and it all has to work. The batteries can’t be in upside down. Experimental confidence degrades as you move away from perfect detection.”

Taking a step back to historical tagging days, Welch showed a photo from Popular Mechanics magazine in June 1938. The photo depicted sardines off the coast of British Columbia that had metal tags on them. Although sardines move thousands of miles along the coast of California, they were recaptured in the same location where they were tagged. “It seems like they didn’t move very far, but over five or six years, that fish may have done a lot of movement up and down the coast,” he said. “Their complex movements weren’t known because the simple metal tags only trace a line of movement from release to the recapture site. Electronic tagging offers the opportunity to learn much more.”

Just prior to when the technology was developed for POST, there was much discussion about the movements and population assessments for sablefish, one of the most economically valuable fish species off the coast of Vancouver Island. The various population models generated for this species were not always in agreement with one another and often did not reflect the true stock status of the fish.

The models indicated there to be two separate populations of sablefish — one off the coast of Queen Charlotte and one in southern British Columbia. The models assumed fish populations to be closed, with no movements between the populations. “Even really small numbers of interchange can lead to very major changes in the results because basically your model is leaky,” Welch said. However, when actual fish movements were examined, it was noted that fish from both areas commingled, moving up to Alaska, down to California, and everywhere in between. This violation of one of the basic model assumptions had huge impacts on the sablefish population estimates. “If a model can’t recreate fish movements, then no matter how sophisticated the model is, it won’t give you the correct answer,” he added.

Sablefish are not the only species moving far off the coast of British Columbia; dogfish previously marked with titanium tags near Vancouver Island moved as far away as Mexico, Alaska and Japan. Thus, restrictions on harvest near British Columbia may or may not have an impact on fish populations. It is evident that fish movements are highly complex and that the more information that is available will only help improve management decisions.

With the POST system, a uniquely identifiable electronic tag is surgically implanted in the fish, and then movements can be followed as the tag transmits its signal which the tracking array detects. The advantage to this setup is that a fish never has to be caught again, because as long as the tag transmits the code to the array, detailed information about fish movements can be discerned.

Each acoustic tag costs approximately $400, “so we want to treat these fish really, really well to keep them...
alive,” Welch said. “If the surgical process to insert the tags is done well, there is essentially no mortality. I would maintain that the animals recover fully and quickly with our methods.”

Currently, the POST array runs for 2,500 km from the Snake River, down the Columbia River, out to the bay and around Vancouver Island, and it then extends up into Alaska. There are 182 array receivers stationed in these regions, each at about 150 m depth. The receiver “nodes” have a four-year life span and they sit autonomously on the sea bed. Researchers can drive a boat within close range of them and retrieve data stored in the nodes via a short-range wireless link.

Welch showed a photo of one of the Vemco VR3 receivers. They look like upside-down lawn chairs, he joked, but their design allows the units to be stationed in the ocean permanently for 10 years. Initially, relatively cheap 500 lb. concrete blocks were used for the anchoring system. “We discovered that cheap can be really expensive when you're trying to get these systems to work,” he said. Now they use a more sophisticated, albeit expensive, anchoring system. There is no metal on the receivers at all to prevent corrosion, and the anchors are extremely heavy to withstand the pull of fishermen's trawling gear that may accidentally catch on the equipment. “Success is defined by having the system remain in place and to be able to retrieve the data,” he said, which justifies the high cost.

Commercial fishing boats are chartered to set the arrays in place. “The folks that run those boats have a Ph.D. in actually getting things done,” Welch said. “The fishermen have been enormously successful in holding the vessels in position while the receivers are put in precise locations.”

After explaining all the array details, Welch discussed examples of how POST has been used. One project involved sockeye salmon in the Fraser River. The population is composed of three groups based on the time of year they migrate upriver, and include the early run, mid-summer run and late-run stocks. Although these fish are all from the same species, distinct movement patterns occurred like clockwork during the past century. The early run fish came in from the ocean, up the Fraser River, spawned and died. The mid-summer runs came up the river, stayed in the inland lakes for six weeks, then moved further upriver, spawned and died. The late-run stocks came in to the Strait of Georgia, held there for six weeks, then moved up the Fraser River to spawn and die. Then in 1996, migration patterns began to change. The holding period for the late-run stock in the Strait of Georgia began to shorten, and by 2000 there was essentially no holding period.

“That change by itself would simply be an interesting biological observation,” Welch said, “but the devastating result was that 80-90% of the animals that moved into the Fraser River died early, before moving to the spawning grounds.” Thus, no late-run sockeye salmon were available for harvest. In addition, the late-run stocks began to move upriver at the same time as the mid-summer runs, and so the “weaker” late-run stock commingled with the healthier stock, and no fish from either group were allowed to be harvested. This caused a $100 million hit to the British Columbia economy and has created a major fish conservation problem, he added.

The underlying question is, why, after a century of stable behavior, were fish suddenly leaving the ocean early? By 2006, acoustic tag technology was working at 100% tag detection efficiency, so Welch and his colleagues designed a study to answer that question. Sockeye salmon were tagged and released in the Juan del Fuca and Johnson Straits.

The working assumption had been that poor salmon survival was a function of early arrival to the river. Using POST, it was discovered that there was a very high mortality rate in the ocean prior to when the fish migrated upriver. To further explore this observation, some of the tagged fish were recaptured and moved to laboratory tanks, some in freshwater and some in saltwater. The fish were injected with a hormone to slow down maturation in hopes of slowing their mortality. Welch said he was surprised to learn that the fish, which are normally robust in lab tanks, were dying “like flies” in all the saltwater tanks. The mortality rate in saltwater tanks was at 10%/day, similar to observations of free-ranging fish. Salmon held in freshwater tanks had much lower mortality rates at 1%/day.

One of Welch’s colleagues, Christie Miller at the Canadian Department of Fisheries and Oceans in
Nanaimo, British Columbia, took a look at the fish genes to learn more about this strange situation. The DNA was taken from late-run tagged fish in John-son Strait, about 300 km away from the Fraser River mouth, and from fish that survived to spawn up-stream. The fish that died prior to getting halfway up the river somehow “turned on” certain genes that are associat-ed with an immune response. Mortality of the late-run stocks appears to be related to a disease.

“These animals knew they were physiologically in trouble long before they went to the river mouth, and at that point they decided to migrate upstream early,” Welch explained. Apparently, the fish are dying while still out in the ocean but they know that getting to freshwater might help their survival. “That’s the key to very precise observational systems like POST,” he added. “It gives us the opportunity to completely change the way we think about scientific observations.”

To further test the hypothesis of the dams influencing smolt survival, one of Welch’s Ph.D. students at the University of British Columbia compared the fish in the Snake River to those in the nearby Yakima River. The salmon smolts must go through eight dams on the Snake River to reach the ocean, but the Yakima River smolts only need to go through four. It was determined that the survival rates of the smolts leaving the two rivers were similar, about 50%. “We’re not seeing any manifestation of different mortality rates within the first month after they pass the final dam and head toward the ocean,” Welch said.

The number of adult salmon that return to these river systems is different; the Yakima River salmon exhibit a 2% survival rate, while 0.5% return to the Snake River.

Special barges were constructed to transport the smolts down around the Snake River dams to help decrease the mortality rates. “Somehow the barging activities must increase their stress levels because it turns out barging does not improve smolt survival.”

Welch noted that the barge system allows smolts to reach the ocean three weeks earlier than they normally would. The extra three weeks they spend in the ocean does not guarantee that more will survive. “The assumption by freshwater fish biologists is that the
ocean is a kinder, gentler place than rivers,” he said. “Most people who have seen sharks know that is not necessarily true.”

Switching gears, Welch discussed performance and design issues for the POST arrays. When the system was first put in place, it took an enormous amount of effort to keep it operational. As time progressed, the technology improved and the system was easier to maintain, which led to less error in the data and therefore greater scientific confidence in the results. Vemco, the company that manufactures the acoustic tags, now produces thirteen different tags that researchers can choose from. This is a far cry from the one tag that was available when POST originated. Thus, POST technology must keep advancing, he said.

Finite financial resources often limit acoustic tagging projects. The question then becomes how should researchers distribute those finite financial resources among receivers, acoustic tags, receiver placement and tag programming? Refining the scientific objective may be necessary to achieve the level of precision that is required for a project. A certain number of receivers are necessary to optimize the detection efficiency. Otherwise, an enormous number of acoustic tags will be needed to compensate and collect accurate fish movement data.

In summary, Welch noted that technological advances historically have led to big advances in science. POST allows for experimental studies to occur directly in the ocean and he believes this technology allows for rapid progress in fisheries stock assessments. He urged the audience to think about how each project fits into the bigger picture of regional scientific dilemmas, particularly as acoustic arrays are installed in New England and Halifax in the future.

One audience member noted that the acoustic and PIT tags used on Columbia River smolts yielded very similar results in regards to fish survival rates. Welch explained that although acoustic tags cost $400 each and PIT tags are $2.15, it takes about 200,000 PIT tags to run an experiment, which ends up costing just under a half million dollars. “Well, if you only need 50-100 acoustic tags at $400 a piece, that’s about $40,000,” he said. “That’s starting to look like a more reasonable investment return, and you get a lot more information too.”
Striped bass are migratory fish found along the Atlantic coast and are important both recreationally and commercially. Although numerous tagging studies have been conducted along the coast and in the Chesapeake Bay, it was not until the 1980s that regular tagging studies began, Sharov said. The striped bass population crashed in the mid-1980s and a five-year moratorium was placed on the fishery. In response to the collapse, an emergency striped bass action study plan was created to gather information about the fishery, including age and sex composition of the stock, seasonal and regional mortality rates, survival and spawning potential.

In 1987, the Maryland Department of Natural Resources (MD DNR) began regularly tagging striped bass on the spawning grounds in April and May. This effort was part of the U.S. Fish and Wildlife Service’s cooperative coastwide tagging program. Sharov explained that tagging studies like these allow researchers to learn about fish migration routes and movement rates, survival and mortality, and to estimate population size. This information helps influence management decisions.

The fish were caught with multi-panel gill nets and marked with Floy tags. Their biological information, including size and sex, were recorded and scale samples were taken for age determination. Fish were tagged primarily in the upper Chesapeake Bay, Potomac River and Choptank River.

“Once we tag these fish, where were they recovered? Russia? Mozambique?” Sharov joked. “The most interesting slide to look at is the one that shows where the fish were recaptured.”

Data collected over the past 20 years indicate that striped bass that spawn in the Chesapeake Bay move throughout the Bay and along the Atlantic Coast. Some go as far away as North Carolina and Maine. This information is essential to determine migration rates; specifically, the probability of striped bass tagged on the Chesapeake Bay spawning grounds that would be recaptured along the Atlantic coast.

Migration rates from the Chesapeake Bay were estimated to determine the probability of fish that are recaptured and reported. “You have to endure a little bit of headache going through the mathematical equations, but being confident about our estimates is important,” Sharov said.

The calculations yielded some interesting results. “The striped bass migration probability is a function of size…a 100 cm fish has almost a 100% probability of moving out to the coast.”

A release and recapture matrix was tabulated to summarize the number of fish recaptured each year after the tagging event. The number of yearly releases from 1987 to 2007 ranged from 525 to 2,354 fish. The number of recaptures typically peaked the same year or one year after the tagging event occurred and decreased over time until no fish were recovered.

Recapture locations for striped bass tagged in the Chesapeake Bay.
Multi-year tagging studies such as this can be helpful in estimating the fish survival rate by comparing the expected number of fish recaptured to the actual number of fish recaptured as the years progress. The Brownie equation was used to calculate the expected number of recaptured fish for a given year.

There are certain assumptions that must be met in order for multi-year tagging data to work correctly in stock assessment models:

- The tagged sample of fish represents the overall population;
- All the tagged fish within an identifiable class have the same annual survival and recovery rates;
- There can be no tag loss from the fish;
- Fish survival is not impacted by the tags; and
- Each fish must be independent from one another.

With these assumptions, fish survival can be estimated in a different way, using the MARK computer program, in which survival is directly related to the instantaneous rate of mortality (Z), where \( Z = -\ln(S) \). The instantaneous rate of mortality is then used to calculate fishing mortality \( F \). “For a long time, we assumed that the striped bass natural mortality was constant at 0.15, or 15%,” Sharov said. Thus, to calculate \( F \), he used the equation \( F = Z - 0.15 \).

A variation to this approach uses the catch equation model, which also takes into account a relationship between fishing mortality, fish harvest rate and total mortality. “There is a third model approach,” Sharov added, “that is very similar to the previous two I mentioned, but it exclusively considers the fact that the exploitation rate is a function of the fishing mortality and natural mortality.” All three models were used to analyze the data from the striped bass tagging programs in the Chesapeake Bay.

Estimated rates of striped bass survival and mortality in the waters of Maryland were combined with data from Virginia, Delaware and the Hudson River in New York to examine striped bass population trends between 1987 and 2006 on a larger scale. There was a decline in the survival rate and an increase in the fishing mortality rate of striped bass in most regions during that time span. The fishing mortality trends were more erratic than survival trends; in Maryland and Virginia, the striped bass fishing mortality spiked in the mid-1990s at around 0.29, or 29% total mortality, but has declined since that time. These coast-wide estimates indicate general trends and are not specific to the Chesapeake Bay itself, Sharov said.

The MD DNR strives to keep fishing mortality under 0.27 for striped bass in the Chesapeake Bay to help maintain stable fish populations. To confirm population status and mortality estimates, additional data analyses were conducted using a summer-fall tagging study between 1993-2004 that targeted “resident” fish under jurisdiction of Maryland, Virginia and the Potomac River Fisheries Commission. Legal-sized fish — those measuring 18” or longer — were tagged and released during five synchronized release periods starting in Maryland and working south to Virginia. For example, in 1997, approximately 9,200 striped bass were tagged and released, starting in Maryland waters in August and ending in Virginia waters during November. A logistic model was used to help estimate the fish recapture rate based on these data, he explained. From that, the exploitation rate was calculated and then total fishing mortality was estimated.

All the equations and models showed that the striped bass in Maryland had a maximum fishing mortality rate at \( F = 0.24 \), below the target of 0.27. Since the summer-fall tagging program ended in 2004, another approach is necessary to calculate the survival rate and mortality estimates for striped bass in the Chesapeake Bay.

Estimates of total mortality (Z) for striped bass larger than 18” have generally increased in the last two decades.

Fishing mortality (F) for striped bass larger than 18” in Maryland waters in the Chesapeake Bay was 0.24, below the target maximum of 0.27.
mortality rates for later years. The data from the annual spring tagging study was used. To estimate the striped bass fishing mortality for the Chesapeake Bay alone, Sharov said he only used the tagging data from fish typically residing in the bay — primarily male fish between 18-28” in length.

Data from the spring tagging studies were applied to the same calculations and models as previously described. Based on this information, there was a declining trend in striped bass survival from 1987 to 2006 for both Maryland and Virginia waters. Virginia’s data showed more erratic fluctuations in survival rate than that of Maryland. “We hypothesize that it is likely the result of fish not mixing together and the fact that researchers are tagging fish only in one location,” Sharov explained. “These estimates might not be representative of the total striped bass population in Virginia waters.”

As the survival decreases, mortality rates increase. However, even with the increase in mortality rates over time, for each model and calculation used the striped bass fishing mortality for the Chesapeake Bay is still less than the maximum limit of 0.27, which is good news. “What is worrisome is that the estimates of natural mortality are much higher than we originally thought they were at 0.15,” Sharov said. “This may be due to the development of mycobacteriosis, a wasting disease found in striped bass throughout the bay. For that reason, there are ongoing studies in the bay to look at the mortality effects of this disease.”

Managing the striped bass fishery in real-time is an extremely challenging task, but researchers are currently trying to do so based on the estimates of fishing mortality and quota. The harvest control model is the best choice for this application. It calculates exploitable stock biomass, the amount of fish that can be harvested without negatively impacting the population. The model requires data for the abundance of striped bass at age one in the Chesapeake Bay, but this information is not known. Instead, researchers are using the juvenile index, which is a good measure of the year class strength. This yields a relative index for the exploitable stock biomass that can be used in the harvest control model. The outcome from all these calculations will be used to estimate fishing mortality, migration rates and the striped bass population status. “These estimates are the integral implements for fisheries management of the striped bass population in the Chesapeake Bay,” Sharov said. “Data from our tagging studies are used in the management process, so that’s where we’re at.”
Cadrin mentioned that a similar symposium was held in 2004 in Kennbunkport, Maine, where scientists reviewed the project designs of various tagging studies. Examining the strengths and weaknesses of the studies allowed Cadrin to improve the scientific design for the yellowtail flounder tagging program that began in 2003.

“There are many different decisions to make when designing a tagging study, including when and where you’re going to tag, how to capture the fish, and how to get a high reporting rate from the fishing industry,” Cadrin explained. “A lot of the expertise out there on the water helped our scientific design.”

Originally, Cadrin and his colleagues wanted to estimate flounder movement, mortality and growth in New England waters, but he realized that it is difficult to optimize a sampling design to meet multiple objectives. However, representing the entire yellowtail population by the tagging subset allowed the researchers to get reliable estimates of movement, growth and mortality within one project.

NOAA trawl survey data were used to determine relative yellowtail abundance throughout New England waters. The number of fish to be tagged in each area was set proportional to local abundance. Between 2003-2006, approximately 40,000 legal-sized yellowtail flounder were tagged with Peterson disc tags. Of those, 10% were high-value reward tags and 20% were data storage tags that recorded time, depth in the water column and water temperature.

Cadrin said approximately 4,000 flounder have been recaptured so far, but tag reports are still trickling in. The reporting rate is estimated at 58%, a number that is relatively good for a commercial tag recapture system. “That is thanks to the outreach efforts of all the people involved,” he added.

The data indicate that yellowtail flounder make frequent movements inside the current stock management units of Georges Bank, Gulf of Maine/Cape Cod and southern New England. In Nantucket Shoals, a large portion of tagged flounder in the Lightship Closed Area moved east into Georges Bank. “We might have a bit of a stock boundary issue going on there,” Cadrin said. “Some of the movement there was higher than we expected.”

Ancillary studies for this program, including tests for tag loss and tag-induced mortality, help augment the data and clarify the results. Commercial fisherman David Goethel participated in a cage study, holding a subset of the tagged and untagged fish. Very high survival rates of both tagged and untagged fish indicated low tag-induced mortality. Cadrin’s previous lab studies, some three years in length, have shown no tag loss on flounder using the same type of tag that he describes as “pretty heavy hardware.”

To highlight how tagging data have traditionally been used in fishery science, Cadrin explained how the stock boundaries were re-evaluated in 2002 for New England yellowtail flounder. The mid-Atlantic and southern New England regions had been considered as separate self-sustaining resources. However, after evaluating the genetics, morphometrics and larval drift of flounder in these regions, scientists determined that a large portion of flounder in the mid-Atlantic New York bight were moving up into southern New England. A tagging study conducted in 2002 showed the percentage of yellowtail flounder that were residents of each area; 98% in Cape Cod, 97% in Georges Bank, 94% in southern New England, but only 30% for the mid-Atlantic region. Cadrin said the low residency in that area is due to fish moving freely between the mid-
Atlantic and southern New England, and these two areas are now treated as one management stock rather than two.

“What we want to do now is advance the applications of tagging and get more intimately involved with stock assessment,” Cadrin said.

He moved on to discuss stock assessment models that are based on tagging data. He showed an example of how the data can yield different results depending on the type of model used. The two models considered in the 2008 stock assessments of yellowtail flounder used different patterns of gear selectivity, the vulnerability of the fish to the gear due to its size or age. One model assumes a flat-top selectivity curve, where small fish are not vulnerable to the gear but once they reach a certain size and age, they became fully vulnerable. This assumption implies that a lack of old fish in the fishery indicates low survival.

The second model assumes a dome-shaped selectivity, where young fish are not vulnerable, middle-aged fish are caught and selectivity peaks, and older fish demonstrate low selectivity. Cadrin explained that this would mean older fish are somehow better able to avoid fishing gear than younger fish, or perhaps that they move off the fishing grounds while the younger fish do not.

Scientists rarely have all the information necessary to make a decision on which selectivity model to use, as was the case for the yellowtail program. So instead, the assessment team used the tagging data to determine if there was a reduction in recapture rate by size. Female yellowtail flounder had a constant recapture rate over the range of sizes. Males exhibited the same pattern, although fewer males were released and recaptured, which makes this assumption less certain. Therefore, because there was no reduction in the recapture rate by size, the final stock assessment used the flat-top selectivity model rather than the dome-shaped assumption.

“This is one example of not using tagging data directly in the stock assessment, but rather using the tagging data to make a decision about the stock assessment,” he said.

Although more female yellowtail were tagged than males, there were proportionally fewer males recaptured. The significant difference in recapture rates indicates an imbalance in their population dynamics, Cadrin explained. Data collected during fish surveys also indicate that the majority of flounder that comprise the fishery are indeed female. Male flounder might be experiencing higher natural mortality or they may simply not be growing large enough to be recruited to the fishery. Thus, sex disaggregated stock assessment models are currently being created to account for this difference.

Tagging studies are also used in stock assessment to identify independent estimates of survival. Initially, the yellowtail tagging program’s goal was to model movement and mortality simultaneously using a fairly simple process equation. There is an entire matrix of flounder movement possibilities, and a recapture model is also used. The known fishing rate, tag reporting rate and number of tags at large are used to predict the number of recaptures. Comparing the predicted recaptures to the observed recaptures allows for an estimate of survival and movement.

Larry Alade, one of Cadrin’s graduate students, ran ancillary simulations to determine how well their yellowtail model performed on different management areas. He found that the model was fairly accurate for most areas except for southern New England. Cadrin noted that the decreased model accuracy for that region is likely due to the lack of yellowtail in that area. The yellowtail flounder populations are depleted in southern New England, and thus the proportionally low release of tagged fish reflected that. Because so few flounder were tagged, the model estimates suffered from the low sample size.

“In retrospect, we probably should have listened to the fishermen from southern New England when they were asking for more tag releases down there, because it would have helped us out with the estimation,” Cadrin said.

After going through the model outputs, he admitted that using tagging data to estimate movement and mortality might be a losing proposition. The movement and mortality parameters used in the model...
turned out to be highly correlated, “which is always a bad thing in estimation models, because the model will try to explain a pattern of recaptures using these parameters, but it doesn’t know which parameter to use,” he said. Thus, scientists cannot reliably estimate both movement and mortality.

A few options are available to add stability to the model estimates. The model can be simplified or additional information could be used along with the tagging data to add stability to the model estimates.

“There’s a third option here,” Cadrin joked, “and that’s to quit your stock assessment job and move to an academic position, which in retrospect also has some challenges.”

Model simplification was explored by Tony Wood, one of Cadrin’s post-doctoral students, who used the Brownie model to track the different fates of a fish and estimate the recovery rate. In general, the model estimated that survival was approximately 90% per month, or about 10% mortality. The estimate agreed with their assessment that yellowtail are likely experiencing a high mortality rate. Additional model analyses will be run in the future, such as modeling each release event rather than the entire batch as a whole, modeling different stock areas, disaggregating the recovery rate for males and females, and the inclusion of fishing effort, catch and survey data.

The second option to include additional information along with the tagging data was also explored. Cadrin explained the current methods of stock assessment for the yellowtail flounder populations. The virtual population analysis (VPA) estimates use catch-at-age information to reconstruct the cohort abundance back in time. These VPAs are combined with the tagging data to estimate yellowtail movement. While this is a fairly straightforward method for determining movement between two management regions, it becomes a complex problem when trying to estimate the various movement scenarios among all the regions. A statistical catch-at-age model has similar inputs as the VPA, but has a more flexible framework for the tagging data.

So now, Cadrin and Ph.D. candidate Dan Goethel are using a statistical catch-at-age model, which has similar inputs as the VPA, but a more flexible framework for the tagging data. It uses survey data, tagging data, and a weighting coefficient for each. Cadrin said this allows the model to fit the data very closely. The best model performance occurred when they put a higher weighting coefficient on the catch-at-age data to estimate flounder movement and mortality. However, other snags in the model outputs cropped up, Cadrin noted. The large rate of flounder movement between Georges Bank and southern New England described in model outputs would have indicated that a large proportion of the 1987 year class was caught; however, this was not the case according to past fish surveys.

“It may be that our movement only applies to legal-sized fish and that we can’t include smaller-sized fish in our analyses,” Cadrin explained. “Maybe we are not able to apply the model outputs on movement data to historical data. Or perhaps the management boundaries are coming back to haunt us.”

The tagging data were used to predict the recaptures, he said. However, stock assessment models do not work like that; instead, they predict the fishery catch-at-age and the survey index-at-age, neither of which is a true observation the way tagging data is. “Tim Miller from the Northeast Fisheries Science Center is working on a model that disaggregates the catch-at-age and survey data back to the probability of capturing a tagged fish that is two years old and has a length of 30 cm,” Cadrin explained. “This type of model really turns stock assessment models on their ear. He’s taking a tagging approach to stock assessment by using finite-state continuous-time models.”

This model allows for more finite states, such as a fish being alive in a certain area or natural mortality in another area, than the Brownie model. Some of the early results show that yellowtail populations in Georges Bank are significant contributors to stocks in Cape Cod and the Gulf of Maine areas, Cadrin said. Southern New England still exhibits depleted population levels with this model, but that could change depending on future stock conditions.

Tagging data may be used to supplement or complement stock assessments, but may not work well standing alone.
Cadrin summarized his presentation with a few general conclusions. Tagging data may be used to supplement or complement stock assessments, but may not work well standing alone. Ideally, the tagging data will be used in models designed specifically to incorporate that information. Overall, data collected from the yellowtail flounder tagging program has helped to provide fairly robust representative estimates of tag recapture rates for all sizes of fish.

This highly collaborative program was successful due to the efforts of more than 50 of Cadrin’s colleagues at eight institutions, along with graduate students, fishermen and everyone who returned fish tags.

An audience member noted that when a fish is caught and tagged in one area, it is assumed that the fish is originally from that stock, but asked how the models would account for fish movement between stocks? Cadrin said that current models assume that if a fish was caught in Georges Bank, it was born there, even though in reality this might not necessarily be the case. “Our project is raising a flag that we need to start allowing movement among all the fish stocks in our models.”

Another question dealt with the areas closed to fishing activity. “How will the models deal with fish movement if fishermen aren’t able to recapture fish in the closed areas?” Cadrin explained that the fishery exploitation rate used in the model will change value based on the closure. “If there’s a closed area, there’s no exploitation rate in that area,” he said. “If that area temporarily reopens, now there is an exploitation rate to apply to the model.”
Tallack has been closely involved in the Northeast Regional Cod Tagging Program (NRCTP) since its inception in 2003. She noted that this traditional t-bar tagging study had four primary goals; only one goal dealt with cod movements while the other three focused on the socioeconomics of the fishing industry and data availability to the public. Approximately 40 scientists from Cape Cod up through New Brunswick have been involved, along with 106 tagging vessels and 257 taggers, the majority of whom were fishermen. Tallack noted that an online GIS data mapping interface enables the public to interact with the data collected over the past five years.

The program was initially planned to run for two years, but additional funds helped to keep the project going through 2009. These funds are currently used to maintain the tagging infrastructure, rewarding system to encourage tag returns and data recording when it is reported by the fishermen. “You can’t keep asking for the tags back if you can’t respond to the fishermen providing tags,” Tallack said.

Although cod are no longer tagged for the program, Tallack said the researchers are currently working to involve members of the fishing industry in the data analyses. Fishermen may not be trained to write models, but program managers can show fishermen the initial results, ask for their input and discuss the findings, future analysis and research needs. A summary of the program was distributed in January 2008 to inform the fishing industry of initial project results.

Approximately 114,000 cod were tagged and released and more than 6,500 tagged cod were recaptured through the NRCTP. Additional cod tagging efforts were undertaken by the Canadian Department of Fisheries and Oceans, the University of New Hampshire and the School for Marine Science and Technology at the University of Massachusetts. The combined total of conventional t-bar tagged cod for the region from 2000-09 is approximately 180,000 tagged fish released and more than 10,000 tagged fish recaptured.

These data sets have been archived and compiled for further regional analyses on cod movement in the 2000-2009 timeframe. “It may help to fill some of the gaps we’ve found in the analyses so far,” Tallack said.

Moving into the stock assessment applications of these data, she mentioned that cod are managed as three separate stocks in the Gulf of Maine region: the Gulf of Maine, Georges Bank, and the Scotian Shelf in Canadian waters. The cod tagging program tagged and released cod in all three management areas.

Some key assumptions about a stock are that it is self-sustaining and that it exists in isolation without interacting with other stocks. “What we’re asking with these data is whether contemporary movements of cod support these two stock assumptions,” Tallack said. “If not, is there a need to alter any management or assessment boundaries?”

She showed a slide containing dots on a map indicating where cod were tagged, released and recaptured. Lines were then drawn between the release and recapture points for each fish. “This should be considered a dangerous picture,” Tallack said. One of the primary Cod movements based on tagged fish from 2003-07. Each red line connects points of release and recapture and indicates cod movement across stock management boundaries.
limitations of a conventional tagging study is that you don’t know where the fish traveled in between those two points, so a straight line can be very misleading.

Two other challenges to these types of tagging studies are that the fish need to be recaptured in order to obtain information, and that recapture information is affected by fishing effort. If an area is closed to fishing but the tagged fish are in that location, they will not be recaptured and thus that information is essentially lost. The reporting rate of tags can vary greatly by region and gear type, and the accuracy of a reporting rate is tough to determine.

“It is difficult to observe movements in closed areas for fish tagged with a T-bar tag that doesn’t transmit a signal to a fancy satellite,” Tallack said.

Time-at-large for the fish will also affect the tagging data. A lengthy program offers the fish more time and opportunity to exhibit variable movements and to grow, but that makes it more difficult to detect patterns in the data.

To identify the core areas of cod movement, program managers divided the area into polygons based on bathymetry data. The polygons include areas of Georges Bank, inshore mid, west and central Gulf of Maine, Cape Cod and the Bay of Fundy. Data were also organized by fish length to identify movement patterns based on size and maturity. Partitioning the release and recapture data by season allows determination of where they are located at certain times of the year.

Looking at recaptures by location, fish size and season allows movement trends to become more evident. There is some indication that mature fish show signs of seasonal homing, because their recapture locations tend to be near their original release locations within a given season, she explained.

Some “corridors” of cod movement emerged from the data. There were many east-west movements across Georges Bank, particularly during the summer months. During the fall and winter, these fish traveled further away to the Bay of Fundy. Some fish tagged on Georges Bank are also found in the Bay of Fundy during the spring. “The cod interaction between the Scotian Shelf of the Bay of Fundy and Georges Bank was fairly anticipated,” Tallack said.

The Gulf of Maine cod moved up and down the coastline but were not often found in other locations. Smaller sized cod released near Cape Cod were recaptured in the Gulf of Maine and Georges Bank regions. “When you start putting management areas over top of that, you can see that these smaller fish are essentially contributing to both the Gulf of Maine and Georges Bank stocks,” Tallack said. “The strong connection with the Gulf of Maine is a movement we did not expect to see.”

These data are relevant to cod stock assessments, but incorporating tagging data into stock assessment models is complicated. Tallack cited Steve Cadrin’s presentation on the yellowtail flounder tagging study. “They designed their tagging study for potential use in stock assessments,” she said. “They were able to set goals about releasing a specific number of fish in certain areas relative to the abundance of yellowtail that people expected to find in those areas.”

Because the use of data in stock assessments was not an original goal for the cod tagging program, they did not conduct a proportional release. Therefore, to use the cod tagging data for stock assessments, a weighting factor must be applied to the data. This factor increases or decreases the relative importance of cod releases and recaptures in certain areas according to the biomass and exploitation levels for a given area. This was particularly relevant for the Cape Cod region, where a large number of small fish were released in one area and yet the biomass estimates for this area indicate relatively low cod abundance. “If you look at what’s estimated from the cod surveys, there aren’t many cod there, so we have this big difference between what people expected could be tagged versus what we actually tagged and recaptured there,” she explained.

Tallack cautioned the audience not to read too much into the map indicating cod movements. “The movements we see don’t necessarily correspond to the biomass in that area, the fishing effort or the number of fish that could potentially be recaptured,” she said.

She then showed a simplified version of how tagging data can be helpful to stock assessments and a
A diagram of the tag weighting model that has been used to date. It takes the number of tagged cod releases and reduces them by a tag shedding rate and a tagging-induced mortality rate to estimate the number of tagged cod that survived the tag and release process. To achieve a tag recapture estimate, these live tagged cod are then apportioned based on different indicators of estimated biomass. The weighting factors for recaptures are the fish harvesting rate and the tag reporting rate for each region.

Although there are numerous iterations for the cod stock assessment model, Tallack focused on the data from the different management areas. After running the models and creating a matrix with the results, she pointed out some of the trends. Regardless of whether cod were released in the Gulf of Maine, Georges Bank or the Scotian Shelf, between 86-90% of all fish were recaptured in the same management area where they were tagged. This trend held true for sub-legal (<53 cm) and legal (>53 cm) cod. Although some movement between areas occurred, these findings indicate high retention by all three management areas.

Tim Miller from the Northeast Fisheries Science Center created a finite-state instantaneous movement model that was used with the cod tagging data. Model outputs include fishing mortality and natural mortality, and Tallack reported that the estimates are comparable to certain iterations of the model she used. Ultimately, she believes Miller’s model will likely be the one used in future stock assessments because it can be more easily aligned with current assessment models.

Once the relative proportion of fish moving between the areas is determined, the next step is to figure out if those movements are significant. “At what point do you need to change assessment boundaries and management decisions?” she asked rhetorically.

She also discussed cod growth in the various management areas during the tagging program. Growth assessments were used for fish tagged and recaptured in the same management area for the cod models. Growth curves for each region showed that cod in the Gulf of Maine grow larger but more slowly than Georges Bank cod. Looking at the growth increment in relation to the size of fish at release, the smaller the fish is at release, the more growth it will exhibit. The small fish around Cape Cod demonstrated this; the slope of the regression line is much steeper for that area than for the other areas because the fish released around Cape Cod were smaller in size.

Growth curves for each region showed that cod in the Gulf of Maine grow larger but more slowly than Georges Bank cod. The growth assessments from the cod tagging program are consistent with, but not identical to, previous length-at-age estimates, she added. However, the growth analysis is ongoing and Tallack is currently collaborating with other scientists to model cod growth from tagging data, taking into account gear selectivity and historical changes in the fishery to minimize any biases in the growth estimates.

Looking at the data from the cod tagging program as a whole, Tallack pointed out that the data were included for indirect additional estimates for fishing mortality and natural mortality. “We took a project that did not have specific goals and tried to apply very specific questions to it,” she said. “We’ve done a good job at maximizing the use of this data, but stock assessment use wasn’t identified as a need at the start of the program. For future studies, it would be beneficial to have specific objectives outlined before the project begins.”

Tallack said that although there is growing pressure to include tagging data in stock assessment models for the region, additional model development is needed before those data will truly be helpful in determining trends in cod movement.
Open Discussion for Morning Session:
Stock Assessment Applications

Facilitated by Gary Shepherd, NOAA Fisheries/Northeast Fisheries Science Center

Gary Shepherd from the Northeast Fisheries Science Center kicked off the open discussion period for the morning presentations with his own comment and question. “Many of the presentations noted that the extent of fish movement was relatively unexpected, but these data haven’t been incorporated directly into the stock assessments,” he said. “What is the next step necessary to bring the catch-at-age modeling data together with the stock modeling? Do we need better models, better data or a different approach to tagging, such as acoustics?”

Steve Cadrin responded that he thought inertia might be a factor. Incorporating tagging data into traditional stock assessment models “seems to be a method of last resort” if the model is not working properly, he said. The inertia of continuing down the same old path rather than trying something new might be altered by incorporating some type of external review of the model itself. “We need to break out of our mold a little bit so that the system will accept some non-traditional models,” Cadrin said. “I’m not sure if our machinery of peer review is as open-minded as others. Maybe we should bring in some bird ecologists who are used to making resource management decisions based on tagging data. I would say open-mindedness is one of the things needed to confront this obstacle.”

An audience member commented on project length and funding sources. Most of the presentations appeared to cover projects funded by “unusual” funding sources, such as collaborative research programs or special awards. “How realistic is it to expect that the results of tagging projects will be routinely incorporated into assessment models if the assessment scientists can’t be guaranteed this type of information will be available in the future?”

David Welch explained that this topic steps into the realm of science politics. The organizations and foundations that fund the start of a project hope that the research transitions into part of a long-term funded program. Then the foundations can step away and their money can be seed money to start the next big thing. “The problem for governments, of course, is that they don’t want to incorporate something else because they only have a finite amount of money,” Welch said. “It’s like spreading the peanut butter thinner and thinner on a piece of bread.”

This is a chicken-and-egg scenario, where long-term funding for a project requires the government to incorporate the project into their goals, but the government will not incorporate the project for a variety of reasons. The tagging data needs to be accepted, not to prove models wrong, but to demonstrate how to improve the models, Welch added. “We have to get past the point of showing that the models are leaky, to knowing how to naturally incorporate all data in a way that fits within the funding structure,” he said. “I think we’re just on that edge of showing that there are problems if you don’t include the tagging data into the models, but we’re not necessarily there in terms of showing how we’re going to incorporate it.”

Alexei Sharov followed up with his own thoughts. “Funding is obviously a constant issue, but my general experience has been that the squeaky wheel gets the grease,” he said. Scientists need to clearly demonstrate that tagging studies may offer a very different picture of what is going on with a stock than is traditionally assumed. “If you can demonstrate that you have a problem with overestimating, underestimating or getting a severely biased population estimate resulting in wrong management decisions, you are eventually going to get money to conduct a tagging study to improve that situation,” Sharov said. He thinks money, rather than our ability to build models, is the limiting factor. Project optimization is key, he said, and finding a balance between costs and results is imperative to improve fisheries stock assessment.
A Decade of Bluefin Satellite Tagging: Do Results Support Current Science and Management Paradigms?

Molly Lutcavage, Ph.D., UNH Large Pelagics Research Center

The questions posed by scientists at the UNH Large Pelagics Research Center (LPRC) are really basic, according to Lutcavage. When, where and how often do bluefin tuna spawn? Where do they forage? How do they get to the foraging grounds and back? What characteristics define their habitats? “If you know bluefin, then you know they can go anywhere they like,” she said, explaining that they have a large vertical and horizontal range of movement.

The stock management boundary that separates Atlantic bluefin tuna into “Eastern” and “Western” stocks, or management units, is set in the mid-Atlantic, west of the mid-Atlantic ridge, at 45 degrees west. The known spawning grounds for “Western” bluefin include the Gulf of Mexico and Florida Straits, while “Eastern” bluefin spawn in the Mediterranean Sea. Other spawning grounds may exist and are being investigated.

Even before the advent of electronic tags in the 1990s, researchers knew that bluefin tuna made trans-Atlantic movements that crossed the management boundary. In the 1960s, Norwegian purse seiners recaptured giant bluefin tuna tagged with traditional “spaghetti” or T-bar tags approximately 55 days after those tuna had been caught and released from the sport fishery in the Bahamas. The extent of mixing between the stocks was unknown, but was assumed to be very low.

Conventional tagging was given a leg up with the invention of data storage tags in the early 1990s and the fishery-independent popup satellite tags in 1996, Lutcavage said. Large amounts of data could finally be recorded by sensors to reveal the behavior, thermal associations and movement patterns of tuna.

Light stalks on the tags left outside the fish’s body measure raw light levels and are used to estimate the fish’s daily geolocation. “If you’re a sailor or an astronomer, you know that at each point on the globe there is a unique light curve that is described by the rising and setting of the sun,” Lutcavage explained. Latitudinal position can be estimated based on the time of sunrise and sunset recorded by the tag. Longitude is based on the estimate of local noon. The state-of-the-art technology for light-based tags currently allows researchers to estimate location to within 0.3 degrees of longitude and one degree of latitude.

Light-based electronic tags have been used for a decade, although the first generations of both implanted and popup satellite tags, which cost $1,600 and $4,000, respectively, had numerous errors, so the data were not always accurate. “Given these problems, some scientists suggested that tagging

runas and billfish with those early tags was ‘akin to throwing laptops over the side of the boat,’” Lutcavage said. “Unfortunately, the price had to be paid in the early deployments, the first real sea trials.” Since that time, tag performance has become much more reliable, and the data recorded for fish movements and behavior are now meeting expectations.

She discussed how New England scientists and fishermen became involved in tuna tagging. “It all started with commercial fishermen who wanted us to groundtruth their observations and estimates of how many bluefin tuna schools were present in the Gulf of Maine,” she explained. Lutcavage and sci-
ence colleagues forged collaborative partnerships with commercial fishermen. Aerial surveys were conducted using spotter planes between 1993-1996 to document the number of tuna schools. Hydroacoustic, or “ping” tags, helped track bluefin for up to 48 hours to identify movements and dispersal rates.

Popup satellite tags were also used after being developed in 1996 by Paul Howey of Microwave Telemetry, Inc. After implantation via a tether under the fish’s second dorsal fin, the tag sensors record data such as ambient temperature, pressure and light. After a mission life of up to one year, the tag releases from the fish and floats to the sea surface. The radio transmitter in the tag broadcasts a signal to a receiver on orbiting NOAA satellites to indicate where they are located, and the data are delivered to the researchers via Service Argos, a distribution service. During the first years of this research effort, the populats were simple “one point” location tags, and transmitted only the reporting location and daily mean ambient temperature data. They cost about $3,700, and 20 were deployed on adult tuna to determine where the fish were during the presumed spawning period (April through June). Those first tags were purchased from funds donated mostly by fishermen, Lutcavage said. “No one else really believed the tags would work, so the fishermen were the first to invest in technology to learn more about the fish,” she said.

Popup satellite archival tags are now smaller, lighter and more reliable than their first generation. Some can record water temperature and pressure every 15 minutes for up to one year, or every few minutes for a shorter time period, gathering more fine-scale data about horizontal and vertical behaviors of tuna and their environmental associations. Lutcavage said the LPRC has purchased 400 popup satellite tags over the past decade and has gotten a “compelling amount of data and new information” from them.

Starting in 1997, Lutcavage and collaborators, along with fishermen partners, primarily tracked giant bluefin, the target of the lucrative commercial fishery in New England. In 1998, a joint cooperative tagging program was formed with Canadian tuna fishermen and the Department of Fisheries and Oceans. From 1997-2003, giant bluefin were abundant in the area and the tagging included commercial fishermen in the harpoon, purse seine, and rod and reel fleets. After reaching their bag limit for the day, fishermen stayed out to help researchers tag additional tuna. For seven years, the purse seiner White Dove Too carried a bluefin scientist or graduate student on nearly every trip and would release up to 20 giant bluefin from the same school with popup satellite tags.

The New England fishery for giant Atlantic bluefin tuna has declined dramatically during the past five years, but there are large assemblages of them in Canadian waters, including Georges Bank, the Grand Banks and the Gulf of St. Lawrence. As U.S. commercial catch rates began to decline in 2004, Lutcavage and colleagues shifted their main tagging efforts to Canada and partnered with commercial fishermen in southwest Nova Scotia. “The distribution of schools appeared to shift offshore and into Canadian sectors, and we had to go where we would have access to the fish,” Lutcavage explained. The LPRC is examining possible causes for the shifts in distribution, which include disruption or shifts in their forage base, oceanographic shifts and changes in the availability of fish due to overfishing elsewhere.

Lutcavage showed a few slides to indicate the general distribution and dispersal patterns of the bluefin tuna emerging after 10 years of research. The tags popped up over a broad range in the central and southwestern North Atlantic Ocean. Some tagged tuna moved into the Caribbean Sea and some traveled to the northeast Atlantic, although none of the tags reported in the Mediterranean Sea. Lutcavage pointed out that these locations were indicative only of the tag release and recapture sites, and so fish may have moved to other locations that the logged data reveals after analysis.

Lutcavage also showed examples of bluefin depth patterns. A giant bluefin tuna tagged in Nova Scotia traveled to South Carolina where the tag popped off prematurely. The depth profile indicates that, at times, the bluefin descended deeply in the water column — to 600 m — while at other times remained within shallow depths — less than 150 m. Presumably, depth records indicate the bluefin’s feeding behavior. Deep descent records are consistent with stomach content analyses of tuna — fish found in deeper offshore waters forage for squid and octopi, while those closer inshore feed primarily on mackerel herring, sand lance, menhaden and other species.

In theory, tags that have light sensors allow determination of fish movement. However, “light-based geolocation is extremely messy and requires time-consuming analyses, just like stock assessment,” Lutcavage said. There are errors associated with obtaining and evaluating the light curve, such as light attenuation,
because tuna descend into deep water, surfacing and diving at various times. Thus, the LPRC and other labs have spent the past five years developing better analytical approaches to improve geolocation estimates, defining and minimizing errors.

The raw data collected from popup tags with light-based geolocation provide erroneous locations, and some data even indicate that fish are moving over land. Lutcavage called these data “noisy observations” and explained that there is a mathematical “common filter” that helps translate the raw erroneous data into the real locations. “For the first time, we are able to put bounds around the estimates of the tuna migration tracks,” she said. “That’s really important because if you relied on the earlier data, you might not be able to know if the fish is really on land in Winnipeg or in the Chesapeake Bay.”

Using the filter, researchers were able to show the fish movements along the coast with a 95% confidence interval of their cleaned up data. “It’s nice to finally be able to show other researchers and fishermen that we can trust these data,” she added. “We’re really happy with the status of light-based geolocation now.”

The results continue to raise questions about research on spawning habits and regions, she said. For example, she showed the results of 11 tags deployed off the coast of Nova Scotia. One fish made a trans-Atlantic trip and returned via the edge of the Gulf Stream. At least three tags popped up in the Gulf of Mexico, the assumed spawning ground for western Atlantic bluefin tuna.

“Remember, the underlying assumption about these western Atlantic fishes is that they’re all supposed to be in the Gulf of Mexico during the spawning period,” Lutcavage said. “Many of the fish didn’t play by the rules and were not found in the spawning area during the time they should be there.”

The data collected from the popup tags have raised as many questions as they have answered. If all the reporting locations from tags were shown on the map, Lutcavage said the screen would be covered and it would be difficult to detect a single movement pattern. However, these fish are only tracked for one year at a time, and a longer time series will be necessary to detect overall patterns.

When the daily geolocation data are examined, rather than simply the tag reporting locations, some movement patterns can be detected. “The point here is to see where the fish are at what time of the year,” Lutcavage explained. During the summer and fall, tuna are up on the continental shelf of the northeast U.S. and Canada. Some tuna move into the Gulf of Mexico in late January and February when the water temperatures are too cold to support larval development. “So they’re going to a spawning area way ahead of the spring spawning period, and some don’t enter the area at all,” she said. “Some of the tagged fish leave before the peak spawning time and return to the same location where we tagged them the previous year. There is no way that a conventional tag could reveal that these fish have such diverse dispersal patterns.”

Even with this technology, however, there are still many unresolved questions about their spawning habits. Are the fish spawning on the edge of the Gulf Stream? Are they not spawning annually, as typically assumed? Although popup satellite tags have illustrated the broad distribution of bluefin tuna throughout the Atlantic Ocean, they are not capable of detecting fish spawning activity. Even if the tags indicate a fish has entered a known spawning ground, there is no way to truly know if that fish is indeed spawning.

She went on to discuss the movements of juvenile bluefin tuna. “The cool thing now is that popup tags have been miniaturized, and we can deploy them on juveniles as well as adults,” she said. The LPRC’s “Tag A Tiny” program allows researchers to learn more about juvenile tuna through various tagging efforts, biological sampling and direct assessment.

More than 50 “X Tags,” the miniature popup tags, have been deployed on juvenile tuna between two and four years old in the past two years, and the data have yielded some interesting findings about the young fish. They were found diving as deep as 800 m and had a thermal range between 40-75 degrees F. Although all of the X tagged juveniles remained on the continental shelf most of the year, some conventionally tagged juveniles made a trans-Atlantic crossing.

There have been many important findings from tagging data collected during the last decade, but Lutcavage pointed out that tagging studies cannot stand alone. “A large array of ecological information and supporting studies are required to interpret the data,” she said.
Movements of Cod Relative to Closed Areas: Observations from the Northeast Regional Cod Tagging Data

Shelly Tallack, Ph.D., Gulf of Maine Research Institute

The Northeast Regional Cod Tagging Program was not designed to look at closed area usage by the fish. However, two of the program’s tagging partners, the Maine Department of Marine Resources (Maine DMR) and the University of Massachusetts School of Marine Science and Technology (SMAST), had project designs that included tagging and releasing cod in closed areas. Maine DMR focused their efforts on Cashes Ledge and the Western Gulf of Maine Closure Areas, while SMAST focused on Georges Bank Closed Area II (CA II) and Closed Area I (CA I).

As Tallack presented release and recapture data related to closed areas, she stated that she is often asked how tagged fish are captured and reported in areas closed to commercial fishing. “Many of those fish were reported by vessels out there during tagging trips, which means that the time at large for these fish was quite minimal,” she said. Sometimes while fish are tagged and released, another haul is coming up with fish recently tagged, although that is not always the case. She added that tagged fish reported in closed areas are sometimes caught using exempted fishing gear, particularly those in the recreational fishing industry.

Approximately 20,000 of the 114,000 tagged cod were released in closed areas throughout the region, and 694 tagged cod were recaptured in closed areas. Of the tagged fish released in closed areas, approximately 27% of those recaptured were located in closed areas and 73% were located in open areas. Of the fish released in the open, only 5% of the recaptures were found in a closed area, while 95% were found in an open area.

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She discussed the movement patterns of fish released in closed areas. The patterns varied based on the closed area. For example, fish released at Cashes Ledge did not seem to display any movement pattern, while those released in CA I moved slightly inshore. Some cod released in CA II moved inshore, while others moved to the Bay of Fundy and into Canadian waters. Cod in the WGOMCA did not move very far, but

“Do cod see the closed areas as ‘safe zones?’ Do they see signs of the boundary and adhere to them?” Tallack asked. She says there are people who believe fish hang around these closed areas because they can sense they will not be hunted within the boundaries. Perhaps the habitat is better inside because the seafloor is not impacted by commercial fishing gear.

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but they moved in a slightly southern direction. Tallack cautioned that these patterns are represented by relatively few recaptured fish, so the patterns may not be completely representative of all cod movements out of closed areas. In addition, many of those fish were recaptured on tagging trips, so they did not have time to move very far.

For the purposes of this presentation, Tallack defined a fish as “resident” if it was released and recaptured in the same closed area. About 30% of the cod released in closed areas were resident. Approximately 5% of the cod in CA I were residents, while 64% were residents of CA II and 69% were residents of the WGOMCA.

For the fish that were out for longer periods of time, there was no obvious pattern in their movements in terms of distance traveled. “This is pretty consistent for most of our tagging data, whether it’s open or closed areas,” Tallack said. “You only see a pattern develop when you break down the data into the time of year when the fish was released. There seem to be homing patterns at certain times of the year.”

Some closures, such as rolling closures, are put in place to protect spawning cod from March-June and October-November; however, their effectiveness for cod spawning is in question by some members of the fishing industry, management and science. Of the 114,000 cod tagged during the program, only about 1,000 were observed to be spawning at the time of release. Tallack showed a map that overlaid the locations where spawning fish were recaptured with the rolling closure boundaries on a month-by-month basis. Some of the spawning fish moved into areas where the rolling closures occurred, although many did not. With such low sample numbers, it is difficult to determine if the movement patterns are indicative of the larger spawning cod population.

“Although our data are limited by fishing effort to some degree, it seems as though the rolling closures may be missing a lot of the spawning fish they were intended to protect,” Tallack said.

In summary, she said that although the Northeast Regional Cod Tagging Program was not designed to assess closed areas, it has still provided useful information, though it should be handled with caution. Keeping the fishing effort limitations in mind is essential when interpreting the data. Overall, there is evidence that some cod stay in closed areas and that rolling closures protect some spawning cod but also miss many of them.

Tallack reiterated that although cod tagging data has not yet been used in management, it has been used in the latest cod stock assessments. She expects other applications will follow in the near future.

“The tagging data are just one piece of information and they will not result in major changes alone,” she said. “You can’t just throw out the more traditional data. It is, however, hoped that these data will continue to be applied in future stock assessments, and as such, will indirectly have an impact on management.”

One audience member asked if dividing up the closed areas into quarters would help tease out more information from the data. For example, in the western Gulf of Maine there are places where fish go to spawn and other places to feed and rest. Tallack responded that she has only broken the data down by month so far. Future analyses could include a more detailed examination of closed areas to address that question.

Another symposium attendee pointed out that most of the cod were recaptured along the edges of the Gulf of Maine, whereas there were very few fish recaptured in the central area of the Gulf of Maine. “Is this a function of lower fishing effort, or are the fish really not there?” she asked. Tallack said this pattern is definitely linked to fishing effort. She cited Cashes Ledge, where no fish were recaptured due to the lack of fishing effort. A commercial fisherman added to this explanation. The deep water and flat bottom in the central Gulf of Maine is not prime cod habitat, he said, so few cod live there. “There is a lot of fishing effort in the central Gulf of Maine, but it’s focused on other species like monkfish, white hake and redfish,” he said. “There is plenty of fishing effort there, just not for cod.”
Haddock populations and landings have fluctuated in past decades, with a few particularly low points in the 1970s and the early 1990s. Stocks have been on the rise recently and landings have been increasing, giving fishermen other fishing opportunities when cod and yellowtail flounder stocks are lower.

“This is important to note because many fishermen are excited about the possibility of more economic opportunities to catch haddock,” Slifka said. She cited the large 2003 year class as the likely reason haddock populations are currently sustainable and open to commercial fishing.

Fishermen and scientists had questions about the influence of closed areas on haddock populations; specifically, if fish were moving in and out of the closed areas and if there were interactions between the haddock stocks in the Gulf of Maine and Georges Bank. A haddock tagging program was organized in 2005 to address these questions.

The haddock tagging program was a collaborative effort between the Cape Cod Commercial Hook Fishermen’s Association (CCCHFA), the Gulf of Maine Research Institute (GMRI) and the Northeast Fisheries Science Center (NEFSC). The interactions between scientists and fishermen on the project allowed them to develop better relationships with one another, Slifka noted.

The tagging program focused on geographic areas closed to commercial fishing, including the Western Gulf of Maine Closed Area (WGOMCA), Cashes Ledge Closed Area and Closed Areas I and II on Georges Bank.

Twenty-three hook and line vessels conducted 108 tagging trips from 2005-2007. Haddock larger than 14” were tagged with lime green T-bar tags.

The CCCHFA was responsible for coordinating the boats and the tagging portion of the project.

A database similar to the one used for the Northeast Regional Cod Tagging Program was created for this project and managed by GMRI. “Mirroring the cod database was cost-effective,” Slifka explained. The database is linked to a web site that allows the public to view haddock movements and recaptures.

The program team decided to give out rewards as incentives to encourage fishermen to report recaptured haddock, specifically tag numbers, recapture locations and fish length. Rather than handing out hats or mugs for tag reports, they sent fishermen scratch-off tickets with a 30% chance of winning between $10-500. “I don’t know if this was more effective than t-shirts, but it was a new approach,” Slifka said.

The NEFSC set goals for the number of fish to be tagged in various closed and open areas based on the haddock populations in each location. They targeted 8,000 haddock in CA I and 2,000 in CA II, although only 7,316 and 1,091 haddock were tagging in those areas, respectively. Over 4,000 fish were tagged in the WGOMCA, 47 on Cashes Ledge, 6,718 in Georges Bank Open Area and 1,188 in the Gulf of Maine Open Area. Recreational vessels were used to assist with tagging operations in the Gulf of Maine Open Area. Slifka cited problems with dogfish encounters on many of the trips and expired exempted fishing permits as reasons why their goals were not always met.

Project funding was secured through a novel approach. Most of the funding came from the Northeast Consortium, but the remainder of the budget was supplied by proceeds from fish landed during dedicated tagging trips. Surplus proceeds were sent to the Northeast Consortium to fund future projects.
The NEFSC is responsible for conducting the ongoing data analyses and Slifka shared some of the basic results. More than 20,000 haddock were tagged, and so far 364 have been recaptured, although tags are still being reported. The number of recaptured haddock is low, but a few trends are emerging. Some fish that were tagged and released in closed areas were recaptured in open areas. Haddock moved in between the Gulf of Maine and Georges Bank Closed Areas, and some moved as far away as the Bay of Fundy, Long Island and south of Nantucket. Trends in the data by region indicate the majority of fish tagged in CA I were recaptured in the open area of Georges Bank; however, this trend is based on only 10 recaptured fish. “One of the reasons we think we’ve had such a low return rate from CA I is because it was deep and perhaps not all the tagged fish survived,” Slifka said. In addition, this area is only open to hook fishing during certain times of the year, so there is not as much fishing effort. Fishing is also limited to haddock 18” or larger, so smaller tagged fish may not have been caught by the commercial fishery. The majority of haddock tagged and released in CA II were recaptured in the Georges Bank Open Area, both on the U.S. and Canadian sides. One of those fish moved into Gulf of Maine waters, and Slifka noted that it therefore moved across haddock stocks previously assumed to be separate.

For the haddock tagged and released in the WGOMCA, most were recaptured in the Gulf of Maine Open Area, although some moved down into Georges Bank. The haddock tagged and released in the open areas of the Gulf of Maine were all recaptured in that same area. The length of time the fish were at-large ranged from four to 930 days. Fish traveled between 0.5 to 203 nautical miles and exhibited an average growth rate of 9% while at large. “We’re hoping the data continues to pour in and that we keep getting more recaptures,” she said. Many questions remain, but Slifka said further data analysis of the haddock tagging data may help. In particular, she said there are questions regarding whether or not haddock in the Gulf of Maine and Georges Bank are separate stocks. “What is the importance of closed areas to the haddock population?” she asked. “What about the degree of haddock resource sharing between the U.S. and Canada? Did the 2003 haddock year class grow more slowly than normal year classes?”

She said future projects are needed to help researchers learn more about haddock populations. She suggested implementing additional tagging programs, using electronic tags, and increasing the time series of tagging programs. Slifka also mentioned the need to secure a regional tagging infrastructure. “When tags continue to come in, we need to continue having someone who can answer the phone, collect the information and enter it into the database,” she said.
Automated Acoustic Monitoring to Assess Movement Behavior and Residency of Haddock in Closed Area I, Georges Bank

Graham Sherwood, Ph.D., Gulf of Maine Research Institute

Sherwood’s presentation focused on the use of acoustic technology not to learn where fish go, but to find out if they stay — in particular, if they stay in Closed Area I (CA I) of Georges Bank. The underlying research question, he said, is whether or not CA I is serving as a refuge for haddock. The experimental design was important to consider. An acoustic array similar to that of the Pacific Ocean Shelf Tracking project was deployed off Cape Breton in Nova Scotia to learn about cod movements. Using similar acoustic receivers with overlapping detection ranges would work for haddock movements in CA I, although it would take an estimated 200 receivers to cover the entire closure, he explained.

One of the major goals for this project was to determine the extent to which closed areas are helping to improve haddock populations. “It’s not too far out there to think that closed areas might be having a positive impact on haddock populations,” he said. “If you look at the total area encompassed by closures, there really is a significant amount of the region that’s closed to fishing year-round.”

He noted the likelihood of fish spilling over the boundaries of CA I. If the area is serving as a refuge for haddock, then it is also benefiting the fishery on the outside of the closed area simply from the fish moving across the boundaries, he said. Ideally, scientists would be able to quantify the rate of spillover, or the amount of fish moving out of the closed area.

Sherwood showed a photo of two houses with adjacent lawns; one had leaves strewn all around and spilling over into the tidy lawn next to it. “I like to visualize things,” he said, indicating that his own leaf-filled lawn in the photo could be representative of haddock in CA I spilling over into the open areas across the boundary.

The cost and boat time associated with setting up and maintaining that many receivers was unrealistic, so the design had to be modified. Although the original goal was to quantify spillover, that research question had to be changed to determine if CA I serves as a residential area for haddock.

Project funds allowed the purchase of 19 receivers. “This was one of those moments where you sit down and try to optimize the equipment you have,” Sherwood said. “You rephrase the questions so you can put the technology to use to answer a question.” He pondered putting the 19 receivers in an enclosed arrangement or a straight line. Releasing tagged haddock in the middle of the enclosed setup meant that fish might move out and never return. A straight line of receivers in the ocean brings to mind a door in the desert, he said, where the array might miss all the fish.

Based on input from fishermen, haddock tend to be localized in the northern part of CA I, so a non-overlapping grid array deployed in the northwest corner. This region was also chosen because of its proximity to shore — it was close enough for researchers to get to the site, download the data from the receivers and come back to land in the same day. The array setup allowed researchers to gain insights into the fine-scale movement behaviors of haddock in that region.

Haddock catch per tow from 2001-04 outside of Closed Area I (CAI) in Georges Bank indicates some spillover, but residency rates were unknown.
Eighty haddock were tagged with internal acoustic devices using standard surgery protocols and then released back into the array starting on Aug. 1, 2007. The receivers were set out in CA I and were downloaded every three weeks for two months' duration. Of the 80 haddock originally tagged, 37 of them were tracked by the receivers during those first two months.

Sherwood showed a map of the grid array with animated movements of tagged haddock to demonstrate where the fish went. The receivers made more than 23,000 usable detections. Additional detections that represented dead fish near receivers were not included in the data set.

The animation showed a lot of activity along the eastern edge of the array towards the center of the closed area. The bathymetry of that region shows that these movements in the central portion occurred in the deep water area of the Great South Channel. Fish moved north and south along that array line to the northern edge of the closed area boundary and turned back around. The number of detections per receiver indicated less fish activity around the edges of the area, but we just didn't have receivers set up that far out.” He said it was also interesting that very few fish movements were recorded in the top corner of the array, one of the regions they had originally planned on placing the grid. “A number of fish also showed what I think is representative of a high degree of residency by hitting at least half the receivers in the grid array,” Sherwood explained.

The idea of the fish sensing the boundaries of the closed area and turning around to remain inside may be a reality, Sherwood said. The only instance of significant lateral movements occurred just at the edge of the closed area, where fish moved out to the edge, turned around and came back. “If you look at the fishing effort on the eastern edge by draggers, there might be a difference in the benthic community outside the closed area compared to inside,” he said. “I don’t think it’s too far-fetched to suggest that haddock are somehow cueing in on that and staying in areas where foraging might be more optimal.”

Haddock swimming speeds were calculated from the data between adjacent receivers. In laboratory observations, haddock have a maximum sustainable swimming speed of 0.6 m/s. According to the array data, the haddock were swimming at two to three times the maximum sustainable swimming speed. “At first I thought we had some super haddock here,” Sherwood joked, “but the direction of their movements line up with the tidal ellipse for the area.” This indicates that tidal current may be an important habitat variable for haddock. It might explain why the Great South Channel is an optimal location for the fish – they can forage large areas of the bottom with very minimal effort by going back and forth using the currents.

Hurricane Noel came through CA I at the end of November 2007. The storm wiped out all but three receivers. Two additional receivers were dragged up by fishermen in their nets and returned to their original position. Thus, only five receivers survived into 2008. This smaller array and active telemetry were both used to determine if there were still haddock in the closed area and if there were any changes in their movements. Active telemetry allowed researchers to track fish outside the closed area, including areas to the east of where the haddock seemed to move most frequently inside the original array.

The active telemetry was conducted on seven different days, with the same sites sampled each day. They picked up a few signals from tagged haddock, although Sherwood compared the task to finding a needle in a haystack. “We’re out in the middle of the ocean and we managed to find 11 fish,” he said, three of which were confirmed alive. Only one of those 11 fish was located outside the closed area, which potentially indicates some residency behavior.

Some tagged haddock were still inside the closed area, and the array recorded movements near the top corner where there had not been much activity previously. “This suggests there was some sort of shift in the aggregation of the haddock,” he said. “Overall, most of the movement we saw occurred along that one corridor, which suggests the ‘haddock highway’ operates throughout most of the year.”

Using the first year’s data, Sherwood created an attrition curve to help indicate how useful the array was for a certain period of time. It indicated that the first...
six to eight months of the array’s deployment yielded usable data. However, after a year or more, there was likely too much fish mortality and emigration to discern any movement patterns from the data.

By way of summary, Sherwood noted the haddock movement indicated that CA I served as a refuge for at least some of the fish. The array allowed for observation of their fine-scale movements, which had not been observed in this manner before. The project design was such that the array had to be contained within the closed area, and the number of receivers and boat time limited the extent of data recovery within the area. Active telemetry in concert with the array could make up for these shortcomings by expanding coverage within and outside of the closed area.

Sherwood suggested that similar studies conducted in the future should expand the array and telemetry coverage and use more robust mooring systems. The mooring systems used in this project needed to be the type that can be pulled up out of the water rather than the more expensive type that stayed underwater while the data are downloaded. There is a tradeoff between the number of receivers purchased and the quality of the technology and moorings. For this project, they lost a lot of the receivers and moorings because they were cheaper, and that cost them potential data.

“Overall, I think this study demonstrates the utility, once you work out the kinks like the mooring system, of deploying a non-overlapping grid array for studying residency behaviors of fish in an open water system,” he added.

An audience member asked if the acoustic signals from fishing vessels had any impact on the haddock movements. Sherwood said that is a possibility, but does not know of a way to test that theory. At this point, no one is entirely sure what the fish cue in to that influences their movements, but he thinks that a vessel signal is as likely a possibility as food availability. “It’s something that remains to be tested,” he said.

Another individual asked if there were any biological data available on which fish stayed inside the closed areas versus which ones left. Did males leave while females stayed? Did fish of a certain size or spawning status display movement patterns? Sherwood said biological data of that type are not available and so he could not comment on it.

A commercial fisherman mentioned that haddock are very habitat-dependent, and that when they move around they are often “prisoners of their food source.” The ‘haddock highway’ might be good habitat, where they migrate up and down the corridor looking for food. He suggested that perhaps when they turn around at the edge of the closed area, there might be a change in the fathom curve where the bottom changes to a ledge and that could be influencing their movements. Sherwood noted that the bottom is mostly uniform at 80 fathoms throughout the corridor and even to the edge, so that might not have as much of an impact as suggested.

An audience member posed a question to Sherwood. “You can interpret the decline in the fish detected over time as either residency or mortality but you can’t distinguish between the two,” he said. “Given your experience, what would you do differently next time to address that issue?” Sherwood said he would first spread out the array to hit the full fish distribution and to determine movement and emigration. Using telemetry in addition to the array could help determine if fish had died or moved out of the area. “If we had conducted that telemetry survey from the very beginning of the project, we might have gotten an indication of the number of fish dead at the bottom, which would help us determine mortality.”

Another audience member noted that approximately 50% of the tagged fish signals were never picked up on the array receivers after release. Was that impacted by where the fish were tagged and released? Sherwood said all the release sites were well spread out within the array area, and the fish were not released within detection range of a receiver. Fish would most likely die just after tagging, so they did not release the fish near a receiver for that very reason. “We did end up seeing some dead fish by receivers, but they had to swim into detection and die by the receiver,” he explained, adding that all the tags were turned on and tested prior to deployment, and that none of the detection ranges overlapped.

Sherwood’s research was a collaboration of numerous organizations and individuals, including the Cape Cod Commercial Hook Fishermen’s Association (CCCHFA) research coordinator, fishermen in the CCCHFA and in Maine, along with other individuals at GMRI.
Evaluation of Closed Areas Using Yellowtail Flounder Tagging Studies

Steve Cadrin, Ph.D., NOAA/UMass School of Marine Science and Technology

In 1994, many seasonal closures on Georges Bank became permanent to allow fish populations to rebound. These closed areas, along with management measures such as days-at-sea trip limits and increased gear mesh size, gave scientists the perception that yellowtail flounder populations were rebuilding rapidly. In response to that perception, fishing access to a portion of Closed Area II (CA II) was allowed, first to scallopers and then to groundfish trawlers. However, Cadrin noted that a fishery assessment conducted for yellowtail flounder indicated a more pessimistic outlook for their spawning stock biomass. After trawlers were allowed to take flounder in CA II, Cadrin said there was a large decrease in spawning stock biomass that set back the yellowtail rebuilding program.

A few questions arose due to all of this: What has been the effect of CA II on yellowtail populations? Is there a stockpile of yellowtail in CA II? If so, is it somehow skewing the stock assessment? Based on survey data from the Northeast Fisheries Science Center, Cadrin said about 80% of the yellowtail resource in northeast U.S. waters is believed to be in the vicinity of CA II. “So now we have to ask, is CA II forming a refuge for yellowtail? How much of the resource is actually in that closed area?” Cadrin asked.

Cadrin discussed the idea of assessing closed area spillover effects using the yellowtail flounder tagging program data. The number of tagged fish released for the program was proportional to the population in each location. Because a large portion of the population was located within CA II, approximately 15,000 tagged flounder were released in that location and about 1,000 of those were recaptured within and outside of CA II. The data indicate that fish moved an average of 42 km from release to recapture sites, although there were differences in the distance traveled based on fish gender and the season of recapture.

There was dispersal to the south and west of CA II, although some yellowtail spilled over the northeast boundary during the spring spawning season. These trends are consistent with the commercial fishing patterns; a productive flounder fishery occurs in the locations of the most spillover, particularly during the fall and winter.

The size distributions of flounder caught inside and out of CA II were almost identical. “What we're inferring from this is that the fish inside the closure experience the same mortality rate as those outside,” Cadrin said. These fish appear to be moving in and out of the closed area frequently. Although the closed area is offering some protection from fishing mortality, it is not permanent protection for their populations.

Cadrin and his graduate student, Jess Melgey, organized a 10-day tagging experiment using the Peterson method in June 2007 to determine how many yellowtail flounder are in the portion of CA II that has remained open to scallopers and trawlers since 2004. The Peterson experiment uses a simple model to estimate the population based on the number of fish tagged and recaptured. The estimate for population abundance is derived by multiplying the total number of fish captured by the number of fish tagged, divided by the number of tagged fish that were recaptured.

Every model has certain assumptions that must be met in order to provide accurate outputs. “We tried to confront each assumption by either adjusting our model estimates or designing the project to minimize the effect of assumption violations,” Cadrin explained. For the Peterson experiment, they assumed that the fish population is closed, so no fish were...
leaving or entering the area of study, and that no fish were born or had died during the time of the experiment. “We know that fish disperse and that there is spillover from the closed area,” he said, noting that he would address this assumption in the final model estimates.

Another assumption was that the fish are recaptured in random positions. The tagged fish are also assumed to be representative of the entire flounder population. Strict fish handling protocols were used to minimize stress and tag loss and to ensure that all recaptures were recorded.

Their Peterson tagging experiment consisted of one day of travel to and from the site, five days to tag fish and three days to recapture the fish. Five boats were used during the experiment, visiting 300 different sampling locations within CA II. Double T-bar tags were used due to their low cost, high retention and minimal impacts to the fish. Approximately 72,000 flounder were tagged, making it the largest Peterson experiment ever conducted, Cadrin said.

During the experiment, 159 tagged fish were recaptured, giving a population estimate of 20 million flounder in CA II. Comparing that estimate to the 2008 stock assessment, it suggests that about 40% of the Georges Bank stock is located inside the fishing access portion of CA II. “These preliminary results suggest there is substantial stockpiling of fish in the closed area, but it does not appear to be a permanent stockpiling because fish are also moving out of there,” he said.

To determine the fish dispersal rate, the Peterson model was modified to reflect emigration and immigration across a discrete boundary. The data suggest that there is indeed movement in and out of the closed area, at least during that 10-day experiment.

The preliminary results suggest there is substantial stockpiling of yellowtail flounder in CAII, but it is not a permanent stockpiling.

Another individual asked if the fish exhibited local movement, where tagged fish were recovered close to the location where they were released. Cadrin said that each of the five sampling boats had different colored T-bar tags; thus, when fish were recaptured, it was obvious where it had been tagged. Many of the fish were recaptured in regions adjacent to where they were tagged, so they did exhibit some local movement.

One individual was curious about flounder density in Georges Bank and CA II. The large region outside of CA II had a low density of fish per square mile, while the small region inside CA II had a very high density of fish. How can they be compared? Cadrin agreed that the heterogeneity in flounder density needs to be accounted for when calculating spillover estimates and for comparison purposes.
Fish in New England are managed on the basis of stocks rather than species, and all stocks tend to have a geographic component to help define them, Nies explained. This allows the data collected from regional tagging studies to be applicable to fisheries management decisions. “If we know about a stock structure in theory, then management measures can be better designed to protect a weak stock in an area of interest,” he said. “It’s striking to me that the information provided from a tagging study is very similar to what assessment scientists need to manage fish stocks.”

For example, herring are managed based on different geographic components of the fishery. Each component has different management acts placed on it. As the herring move around, those components often mix, thereby creating unanticipated complexities for management. There are tagging studies currently under way to learn more about the mixing of the herring fishery components to better manage their populations.

Nies mentioned the Northeast Regional Cod Tagging Program and its importance to overall groundfish management. “For years, there has been a lot of concern about the movement that occurs between the Georges Bank and Gulf of Maine cod stocks and their overall status,” he said. Tagging studies have indicated that there are indeed movements between the two stocks, and that their populations, although increasing, are still very low. “Getting the answers to these questions can only help improve fishery management decisions,” he added.

Tagging studies can also be used to evaluate pre-existing management decisions. Groundfish stocks are managed by a variety of measures, including commercial harvest closures in certain areas like the Western Gulf of Maine. “Most of these areas were designed well before there were any tagging studies and were based only on commercial catch information that was available,” Nies explained. “Those areas and boundaries have not been revisited to any great extent since their initial implementation.” Tagging studies can help researchers and managers determine if the closed areas are located in the best place for the fish.

As changes occur in the types of management measures that are required, Nies said the need for information regarding fish movements will still prove to be useful. “I think we’re always going to be faced with the issue of some stocks being in good shape while others are not,” he said. “If you have an idea of how these fish move together, which is something I think most fishermen have an innate understanding of, then it may be possible to maximize your benefits without hurting your other stocks.”

However, Nies cautioned that current tagging studies may not enable a full understanding of the fish movement complexities. Most tagging studies focus on one fish stock at a time, while mingling among stocks might be overlooked. There are a number of species that comprise the New England groundfish fishery, so management decisions need to be based on multi-species data and models in order to be effective. This can be a highly complex task, Nies said.

To further illustrate these complexities, Nies cited the whiting fishery, which requires the use of certain gear and area closures to catch the targeted fish while excluding others. “We want to put these regulations...
in place, but it takes two years to get the regulations passed and then it stays in place for time immemo-
rial,” he said. “The reality is that those fish don’t neces-
sarily follow our management calendar, and so here is the potential place for improvement in the process.”

Improvements may come in the form of real-time fish data from acoustic tags. Fish may not always migrate at the same time each year, so if they were tracked in real time, adjustments like “triggered” closures could be adopted to make the management more effective. “I’ve got to be really honest,” Nies said. “I’m not sure the benefits would outweigh the costs of such a change. Our present management system can be pretty difficult to push regulations through and get them implemented. The regulatory process is slow, and we’ve had problems with triggered closures in the past. These are issues that would need to be worked out.”

He stressed the importance of moving away from managing for single stocks and towards multi-species that more accurately reflects the status of the New England groundfish fishery. He noted that there are a number of individuals in the management process that are aware of tagging studies and how they can aid in the decisions being made. Improvements could be made by determining what research questions managers need answered and then designing a tagging program that best addresses them.

An audience member asked Nies to explain the details of an electronic chip system for fish that is cur-
rently being developed. Although Nies was unfamiliar with this technology, David Welch explained that it is akin to a GPS system for fish. Traditional GPS does not work underwater because saltwater grounds the GPS signal so the satellites will not work, he said. But there are transmitters set at certain locations that send out a signal traveling up to several thousand kilometers. The fish tags record the time the fish arrives at the various transmitters, which allows researchers to determine the position of the fish within a few hundred meters or less. For fish that do not come to the surface, like groundfish, this could be a very important technological advancement, Welch said. Steve Cadrin added that there is currently an electrical engineering problem with the tags that will hopefully be fixed once funding is reestablished for the project.
Gary Shepherd facilitated the afternoon discussion by starting with a question of his own. “We saw a lot of presentations that looked at movement among areas,” he said. “I would like to know if the traditional fisheries stock concept is becoming a thing of the past?”

Steve Cadrin said that it probably is. In the past, managers and scientists have drawn management area lines in the ocean. The use of advanced tagging technologies and genetics has shown the complexity of marine systems that researchers and managers never knew existed. There is fine-scale local structure to the fish resources that are treated as one homogenous resource, Cadrin said. “We need to move towards spatially explicit assessment and management, breaking away from the use of statistical areas,” he said. “We know the latitudes and longitudes of our catches, we know the capture and release locations in our survey data, yet we’re simplifying it all into these crude blocks and missing a lot of the dynamics.”

Cadrin admitted that moving into the realm of collecting spatially explicit information requires an enormous amount of data, and once that occurs, then the models and management tools must be modified to reflect this change. However, he thinks that is the future for fishery science. “I think these tagging and genetics studies are showing us that these simple stock definitions are not the best way of managing fish populations,” he added, “but there’s a long row to hoe before we can really embrace that structure.”

Another audience member noted, “Most of the studies we heard about today were cooperative efforts with industry and scientists. How can we advance that cooperative work to further involve industry?”

David Welch responded, “Fishermen are an essential player in this equation because they are the ones that know how the fish move between different areas, despite what the stock assessment models assume.”

Fishermen often know information about the fish that is never incorporated into the models, because that data makes the model too complex to work. “The models fail, not because they are computationally incorrect, but because the assumptions are wrong,” Welch said.

He suggested that industry could be involved in helping to define the pertinent information to include in the models in the future. Industry support for improved stock assessment models will help to strengthen the science and data to estimate fish populations.

Shelly Tallack said that regardless of the time length or geographic area of a tagging study, fishermen are actively volunteering to be involved in the process. Fishermen involved with the American Littoral Society buy their own tags to help monitor fish populations, she said, which indicates their strong level of interest. However, one of the challenges that researchers face is trying to be aware of the various tagging programs out there to prevent duplicating efforts.

Data collected from one program may or may not be usable in another program. “We certainly used to get quite a few fishermen trying to give us their data, but it’s not necessarily easy to absorb that data into our own tagging studies,” Tallack said. Thus, the Northeast Fisheries Science Center has been working on a multi-species tagging database that may be able to combine all the tagging projects in one large uniform database.

In the future, this could allow for multiple species to be tracked in an overarching cohesive, region-wide tagging study.

Lara Slifka noted that as funds continue to get tighter, there will be increased competition to obtain money for future research projects. She suggested that perhaps a symposium should be held for fishermen interested in being involved with tagging projects. Tags could be given to them so that while they are out on their own boats, they could help conduct scientific research. “This would definitely alleviate a lot of the costs,” Slifka said, “but you would have to make sure each fisherman was well-trained.”

An audience member made some comments on the progress that has occurred in the past five years. “In such a short amount of time for science, we’ve gotten some resurgence in the number of graduate students studying fish movements and a huge increase in the number of people attending these types of symposia,” he said. “If we had this meeting 15 years ago, there might have been eight of us in the room.” Good progress has also been made with regards to the technologies available to help track fish, he added. However, most stock assessment models are tied to the statistical
grids and stock management boundaries with square-shaped fish closures that are not realistic. How can more progress be made without first improving the models and the management boundaries?

Cadrin said most of the presentations noted that researchers must have an idea of the desired end result when designing the tagging study. He cited the yellowtail flounder tagging program to explain his point. It was designed to complement stock assessment models, but some money was used to buy a few data storage tags as well. Although that was not part of the original objective, Cadrin said it helped the researchers learn more about the basic biology of yellowtail than they could have learned simply from the conventional tags. “We need to accept that we are going to see things in our results that we did not anticipate,” he said. “We want to have well-designed studies, but we also want to learn while we’re doing the study and not stifle other opportunities to learn from our data.”

A commercial fisherman in the audience asked Tom Nies about multi-species tagging studies. “All the previous programs have tried to answer research questions on one specific species,” he said. “What’s the research question you would want answered with a multi-species tagging program?”

Nies said that as scientists move towards multi-species management, one major challenge will be the commingling of fish stocks that are healthy with those that are in poor shape. For example, fishermen would be able to fish for haddock but not for cod in Georges Bank due to differences in their population status. “The question I have for any multi-species tagging study is how do those fish mingle and move about together?” Nies asked. “If we know the answer to that question, that would enable people to design a fishing practice where they could harvest one of the stocks without hurting another stock, and I don’t know if that would be cost-effective.”

Nies added that the answer to that question may not require additional multi-species studies, but may simply entail looking at the already collected results in a different manner. “What I’m talking about is not necessarily just knowing broad movement patterns, like mixing rates. What I’m suggesting is to learn what fish are in various locations at certain times, so managers are able to be more efficient at their jobs.”

Shepherd added that before a multi-species model is constructed, scientists need to learn how to address movement within a single species assessment. “I think the multi-species model is a ways off yet, but it’s a good direction in which to move,” he said.
Shelly Tallack gave a brief symposium wrap-up at the end of the day by highlighting several themes that emerged:

• Project effectiveness was impacted by the ability to adequately address the hypotheses and meet the project objectives; thus, the types of tags used, the method of data recovery and the general equipment design must all be geared to answer the underlying research questions. Most presenters touched upon how project designs changed as objectives were modified.

• Results from the tagging studies are having unforeseen uses outside the scopes of the studies.

• The importance of support for tagging studies was clear. In addition to adequate funding, assistance from colleagues is needed for the tagging, data analyses and model building phases of each project. Regional tagging infrastructure, whereby multiple tagging projects can work together, would serve to benefit the fishery.

• There are ongoing questions about what level of model complexity is best, if and how tagging data should be integrated into models, and what factors should be weighted.

• Tagging studies are ideal for involving fishermen in the scientific process. Fishermen are highly knowledgeable about finding fish in the open ocean, they have a good understanding of the logistical operations of fisheries studies, and they have a strong sense for what research questions need to be answered to achieve the desired results.

• Communication is critical. Open dialogue among fishermen, scientists, managers and the public is essential, but often lacking. The presenters stressed the need for more communication, collaboration and cooperation with regards to management objectives, data needs and sharing, and feedback. Collaboration must not only be between fishermen and scientists, but also extend to managers and the public. More meetings and workshops, such as this symposium, are necessary to provide a venue for idea exchange, learning what gear or techniques worked in similar tagging studies and how mistakes can be avoided. Those attending meetings can also make professional contacts to help apply diverse skills to their projects.

• A lot of progress has been made with regards to tagging technologies. Acoustic and satellite tags provide considerable information to fill in data gaps that cannot be gleaned from traditional tags.

• There are a variety of technologically advanced tags currently available, but with their high costs research needs versus financial constraints must be balanced. In particular, if a study would benefit greatly from the use of acoustic tags, perhaps study questions can be retooled to effectively use the technology in an affordable manner. A couple of presenters discussed the feasibility of using an overlapping versus a non-overlapping grid array for acoustic tag studies. Many tags also collect environmental data that may be important in the management process. The bottom line on study design is optimal allocation of funds and technology, balancing costs with results yielded.

• Tagging studies are offering some important information for fisheries management purposes. Acoustic tags may allow managers to begin instituting flexible, real-time management decisions. Tagging studies have the potential to help manage multiple fish stocks rather than simply focusing on one stock at a time. Presenters also noted that managers may or may not be aware of the tagging data available to aid in their decisions.

Tallack closed by thanking the symposium sponsors, including: The Northeast Fisheries Science Center, New Hampshire Sea Grant, the Northeast Consortium, the Gulf of Maine Research Institute, and the corporate sponsorship of Floy Tag and Manufacturing, Inc., Hallprint PTY, Ltd., and Wildlife Computers. She thanked the presenters, those who contributed posters, the facilitators and the rapporteur. Lastly, she thanked the steering committee and the numerous audience members who made the day a success.
Estimates of Abundance from Mark-Recapture Analysis of V-Notched American Lobster

Authors: Talia Bigelow¹, Steven X. Cadrin¹, Bryan DeAngelis² and John Catena³

In 1996, an oil spill off the Rhode Island coast killed an estimated nine million lobsters. Protection of female lobsters through the application of a V-notch was selected as a restoration tool aimed at increasing local recruitment. V-notching, however, does not provide a discrete mark, which means the V-notch data are unsuitable for many conventional tagging models. Mark recapture models were used to evaluate changes in population abundance during the restoration period. Three batch-tagging models (Schnabel, Schumacher and Eschmeyer, and Overton) were modified to account for mortality and mark-loss, thereby relaxing conventional model assumptions. Ancillary analysis of a smaller sample of banded lobsters using the Jolly Seber model helped with model structure, estimation and interpretation. The resulting estimates indicate that lobster abundance increased in the recovery area during the restoration program.

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Divergent Movement Patterns of Winter Flounder in Plymouth Bay, MA

Authors: Gregory R. DeCelles and Steven X. Cadrin

Recent observations of winter flounder seasonal movements are not consistent with the current view that spawning in the Gulf of Maine is restricted to estuaries. An acoustic tagging study in Plymouth Harbor, Kingston Bay and Duxbury Bay estuary in Massachusetts was designed to address uncertainty in the migration and spawning patterns of winter flounder in the Gulf of Maine. Forty-seven adult winter flounder (27-42 cm) were tagged with acoustic transmitters and their movements were monitored using an array of 15 Vemco receivers. In November 2007, 24 fish were caught, tagged and released in Warren Cove, a coastal area outside the estuary. Of the 24 fish tagged in Warren Cove, only five individuals were later detected within the estuary. These fish entered the estuary from mid-April to mid-May and remained therein for a brief time. Nineteen of the 24 fish tagged in Warren Cove were not detected within the estuary at any time during the study, suggesting that these individuals did not use the estuary as a spawning ground. After an entire winter and early spring of failed attempts to capture adults in the estuary, 23 fish were caught, tagged and released within the estuary from late May to mid June. The majority of these fish emigrated from the estuary between early and late June as water temperatures increased. Results suggest a divergent pattern of spawning migrations in which some winter flounder spawn in coastal areas while others migrate briefly to estuaries from spring to early summer.

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Preliminary Results for Two Types of Electronic Tags and Conventional Tags Used to Study Atlantic Halibut (Hippoglossus hippoglossus) in the Gulf of Maine

Authors: J. Kohl Kanwit¹, Christopher Bartlett², Trisha Cheney De Graaf¹ and Timothy Bennett¹

Since 2000, the Maine Department of Marine Resources, Maine Sea Grant and participating fishermen have been tagging Atlantic halibut (Hippoglossus hippoglossus) in the near-shore Gulf of Maine waters. Three types of tags were deployed on Atlantic halibut: conventional wire tags, data storage tags (DSTs) and pop-up satellite archival tags (PSATs). Electronic tags were incorporated into this study in order to collect data on the temperature and depth preference of Atlantic halibut throughout their annual movements. Tagging results show both localized movements within the Gulf of Maine and long-distance emigrations of juveniles to Canadian waters, demonstrating an interchange between fish in the Gulf of Maine and those considered part of the Scotian Shelf/Southern Grand Banks stock unit. The predominance of long-distance, northeastward movement of juveniles poses the question of compensatory emigration in response to the predicted southwestward drift of eggs and larvae. The methods developed for the application of the electronic tags, preliminary results from PSATs and tag return locations, are presented in this poster.

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Visualization of Conventional Tagging Data: A Methodological Comparison

Authors: Jon L. Loehrke, Steven X. Cadrin, Steven J. Correia, David Martins and Shelly Tallack

Visual analysis of tag-recapture distributions is an important exploratory measure in any tagging program, and was applied to evaluate mixing of fish among different management units in the Georges Bank/Gulf of Maine region and alternative designs for rolling closures in the Gulf of Maine. Both non-statistical (e.g., linkage plots of release and recapture positions) and statistical (e.g. applying bivariate kernel density to recapture positions) methods were used. Non-statistical methods of plotting are assumption free, but tend to focus viewer attention towards the few fish traveling the furthest distances. Statistical methods commonly assume bivariate normal distributions, yet direct viewer attention to the areas of higher recapture density. As an example of visualization techniques applied to stock assessment and fishery management, a decade of Atlantic cod (Gadus morhua) recaptures were visually analyzed to stimulate discussion regarding the most informative methods of presenting and viewing bivariate recapture data.

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An Overview of the SMAST Cod Tagging Program August 2000 to Present

Authors: David Martins, Jon L. Loehrke and Steven X. Cadrin

Atlantic cod (Gadus morhua) tagging activities by the School for Marine Science and Technology at UMass Dartmouth (SMAST) was conducted in two 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 (GoM) and Georges Bank (GB). 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, Maine to Long Island, N.Y. 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: within the Stellwagen Bank National Marine Sanctuary (44%), in Massachusetts Bay, primarily between Cohasset Harbor and Plymouth (33%), along the Great South Channel, GB (16%), and around Cape Ann (7%). To date, 1162 recaptures (4.5%) have been reported.

Phase 2, in partnership with the Northeast Regional Cod Tagging Program, occurred between April 2003 and February 2005 and focused solely on GB. Using New Bedford-based trawl vessels with SMAST technicians onboard to tag fish, seven tagging cruises were conducted in 2003 and 11 in 2004-2005. A total of 20,884 tagged fish were released (7,896 in 2003 and 12,988 in 2004-2005). To date, 1,010 fish (4.8%) have been recaptured.

More recent efforts have focused on tagging spawning groups of cod in the GoM, on GB, in the Great South Channel and on Cox’s Ledge using both T-bar and DST tags. 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.

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Conducting a Large-scale Petersen Tagging Experiment in the Open Ocean: Methods and Lessons from a Closed-Area Application

Authors: Jessica H. Melgey¹, Steven X. Cadrin¹, Kevin D. E. Stokesbury¹ and Christopher M. Legault²

While the Petersen model of population abundance is used frequently in terrestrial and freshwater environments, few large-scale studies have been conducted in the open ocean. A Petersen mark-recapture experiment was carried out in the southern portion of Closed Area II on Georges Bank to provide an estimate of yellowtail flounder abundance and spatial distribution. This data will supplement the conventional virtual population analysis. The tagging experiment took place over 10 days, on five vessels, with a total of approximately 72,000 tags applied at random sample stations in the study area over the first five days. Random tows to sample the population for the proportion tagged were made in the final three days of the study. Roughly 44,000 fish were examined for tags, with a total of 159 tags returned, yielding a population estimate of 19.8 million fish. The large, open system of inference presents challenges that can be addressed through careful spatial design, field protocols and modified models. The success of this project is encouraging for future attempts at surveying resources in marine protected areas.

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Northeast Fisheries Observer Program Tag Reporting Efforts

Authors: Joseph J. Mello, Brian J. Gervelis and Kris Tholke

The Northeast Fisheries Observer Program (NEFOP) deploys observers onboard commercial fishing trips from Maine to North Carolina. The primary gears that are observed are bottom otter trawl, gillnet and scallop dredge, but a variety of other gears are observed as well. Observers do not currently tag any animals other than sea turtles. However, among the observer’s responsibilities while at sea is the recording of information regarding recaptured fish. Since 1994, the NEFOP has documented 1529 tagged individuals. A total of 38 different species were reported. From 2003–March 2008 the NEFOP has returned tag-recapture information to more than 20 tagging programs for 1429 tags. The NEFOP reports recapture information on the animal’s length, weight, sex and disposition as well as the date of recapture, location and depth. A host of other variables are also available to end users upon request (including gear related data or bycatch information).

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Seasonal Distribution and Movement of Black Sea Bass (Centropristis striata) in the Northwest Atlantic as Determined from a Mark-Recapture Experiment

Authors: Joshua Moser and Gary Shepherd

A mark-recapture experiment was conducted on the northern stock of black sea bass (Centropristis striata) in the Northwest Atlantic. Tag recovery data from traditional tags indicate that extensive seasonal movements occur and are not homogeneous throughout the stock. During summer months fish throughout the stock remain stationary in coastal areas with very little mixing among adjacent areas. In autumn, offshore migration toward the edge of the continental shelf begins in the north and progresses southward. During the offshore overwintering period, intermixing of fish from various inshore areas is more frequent. Recap- tures following spring inshore migrations demonstrate a high degree of site-fidelity with occasional straying to adjacent areas. Archival data tags suggest that offshore migration is initiated with declining water temperature.

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**A Tagging Study to Assess Migratory Patterns of Monkfish (Lophius americanus) in the Northwest Atlantic**

Authors: Graham Sherwood¹, Jonathan Grabowski¹, Nicole Stephens¹, Ted Platz² and Tim Caldwell³

Monkfish is currently the most valuable wild-caught finfish in the northeastern region of the United States. Monkfish are managed as separate northern (Gulf of Maine and northern Georges Bank) and southern (southern Georges Bank and Mid-Atlantic Bight) stocks. However, the degree to which these stocks intermingle, or even whether or not they represent separate stocks, is currently unknown. We are examining monkfish migratory patterns using a juvenile and adult monkfish conventional tagging study to examine patterns of monkfish migratory behavior between the northern and southern fishery management areas (NFMA and SFMA, respectively). To date, 139 of ~2800 tagged monkfish have been recaptured. In general, monkfish migrated to the southwest of where they were tagged. Furthermore, 25% of monkfish tagged in the NFMA that were at large for at least 60 days were recaptured in the SFMA, whereas no fish originally tagged in the SFMA has been recaptured in the NFMA. Determining the relative magnitude and direction of exchange between northern and southern stocks is of critical importance to managers charged with sustaining monkfish populations in the Northeastern United States.

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**Expansion of the Northern Gulf of St. Lawrence Groundfish Sentinel Cod Tagging Program**

Author: Jason Spingle

Funding from the Provincial Department of Fisheries and Aquaculture in Newfoundland and Labrador allowed for expansion of the Northern Gulf of St. Lawrence Groundfish Sentinel Cod Tagging Program by introducing the most recent technology to the traditional approach with spaghetti tags. Data Storage Tags were purchased from a company in Newfoundland and Labrador and surgically implanted in cod in the Northern Gulf of St. Lawrence (NAFO 3Pn, 4RS) along the west coast of Newfoundland in late summer and fall in 2007 and again in late summer in 2008. These small sensors record temperature, depth and time every 30 minutes for a two-year period. These tags are intended to provide information between the initial tagging and recapture that could occur years later, which regular spaghetti tagging experiments do not record. These tags will help determine additional information about northern gulf cod, including details on over-wintering, habitat preference, timing of inshore migration, vertical migrations during spawning and also changes in oceanographic conditions. This in turn should help both harvesters and fisheries managers make better decisions to ensure a sustainable cod fishery in the future. This is a collaborative effort involving the federal Department of Fisheries and Oceans, provincial Department of Fisheries and Aquaculture, Fish, Food and Allied Workers Union, and Memorial University of Newfoundland and Labrador, through the Community-University Research Recovery Alliance.

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