Elucidating post-release mortality and "best capture and handling" methods in sublegal Atlantic cod discarded in Gulf of Maine recreational hook-and-line fisheries

John Mandelman[1], Connor Capizzano[2], William Hoffman[3], Micah Dean[3], Douglas Zemeckis[4], Marc Stettner[5], James Sulikowski[2]

[1]John H. Prescott Marine Laboratory – New England Aquarium, [2]University of New England, [3]Massachusetts Division of Marine Fisheries – Annisquam River Station, [4]University of Massachusetts, Dartmouth – School for Marine Sciences and Technology, [5]Non-affiliated

Abstract

Recreational hook-and-line angling for Atlantic cod, *Gadus morhua*, in the Gulf of Maine (GOM) has increased over the past decade and recreational discards are currently approximately double the recreational landings in this region. However, the post-release mortality (PRM) of cod remains poorly understood, creating uncertainty in GOM cod stock assessments and in setting size and possession limits in the recreational fishery. The current project aimed to estimate 30-day PRM after recreational catch-and-release, and assuming the occurrence of fatalities, to establish capture and handling guidelines to increase the survival of cod discarded in this fishery. To account for potential future shifts in the size limit, both sublegal and just above legal cod (n = 637; 10 – 28 in) were caught under actual recreational fishing conditions, and by anglers with a range of experience levels. All cod were assigned a condition score and tagged (standard t-bar), while a subset (n = 136) were additionally affixed with ultrasonic transmitters prior to release into a fixed acoustic receiver array. After compiling and distilling all acoustic detections, qualitative assessments conclude a 21% PRM rate. This will be verified or adjusted when models are completed. A mixed-effects logistic regression model is also being applied and will reveal any PRM predictors, which in turn will allow the determination of "best practice guides" that will be disseminated to stakeholders.

Introduction

For centuries, the Atlantic cod, *Gadus morhua*, has been one of the most important commercial and recreational species in the north Atlantic (Artigas et al., 2005). At the expense of multiple stakeholder groups, however, cod stocks have undergone major declines in recent years, and have yet to recover. According to the latest stock assessment, the Gulf of Maine (GOM) cod stock is currently overfished and overfishing is occurring (NEFSC, 2013). Despite the common assumption that only the commercial industry exerts pressure on cod stocks, recreational fishing for this species has increased over the past decade, accounting for 31% of cod removed by weight in the GOM in 2011 (NEFSC, 2013). Presently, discards by number are approximately double the landings in this fishery, with the majority being individuals below the mandated size limit (i.e. sublegal) (NEFSC, 2013). Recreational discards are important when evaluating the total mortality (landings and discards) in GOM cod.

Research for this technical report was undertaken with funding from the National Marine Fisheries Servcice, Office of Sustainable Fisheries, Bycatch Reduction Engineering Program (BREP).
The views expressed herein are the author's and do not necessarily reflect the views of NOAA or any of its sub-agencies.

Given the high discard rate of sublegal cod within the GOM recreational fishery, the fate of these discards is an important management aspect to consider. Furthermore, anything other than a negligible acute and/or post-release mortality (PRM) rate would suggest reducing recreational catch-and-release stress and injury and increase survival in this important species. Only a handful of studies have assessed Atlantic cod PRM in the GOM, and these focused on commercial fishing gears (Robinson et al., 1993; Milliken et al., 1999; Milliken et al., 2009). These, along with other non-GOM based studies on cod (e.g., Soldal and Engas, 1997; Suuronen et al., 2005; Ingolfsson et al., 2007), reported moderate-to-high cod PRM or escapee mortality estimates. Factors such as elevated seawater and (on-deck) air temperatures (Robinson et al., 1993; Milliken et al., 2009), increasing depth, and injuries sustained (Pálsson et al., 2003) were found to negatively influence survival. Prior to a recent (non-GOM) study by Weltersbach and Strehlow (2013), however, hook-and-line/jig capture has functioned merely as a control treatment (i.e. to retrieve minimally stressed/injured fish). As such, studies have not accounted for the true range of capture/handling practices conditions indicative of the GOM recreational fishery. Moreover, instead of true discarding, these aforementioned previous cod PRM studies held cod in seafloor deployed cages or on-board aquaria to monitor survival for short (3-9 day) observation periods. While such methods enable high sample sizes, they also bias study results by unnaturally increasing (i.e. stress from high densities/confinement, forced thermal and recompression stress, lack of foraging ability, injury from cage's structure) and decreasing (i.e. protection from avian and other marine predation) mortality risks. They also fail to account for fatalities that occur beyond these initial days. Thus, while previous studies have established a strong foundation, true sublegal cod PRM remains poorly understood, especially with respect to recreational hook-and-line/jig capture (angling) and handling methods in the GOM.

Due to this uncertainty, GOM cod stock assessments prior to 2012 assumed a 100% PRM across all fleets and gear types, acknowledging the true rate was between 0 and 100% (NEFSC, 2012). This conservative assumption that all cod thrown back will die called for the need to implement policy to reduce the number of cod discards at all costs. On the notion that less stringent size limits would allow the meeting of recreational possession limits with fewer discards (NEFSC, 2013), the legal size limit for GOM cod was reduced from 24 to 19 inches (in) total length (TL), and a possession limit of 9 fish per angler were declared for the 2013 fishing season (NEFSC, 2012). Following release of the 2013 GOM cod stock assessment, the 100% assumption was reduced to 30% for recreational hook-and-line fishing through a modified Delphi approach (NEFSC, 2013); however, a robust understanding of the true sublegal cod PRM was still direly needed for the most effective management of this depleted stock.

Objectives

Given the data needs mentioned, the current study proposed the following study objectives relative to this GOM fishery:

(1) Estimate the total PRM in the recreational fishery according to various factors and conditions.

(2) Establish "best angling practices" to maximize the survival of released cod captured via rod and reel.

(3) Disseminate these methods to all fishery stakeholders, particularly individual and angler groups, party/charter captains, local and regional management bodies, and others with a direct influence on the GOM cod fishery.

Methods

Study site and sampling

Atlantic cod, both under and above the 19 in legal size, were targeted on the southern portion of Jeffreys Ledge from July 2013 – October 2013. This area was selected due to its reputation as a popular recreational fishing locale in the summer months, and because it offered a low probability for acoustic receiver loss. Because cod are primarily fished recreationally in warmer times of year, sampling efforts were concentrated during the boreal summer months (July – August 2013). Moreover, as elevated seawater and air temperatures have been shown to decrease cod survival (Robinson et al., 1993, Milliken et al., 2009), staging the study in summer provided a conservative "worst-case scenario" estimate for PRM. Cod were captured at depths ranging from 44.5 – 83.0 meters (m) with standardized rod and reel setups (Shakespeare Ugly Stik rod, model BWB 1120 8'0; Penn Senator reel, model 4/0 113H) and two different hook styles: a stainless Solkroken Norwegian jig (14 oz, model HK-03-375; 17.5 oz, model HK-03-380) or a sea clam-baited high-low ground fishing rig (Mustad J-hook, model 92642; 12 oz/16 oz lead sinker). Gear types were representative of the most common

gear types used in the GOM recreational fishery, as determined through a set of pre-study questions included in the NOAA Marine Recreational Information Program Surveys (MRIPS), orchestrated by the Massachusetts Division of Marine Fisheries (MADMF). This data was corroborated via input from various long-time recreational anglers, including a veteran party boat owner/captain.

Field sampling trips were conducted aboard chartered vessels that were outfitted to capture cod via hook-and-line for research and recreational/commercial purposes, respectively. Three to five recreational anglers of varying experience levels were recruited for each sampling trip and were given no additional fishing and handling instructions as to remove bias and keep the range of angling practice realistic (see Weltersbach and Strehlow, 2013 for a similar scheme). The gear configuration (jig vs. bait) used by a given angler as well as the number of fish caught by each were roughly proportional each trip.

A series of physical, biological, and environmental parameters were assessed for each capture event to allow for later determination of the factors most likely to influence mortality. Each angling event was timed (min:sec) from the setting of the hook to the landing of the fish on deck. Air exposure was also timed from landing of the fish on deck to its release back into the water. Other notable observations recorded for each landed cod included time of capture, depth, and angler ID (which could later be linked to an experience level index). Ambient surface and bottom temperatures (°C) were recorded over the entire length of the project at 5 minute (min) intervals using data storage tags (model Star-Oddi DST milli-L depth temperature archival tag, accuracy ± 0.1°C, range -1°C to 40°C, Star-Oddi Ltd, Iceland) affixed to fixed acoustic receiver stations in the center of the array. Ambient air temperatures (°C) were obtained online from NOAA Station 44029 - Massachusetts Bay/Stellwagen Bank meteorological buoy (42° 31’12" N, 70° 34’12" W, http://www.neracoos.org) over the entire sampling period at 10 min intervals.

Physical trauma and vitality assessment

For each fish, the total length, and hook location and hook removal method were noted. Injury type and severity of each landed fish were then rapidly scored (~10 seconds (s)) according to a four-tiered condition index (Table 1). Every assessed cod was tagged in the epaxial musculature between the first and second dorsal fins with two FD-94 T-bar anchor identification tags (Floy Tag & Mfg, Inc., Seattle, WA) and released at the surface. Released cod were assessed for their surface activities according to Campbell et al. (2010): swimming straight down (Sd); floating (Fl); swimming erratically (E) or any combination of the three categories. If a tagged cod was consumed by a predator (e.g. herring gull, blue shark, spiny dogfish), the observation activity was noted as (P) for predation. (Table 1)

Fine-scale post-release survival monitoring

Prior to release, a select subsample of all captured cod (n = 136) were each externally fitted with a Vemco V9P-1H coded-acoustic transmitter equipped with depth sensor (9mm x 42mm, 5.2g in-air, 2.7g in-water,

Table 1. The four-level ordinal scale/ index used to score the degree of physical trauma in captured cod. Condition code level was likely to change upon observation of severe bleeding events once the hook was removed in order to be conservative.

Condition	Code (#)	Definition	Examples
Excellent	1	No to minimal injury; limited to hook entry/ exit hole	Not applicable
Good/ fair	2	Minor barotrauma or physical trauma(< 1cm diameter)	Eye cavity damage as hook exits through mouth; mouth-hook and bleeding; foulhooked; expanded swimbladder
Poor	3	Moderate barotrauma or physical trauma (> 1cm diameter)	Eye or head puncture; gill damage; foulhooked esp. of ventral surface (organs remain in cavity); exopthalmia
Moribund	4	Putatively dead; due to severe barotrauma or physical trauma	Wound showing internal organs or organs on outside of body; torn operculum; severe bleeding from gills or ventral cavity; inverted stomach

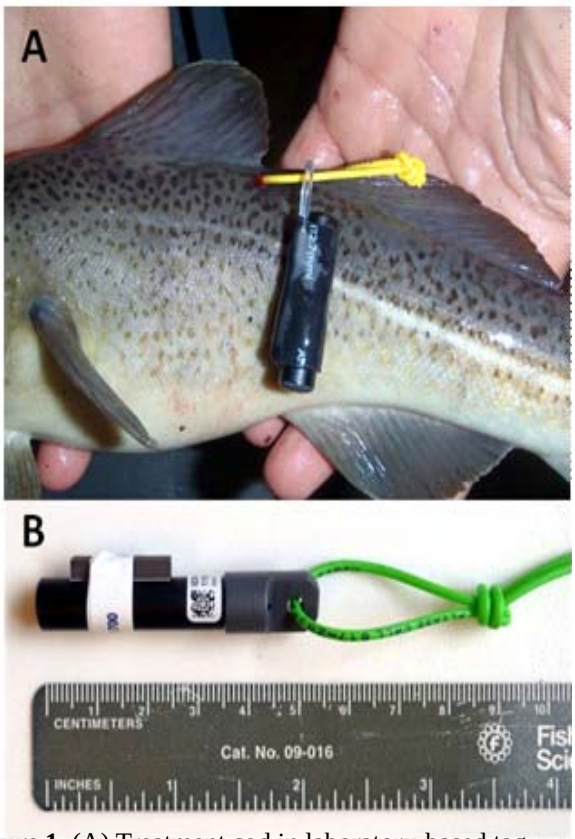
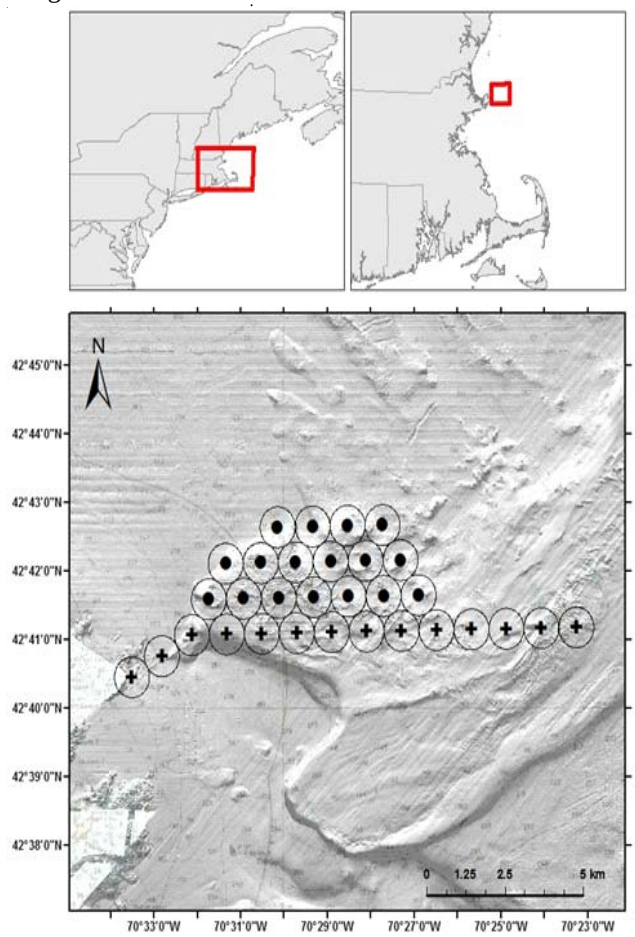


Figure 1. (A) Treatment cod in laboratory-based tag retention study affixed with dummy tag/ spaghetti tag package in musculature between first and second dorsal fins. (B) Final tag package to be deployed on cod. A Vemco V9P-1H acoustic tag affixed with an endcap (provided by Vemco) is attached to the animal via FT-4 spaghetti tag.

Vemco Division, AMIRIX Systems Inc., Halifax, Nova Scotia) to monitor post-release activity. Transmitters were attached via FT-4 spaghetti tag (Floy Tag & Mfg, Inc.) through the epaxial musculature between the first and second dorsal fins of each cod (Fig. 1). Prior to field work, a lab-based tag retention study was conducted to evaluate an optimal external tagging site and method, tag shedding rate, and tag effect on behavior/survival for under- and legal-sized cod. Ultimately, this was determined to be the optimal tagging method due to its rapid application (< 30s), high retention rates and minimal stress and health impacts.

To assess the PRM of acoustically-tagged cod, a fixed acoustic receiver array (model sVR2W-69kHz with Bluetooth, Vemco Division, AMIRIX Systems Inc.) was deployed in the study site preceding sampling efforts (Fig. 2). Both short-term (< 3 days (d)) and long-term (> 3 d) PRM were assessed by passively monitoring the fine-scale horizontal and vertical movements of acoustically-tagged cod within the array. The three dimensional perspective allows a more fine-scale ability to discern live versus dead acoustic signatures. A single dead cod specimen was tagged with an ultrasonic transmitter and released into the array in order to serve as a control and define the detection

Figure 2. All fishing was performed inside acoustic receiver array, located on the Southern Jeffreys Ledge, off the coast of Cape, Ann, Massachusetts. Each receiver (model VR2W-69kHz; indicated by % and + symbols) had a theoretical 550m detection range in every direction. The configuration of the receivers provided a continuous coverage area of 35.1km^2.



signature of a dead specimen to which others could later be compared. All acoustically-tagged cod were caught and released within the array in order to reduce the likelihood of rapid emigration. The PRM of cod that emigrated from the array was impossible to confirm and relied entirely on opportunistic recapture by commercial and recreational anglers in the surrounding area and, to a lesser degree, detection confirmation in other acoustic arrays operating in the region.

Receivers were downloaded and cleaned monthly over the course of the field season before removal in October

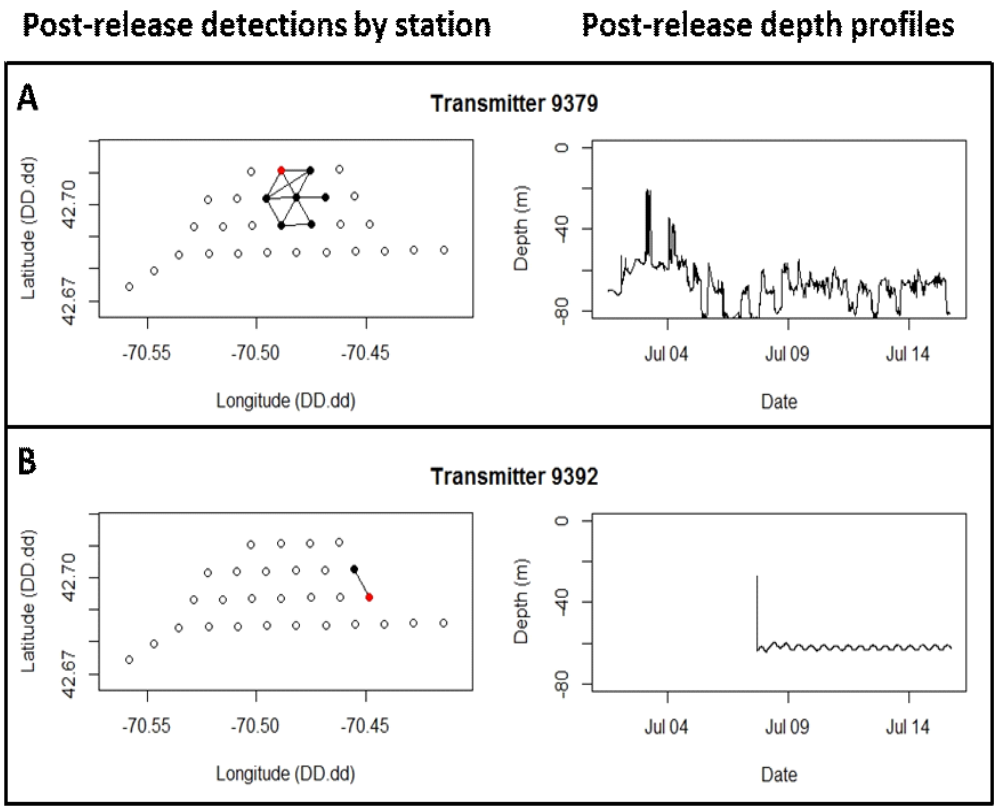


Figure 3. Sample acoustic receiver data for (A) a living and (B) a dead cod. These data demonstrate that mortality is distinguishable based on movement between receiver stations (left side) and depth profiles (right side). In the detections by station figures, each dot represents an individual receiver station; the red dot indicates the location of capture, while the black dots indicate stations that have detected the transmitter. These traces will allow us to assess PRM for transmitter-affixed fish under different capture conditions.

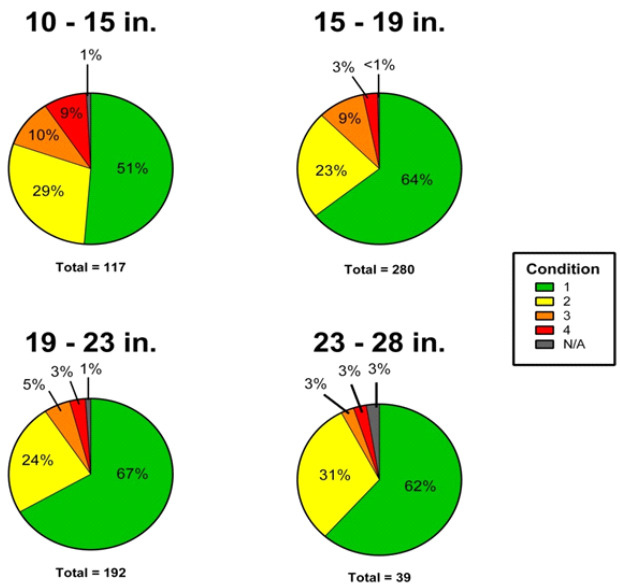
2013. Despite the high shipping and fishing activity in and around the study area, there was a 95% mean receiver retention rate over the 99 d deployment period. Prior to analysis, all transmitter data were individually evaluated for false detections using the Vemco User Environment software (VUE version 2.06, Vemco Division, AMIRIX Systems Inc.) and the following filter conditions: i) Rxr/ Txr Detection Count < 2 and ii) Rxr/ Txr Detection Separation > 29 min.

Data analysis

Data manipulation and statistical analyses were all performed using the statistical computing software R (version 3.0.2; R Development Core Team, Vienna, Austria). All recorded depth profiles of acoustically-tagged cod were filtered in order to reduce the vertical variability from the tidal influence using the R package "oce" (version 0.9-13; Kelley, 2013). While the analysis is still ongoing, a qualitative assessment of the acoustic telemetry data was performed to best estimate PRM. In general, the horizontal and vertical movement data were evaluated for each cod with a primary focus on depth fluctuations (Fig. 3). Cod were determined to be alive if numerous vertical migrations were made throughout its detection profile and it moved throughout the receiver array. If the depth signature of a cod remained stable with no indication of movement between receivers, it was identified as a possible mortality/tag loss event. Emigration out of the receiver array was defined as the absence of depth data prior to October 3rd and further confirmed if the last recorded detection was by a receiver on the outside of the array.

The PRM of acoustically-tagged cod is currently being evaluated against two criteria: (1) the detections between receivers over a specified timeframe and (2) the comparison of the tide-adjusted depth profiles (Fig. 3). For instance, if movement from one receiver to another occurs over certain time period, the first criterion is satisfied and the fish is deemed "alive". In contrast, the fish would be considered "dead" if numerous detections occurred at a single receiver for an extended time based on the first criterion. The first criterion will be defined as the number of receivers to detect the fish over a certain time interval assuming a dead fish being carried by the tidal current cannot move into the detection range of several receivers. If, however, a tagged cod is alive but displays high-site fidelity about a single receiver, the depth signature will aid in clarifying the animal's vertical distribution and activity.

Figure 4. The post-capture condition of cod by total length (in). The current minimum size limit for Gulf of Maine Atlantic cod is 19 inches (48.2 cm), reduced from the previous threshold of 24 inches. Fish condition was based on a score of 1-4; 1 (excellent) no to minimal injury, 2 (good/fair) minor injury, 3 (poor) moderate injury, and 4 (moribund) likely to die when released. N/A indicates animals whose condition was not assessed.



Since survival is defined as any change in vertical movement over time, it is assumed that a dead cod does not move vertically because it resides on the seafloor. Ordinary acoustic telemetry, however, cannot identify where a cod occurs inside a detection area, which could determine its relation to the seafloor when coupled with depth data. Therefore, by evaluating the depth profile's mean and variance for each specimen, the study area's variability in seafloor depth is removed and all of the depth profiles are theoretically standardized. By assuming a living cod would experience greater depth variance due to more frequent and dramatic vertical migrations (e.g. feeding, predator avoidance), a dead cod would thus remain at depth and produce a smaller variance. Therefore, the second criterion for determining post-release cod survival will be based upon the difference in depth profile variance between the tagged and control cod. With the R package "lawstat" (version 2.4.1; Gastwirth et al., 2013) in R 3.0.2, the Brown-Forsythe-Levene test for homogeneity of population variances will be used to identify whether depth data variances are equal or not using either a parametric or non-parametric approach in accordance with the depth data distribution curve. All events where the hypothesis test results in a significant difference ($P < 0.05$) will be interpreted as a tagged cod exhibiting a behavior different from the control cod and thus being alive.

Once the survival assessment is complete, a mixed-effects logistic regression will evaluate PRM (dependent) against the multiple variables recorded during capture (independent). Further analyses will be conducted on these data that treat injury location and condition as the dependent variable against the other independent variables to determine their effectiveness as predictors of PRM.

Results

Sampled cod

In total, 637 cod (TL 10 – 28 in) were captured, assessed and released over the course of 14 individual field sampling trips with 17 different anglers participating in the efforts. Of these, 136 were tagged with ultrasonic transmitters (6 tags were redeployed following their recovery from individuals that suffered immediate mortality) and 501 with dual FT-94 T-bar tags. With a mean TL of 18.0 ± 0.13 in, more than 92% of the cod captured in the study were within 5 in of the current 19 in minimum size length. Nineteen percent of cod less than 15 in TL were ranked as either "poor" or "moribund" (Fig. 4). In contrast, only 8% and 6% of cod from 19 – 23 in and 23 – 28 in TL, respectively, were given a "poor" or "moribund" ranking.

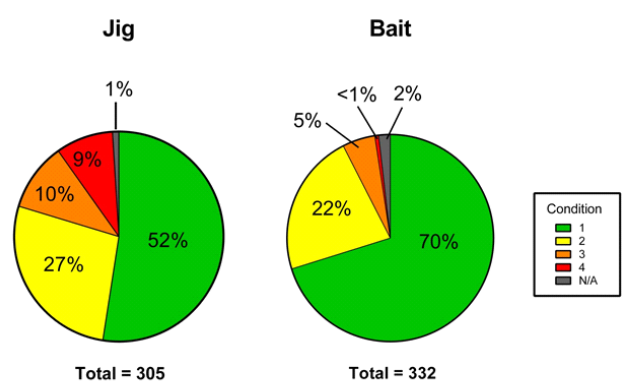


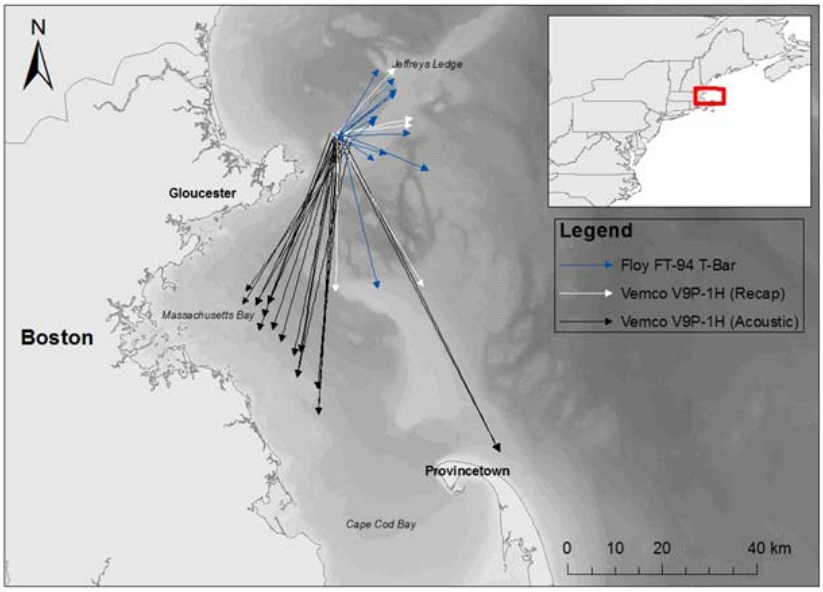
Figure 5. The post-capture condition of cod by gear type. Fish condition was based on a score of 1-4; 1 (excellent) no to minimal injury , 2 (good/fair) minor injury, 3 (poor) moderate injury, and 4 (moribund) severe injury and likely to die when released. N/A indicates animals whose condition was not assessed.

Three-hundred and five (48%) individuals were captured via stainless steel Norwegian jig and the remaining 332 (52%) were caught with sea clam-baited J-hooks. When separated by gear type, baited J-hooks had a greater portion of "excellent" cod (70%) than jig (52%) (Fig. 5). Moreover, 19% of jigged cod were ranked "poor" and "moribund" while the same conditions were observed in only 6% of baited J-hook caught cod.

Acoustic telemetry and qualitative mortality assessment

A total of 526,131 individual detections were recorded by the acoustic receiver array over the 94 d study period (July 1 – October 3, 2013) resulting in 6774.4 cumulative days of movement data. An initial qualitative assessment revealed approximately 103 survivors and 27 deaths, for a PRM of 20.8%. Cod demonstrated a mean resident time within the fixed receiver array of 52.1 ± 33.2 d (range = 0.03-94.6 d). Of the survivors, 67 cod emigrated from the study site while 36 fish were still actively residing within the receiver array on the study's last day. Of the cod who emigrated from the study array, a total of 21 individuals were detected in other GOM receiver arrays (Fig. 6). These cod (TL=18.97 ± 3.29 in) exhibited either "excellent" (52.3%), "good/fair" (33.3%), or "poor" (14.3%) condition at the time of initial capture. They were at liberty 134.71 ± 24.94 d (range=87-182 d) and traveled a mean straight-line distance of 49.1 ± 10.7 kilometers (km) between release and detection sites.

Figure 6. Detected emigration of study animals from Cape Ann acoustic receiver array. Location of recaptures of cod tagged with only T-bar tags (blue arrows) and acoustic transmitters and T-bar tags (white arrows). Location of animals detected in other acoustic arrays indicated by black arrows.



Mark-recapture overview

Between July 2013 and April 2014, local GOM recreational and commercial fishermen recaptured 29 tagged cod (4.55% recapture rate). Recaptured fish (21.71 ± 2.53 in TL) displayed either "excellent" (65.5%) or "good/fair" (34.5%) condition at initial capture. They were at liberty for 77.13 ± 45.05 d (range=8-196 d) and traveled a straight-line distance of 15.00 ± 10.06 km between release and recapture sites (n=22) (Fig. 6).

Utility to Management

The results of this study will provide a more robust estimate for the true Atlantic cod PRM in the GOM recreational hook-and-line fishery. Ultimately, this study will have important implications for the setting of future size restriction and possession limits, which are currently based on an estimated PRM rate of 100%. Given how widely this estimate differs from the 20.8% PRM rate shown by our initial qualitative assessment, our findings, once verified by the completion of analyses, would support a figure closer to the Delphi-established estimate, thereby justifying an increase in the minimum legal size limit for this species. Moreover, while the latest cod stock assessment was not sensitive to divergent PRM estimates (NEFSC, 2013), an empirically derived PRM estimate can be more confidently applied in future assessments.

Vitally, the conclusion of our analyses will also reveal which covariates (e.g. gear types, fishing methods/ techniques, and on deck handling protocols, etc.) are most influential on PRM. In turn, this will enable the determination of the best gear/capture/handling guidelines to lower the PRM of discarded sublegal cod. Once these guidelines are disseminated to the GOM recreational fishing community, a widespread adoption would aid in the recovery of this overfished stock by reducing the PRM of individuals discarded in this growing fishery, which already contributes heavily to the total cod discards in the GOM.

Discussion

Based on an initial qualitative assessment of telemetry data, we estimate a 20.8% PRM rate for Atlantic cod of sublegal to just legal size classes discarded in the GOM recreational hook-and-line fishery. While this

number will be refined following completion of ongoing detailed analysis of telemetry data, the estimate is roughly in accordance with the adjusted 10 d mortality rates (overall mean=11.2%, range=0-27.3%) reported by Weltersbach and Strehlow (2013) for Atlantic cod discarded in the recreational fishery in the western Baltic Sea.

Preliminary patterns observed among both observational and mark-recapture data are suggestive of certain trends. The high (86%-100%) incidence of "good" and "excellent" classified cod that have thus far been confirmed as survivors (i.e. were either recaptured or detected in other arrays), for example, suggests that high vitality and lack of extensive injury upon capture is good indicator that the individual will survive. Furthermore, preliminary analyses suggest that the condition of cod at the point of capture is, in turn, influenced by both fish size and gear type. The majority of the cod that exhibited poor condition upon capture were under 15 in (in TL) and/or caught using jig. This trend suggests that a shift away from jig use could positively influence survival rate among discards; however, this conclusion is tentative, and we could still observe interactions with other factors. The completion of the analysis will reveal a more concrete directive for how cod survival could be increased.

Future Work

Our successful, noninvasive transmitter attachment method, extremely high retrieval rate of acoustic receiver data and confirmed ability to differentiate between dead and surviving discards together demonstrate the utility of using acoustic telemetry to evaluate PRM in Atlantic cod. Using our methods, the PRM rates of other species of management concern and/or importance could be evaluated in the future. Species that 1) are large enough to accommodate an acoustic transmitter without impairment, and 2) do not engage in large scale horizontal movement are good candidates for acoustic telemetry monitoring. Species that fulfill these criteria include several species of management and/or conservation importance in the GOM recreational fishery, including one that we observed routinely during the cod study (cusk, *Brosme brosme*), and one that can be found on softer bottom habitats in the region (juvenile haddock, ***Melanogrammus aeglefinus***).

Acknowledgements

We thank Tim Tower for his time and expertise during the planning and experimental design phase for this work. Jeff Kneebone has provided extensive input, particularly on data analysis. Emily Jones has provided critical administrative support for this work. We thank Massachusetts Division of Marine Fisheries personnel (Matt Ayers, Nick Buchan, Brad Schondelmeier) for critical assistance fishing and tending to the receiver array, as well as the numerous University of New England undergraduates (especially Joe Langan) who served as anglers. This study was sanctioned by the New England Aquarium Animal Care and Use Committee (protocol #2013-02). Finally, we thank the numerous recreational and commercial fishers (especially Jim Ford) for taking the time to call in and return recaptured t-bar and acoustic tags. Funding was provided by the NOAA Fisheries Service Bycatch Reduction Engineering Program (Award # NA12NMF4720256).

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