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David Rudders
Virginia Institute of Marine Science

Sally Roman
Virginia Institute of Marine Science

James A. Sulikowski

John A. Mandlem

Ryan J. Knotek

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Final Report

Discard Mortality of Sea Scallops Following Capture and Handling in the Sea Scallop Dredge Fishery

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Submitted by:

David B. Rudders and Sally Roman
Virginia Institute of Marine Science
College of William and Mary
Gloucester Point, VA

James A. Sulikowski
University of New England

John A. Mandleman
New England Aquarium/ University of Massachusetts at Boston
Boston, MA

Ryan J. Knotek
University of Massachusetts at Boston
Boston, MA

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WILLIAM & MARY
VIMS
VIRGINIA INSTITUTE OF MARINE SCIENCE
MARINE ADVISORY SERVICES

Project Summary

The focus of sea scallop, *Placopecten magellanicus*, management over the past 20 years has been to encourage the harvest of larger animals. This has been accomplished through a series of management measures including gear modifications, effort controls, crew size limitations and spatial management to protect juvenile scallops. While these measures have been effective in reducing the harvest of small scallops, their capture does still occur. Central to fully understanding the impact of the fishery on the resource, is a comprehensive estimate of the non-harvest mortality associated with commercial operations. Non-harvest mortality can be broken down into a number of different processes, with discard mortality being a major category. Discard mortality (DM) is the rate of mortality associated with animals that are captured and subsequently released due to primarily market factors. The latest stock assessment for sea scallops assumes that 20% of all animals discarded will die. There is considerable uncertainty associated with this estimate that is based on a single older tagging study and studies examining a non-Placopecten species under different biotic and abiotic conditions.

For the present study, we estimated sea scallop DM rate characteristics for the commercial dredge fishery. Our methodological approach assessed the short-term survival (~7 days) of observed scallops by holding the animals in a novel, chilled seawater deck tank system engineered for previously funded DM work. Based on these observations we estimated the probability of mortality as a function of covariates that contribute to scallop DM (i.e. physical trauma, environmental conditions, biological characteristics). An additional component of the deck tank trials was to construct a scallop vitality index (SVI) based on a suite of factors (e.g. shell damage, reflex response) that can be rapidly assessed. This index will facilitate the application of our results to a broad cross section of field based research as well as possible inclusion in observer protocols to estimate DM across spatial and temporal scales representative to the fishery. Collectively, results from this project provide: (1) sea scallop DM estimates for incorporation into management, and; (2) A robust SVI, along with a determination of best practices that may aid in reducing the mortality of discarded scallops.

Results indicated the estimated overall mean survival rate was similar to the current DM rate used in the stock assessment of 20 percent or 80 percent survival. While the overall mean was similar to the assessment value, there was considerable variability in the survival estimates by health indicator code (HIC). Healthy scallops with HIC values 1 and 2 (associated with the least physical damage and robust physiological responses had predicted survival rates of 89.7 and 97.35 percent, respectively. Scallops in these two HIC classifications made up the majority of the scallop catch. The scallops in HIC codes associated with extensive physical trauma and reduced physiological impairment, classified as HIC 9, HIC 10 or HIC 11, had much lower survival rates of 14.95 (HIC 9 and 10) and 2.41 (HIC 11) percent. The use of HIC as a method to assess scallop mortality was validated through the use of several survival analyses (Kaplan-Meier survival analysis, Cox proportional hazard models and survival mixture models). Logistic regression and Cox proportional hazard models identified several factors that contribute to increased survival including decreased exposure time, a larger shell height and greater scallop catch.

1. Project Background

Non-harvest mortality represents that fraction of fishing mortality attributed to processes related to harvest operations, not resulting in landed catch. This source of mortality is comprised of several related, but different processes (Figure 1). In aggregate, these components can represent a significant source of mortality and influence the stock assessment and ultimately fishery management processes.

In the sea scallop fishery, discards occur during the portion of the capture process where a scallop is selected for shucking. Generally, this decision is based on the size of the animal where it becomes economically inefficient to devote production time to processing smaller scallops. At times, there exists a large price differential between size classes of scallops with larger scallops generally sold at a premium. A large price differential incentivizes discarding smaller scallops in the attempt to maximize $/lb (i.e. high-grading). This is especially true in situations where a vessel is allocated a trip limit (in lbs.) for an access area trip. In addition to the size factor, there are other reasons that influence the decision to discard a scallop that can reflect market as well as resource conditions.

The mortality associated with discarding can be attributed to a number of causes such as physical trauma (e.g. shell damage or filling of the mantle cavity with substrate), physiological stress (e.g. thermal stress, air exposure) and increased risk of predation (Medcof and Bourne, 1964, Veale *et. al*., 2000; Jenkins and Brand, 2001; Stokesbury *et. al*., 2011). Physical damage can result in the meats being unmarketable and is caused by contact with rocks in the dredge during fishing and damage during emptying of the dredge (Medcof and Bourne, 1964). Scallop meat quality can also result in the discarding of the animal after discovery of unmarketable meats upon shucking. Based on the wide array of factors both influencing the decision to discard as well as those that influence the probability of survival, it is likely that the rate of discard mortality varies both spatially and temporally.

Spatial and temporal variability in the processes associated with discard mortality have resulted in a wide range of mortality estimates. These estimates range from 10% of tagged scallops in the Mid- Atlantic Bight to slightly higher values (15%) in the Canadian Maritimes (Medcof and Bourne, 1964; Murawski and Serchuk, 1989). High (>20° C) sea surface water temperatures as well as elevated air temperatures during summer operations in the Mid-Atlantic have also been implicated in the death of large numbers of juvenile scallops, although an alternative hypothesis suggested that increased predation was to blame (Stokesbury *et. al*., 2011; Hart and Shank, 2011). The combination of wide ranging mortality estimates as well as the paucity of direct sea scallop discard mortality studies highlights the importance of characterizing this important process.

As a result of an overarching management strategy that has attempted to encourage the harvest of larger scallops, the overall amount of discarded scallops is estimated to be relatively small. According to the latest sea scallop stock assessment in 2009, the total amount of discarded scallops from dredges was 1,037 mt. of meats. That is down from a peak in 2004 at 2,418 mt. of meats (NEFSC, 2010). Currently, input into the stock assessment model specifies a 20% discard mortality rate and as a result, the mortality associated with discards is relatively small. While the overall mortality associated with scallop discards is modest, the implication of the point estimate and its associated uncertainty has a potentially wider reaching impact. This impact is reflected in calculations that culminate in estimates of fishing mortality for the stock as well as the calculation of resource specific reference points (D. Hart, personal communication, 2013).

It cannot be understated that the sea scallop supports a fishery that in the 2015 fishing year landed approximately 11,702 mt. of meats with an ex-vessel value of over US $440 million (Lowther and Liddel, 2016). These landings resulted in the sea scallop fishery being one of the most valuable single species fisheries along the East Coast of the United States. Estimates of discard mortality have wide ranging implications starting as assumptions in the stock assessment models that ultimately manifest themselves in the manner by which the fishery is managed. Understanding this complicated process is essential to characterizing the impact that the fishery has on the resource.

One of the most significant issues affecting marine fisheries management is the immediate and delayed mortality of animals that are discarded after capture (Davis, 2002). Understanding this component of mortality allows for the more precise estimation of the scale of removals as a result of fishing. In the case of scallops, the discard mortality rate is assumed to be between 10% and 20%; however, there have been few direct studies done to quantify this and we hypothesize this rate varies significantly spatially and temporally. As previously stated, likely contributors to scallop DM include the physical trauma associated with fishing operations in traditional areas of hard substrate (e.g. Great South Channel) as well as air and water temperatures above the thermal tolerance of scallops (~20°C) encountered during the summer in the Mid-Atlantic. Accurate estimates of DM will enable a more precise point estimate to be used in the stock assessment model and will result in annual fishery specifications that reflect a better understood reality of the mortality processes in the fishery.

In addition to providing updated DM estimates, the generation of an SVI will allow the estimation of DM rates across broad scales of time and space. This index should be robust and have utility should changes occur in how the fishery operates. While scallop management has been successful in increasing the average size of scallops landed, large recruiting year classes are characteristic of this species and interaction with incoming cohorts is unavoidable. Understanding how the fishery impacts these animals is an important part of the capture process.

By examining which factors are independently or collectively most influential on observed mortality, this project provides advice for potential strategies/practices to mitigate the impact of the fishery on discarded scallops. This advice is based on empirical data on the controllable and uncontrollable factors relative to scallop discard mortality, the characteristics of the fishery, and provides the ability to craft approaches to reduce the mortality of discarded scallops (i.e. best-practice guidelines).

For this study, we pursued multiple objectives. The primary objective was to provide a sea scallop DM rate estimate that representative of a range of shell heights and environmental and operational conditions. This DM rate, therefore, represents the short-term mortality of scallops that result from the capture/handling/discarding (CHP) process of the commercial fishery. A second objective of the project was to construct an SVI based on rapidly assessed characteristics that may be employed across broad temporal and spatial scales as well as by fishery observers in the future. As a third objective of this study, we conducted a laboratory experiment with diver caught scallops to evaluate mortality under handling and a worst-case scenario temperature regime associated with summer conditions. A final objective was to provide baseline information and advice to support best industry practices to minimize scallop DM in the future, based on information obtained from the laboratory and field studies.

2. <u>Methods</u>

2.1. Laboratory Experiments

2.1.1. Specimen Collection and Holding

During June 2014, divers collected 100 scallops of varying sizes (4.6-12 cm shell height; umbo to ventral margin) off the coastal waters of Eastport, Maine which were then transported (4 hours) to the University of New England's (UNE) Marine Science Center (MSC) in Styrofoam containers. Scallops were housed in an insulated polyethylene holding tank (internal dimensions: 186 × 104 × 63 cm) equipped with a flow-through (38 L min-1 turnover rate), refrigerated seawater system that maintained the tank temperature similar to that of the capture-site bottom conditions (10°C). Shell height and wet weight (g) were recorded for each scallop prior to being externally marked on the valve with a unique identifier. Scallops were acclimated to laboratory holding conditions for at least ten days and fed *Dunaliella sp*. daily *ad libitum* until the experiment trials began.

2.1.2. Experimental Design

To investigate the effects of acute aerial exposure and elevated air temperatures (TA) on survival, scallops were exposed to environmental conditions typically seen during commercial fishing operations. Scallops were randomly assigned to one of four aerial exposure treatments (0, 5, 15, or 30 min.), which occurred in direct sunlight between 12:00 and 16:00 in order to mimic on-deck "worst-case scenario" summer conditions (TA: 30-31°C). TA was recorded with a HOBO temperature logger (Onset Computer Corporation, Bourne, MA).

The influence of elevated seawater temperature (TW) on scallop survival was parsed into two scenarios that were based on the duration scallops spent above the thermocline (i.e. TW). Thermocline depth was determined using CTD data collected from Georges Bank, NW Atlantic in the summer of 2014 (Knotek *et al*., in review). TW (18°C) was based on the average water temperature during summer months over the past three years on Georges Bank (NOAA NDBC #44011). In scenario 1, all scallops were subjected to TW for 38 sec during the simulated haul-back process. This specific time duration was determined using haul-back rates and fishing depths from 295 tows conducted between three commercial scallop-fishing vessels (F/Vs Araho, Ranger, Resolution; Knotek *et al*., in review). In scenario 2, scallops were exposed to TW after discard for a duration that was determined by scallop sinking rates. Preliminary testing with scallops of varying sizes (i.e. small: < 6.8 cm, medium: 6.8-9.7 cm, large: > 9.7 cm) suggested that the small scallop average sinking rate was slower (5.07 m sec-1) than medium and large scallops (3.55 m sec-1). Therefore, the small size class was subjected to haul-back and discard time durations of 38 and 76 sec, respectively, while medium and large size classes were exposed for 38 and 65 sec, respectively.

Trials were performed in four replicates (n=25) with scallops from the aforementioned size classes randomly selected for one of the four aerial exposure treatment groups (6-7 animals per group; Table 1). Each control group (i.e. 0 min.) remained in the original holding tank (10°C) for the duration of the experiment (i.e. handling effects), while treatment groups were placed into ventilated crates (43.8 × 27.0 × 36.2 cm) for easy transportation between elevated seawater (TW) tanks and outdoor exposure areas. Treatment groups were collectively transported into the elevated seawater (TW) tank for 38 sec (scenario 1) before being moved outdoors into direct sunlight for 5, 15, or 30 min (). Once their aerial exposure limit was met, treatment groups were transported back into the elevated seawater (TW) tank where small and medium/large sized scallops were introduced to TW for 76 or 65 sec (scenario 2), respectively). Upon completion, scallops were moved back into the original holding tank where mortality was monitored at increasing time intervals post-treatment over seven days. According to Dickie (1958), a scallop was considered dead if its velum failed to retract upon stimulation with a wooden dowel.

2.1.3. Statistical Analyses

A logistic regression model was used to analyze the effect of factors on the survival of scallops. The dependent variable was survival (binomial: alive/dead) and potential independent variables included air exposure duration (categorical: 4 levels), elevated seawater temperature duration (categorical: 2 levels), and shell height (continuous). The model was developed using step-wise forward selection and the optimal model was selected based on the lowest Akaike information criterion (AICc) value corrected for small sample sizes. Based on a correlation analysis, elevated seawater temperature and shell height variables were highly correlated ($r = 0.81$, $p < 0.001$). Shell height was chosen in place of elevated seawater temperature for the remainder of the analysis for two reasons; 1) elevated seawater temperature groups were determined sinking rates (i.e. shell height), and therefore this information was inherently part of shell height, and 2) shell height was more applicable in management applications. For air exposure, treatment groups 1 (0 min) and 2 (5 min) were combined following a log-rank test of Kaplan-Meier (KM) survival curves (Cox and Oakes, 1984) that revealed no significant difference in the survival of the two categories (p-value = 0.29). Final candidate covariates included in model development were: shell height and air exposure (3 levels).

2.2. Field Experiments

2.2.1. Deck Tank System

Based on a previously funded Scallop RSA project, we have designed a modular deck-tank system specifically tailored to examine acute (i.e. short term) post-release mortality (Knotek *et al.*, 2015). The biggest strength of the system is the ability to manipulate intake seawater temperature (i.e. holding tank temperatures) to mirror the temperature conditions on the seafloor. To determine these bottom temperatures a HOBO temperature logger (Onset Computer Corporation, Bourne, MA) was attached to the dredge and temperature was recorded while towing the gear on the seafloor. To ensure that tank and bottom temperatures were aligned, water temperature (within each tank) was monitored throughout each trial with YSI 55 (YSI Incorporated, Yellow Springs, OH) sensors. Using this protocol we were able to regulate tank temperatures by adding ice to refrigeration tanks (wherein incoming sea surface seawater was circulated through stainless steel coils immersed in the ice slurry and distributed to holding tanks) based on the variation between tank and bottom temperatures.

Scallops kept in the holding tanks were placed inside of small mesh-wire cages that fit within the larger (internal dimensions: 186 X 104 X 63 cm) insulated polyethylene holding tanks. These cages provided the duel benefit of reducing the amount of movement within tanks that can lead to increased physical damage of individual scallops while also making it easier to access the scallops for subsequent monitoring and sampling. Prior to being placed in the deck tank system, each sea scallop was labeled with a unique identifier to track the individual over the course of a cruise. Scallops were held in the holding tanks for up to 140.6 hours per cruise.

2.2.2. Experimental Design

Eight trips were conducted between August of 2014 and December of 2015 onboard two commercial fishing vessels (F/Vs Røst and Horizon; Table 2). Sampling trips were conducted throughout the Mid-Atlantic and Georges Bank resources areas across different seasons to obtain a representative range of covariates that may potentially impact the DM of sea scallops (Figure 2).

The cruises attempted to replicate actual or near actual commercial fishing conditions so that DM estimates would be representative of commercial practices. Vessels used standard commercial scallop dredge gear (i.e. New Bedford style dredge or a Coonamessett Farm Turtle Deflector dredge). Tows times were randomly varied from between 15 to 90 minutes to account for industry practices. To evaluate the impact of various covariates on DM, the following variables were recorded: date, location, time, tow duration, deck-time (air exposure), depth, substrate type, air and bottom-seawater temperatures, estimated volume of catch, scallop shell height (umbo to ventral margin in mm.), and gender of scallop. The number of tows per cruise are provided in Table 3.

For a sampled tow, the commercial crew was instructed to cull the catch as they would under normal fishing conditions. After the scallops that were classified as retained for processing were removed, remaining scallops were collected, and a subset evaluated and assigned a vitality score via the scallop vitality assessment criteria (see section below). Scallops to be included in the tank trials were marked with a unique identifier. This identifier allowed the field team to follow the disposition of the animal through the duration of the cruise that could last up to seven days. Time on deck (a proxy for air exposure) was also varied over the course of a cruise (1 to 90 minutes) to mimic exposure times typically seen in the fishery. Scallops were either immediately placed into the smaller mesh-wire cages within the deck tank system or placed back on the deck for predetermined intervals that encompass the conceivable range of deck times for this fishery. After the air exposure time elapsed, these scallops were also placed into the smaller mesh-wire cages within the deck tanks.

2.2.3. Discard Mortality Assessment

To assess short-term DM resulting from the CHD process, specimens selected for the holding tanks underwent a vitality assessment in order to evaluate overt physical trauma and degree of vigor using semi-quantitative assessments of shell damage and response of scallops to handling and probing prior to being placed in the holding tanks. Levels of shell damage constituted one component of the data recorded and were assessed by visual inspection of the shell (Figure 3, Table 4). Metrics on pre-determined responses were also recorded. These metrics were assessed by either probing the scallop prior to the scallop or observing a scallop prior to probing (Table 5). These pre-determined responses were determined in prior laboratory trials (based on Davis, 2007) wherein various behaviors (e.g. clapping or mantle retracting) were observed and then assigned to an ordinal response code that was indicative of the degree of health/vigor. The combination of shell damage and response were combined to create health indicator codes (HIC) to populate the SVI (Table 6). HICs were combined based on log-rank tests (described below in Section 2.2.4).

Scallops held in the deck tank system were monitored for mortality on an hourly basis and removed from the tank system upon death. Time of death was recorded for each animal and resulting associated data for each individual (including haul level information) were included in the estimate of survivorship. Scallops that survived for the duration of a field trial were released. This approach resulted in both right-censored data (scallops released alive at the end of the field trial) and uncensored data (scallops that dies during the holding tank time period) (Benoît *et al*. 2012; Benoît *et al*. 2015).

In addition to the scallops monitored for mortality in deck tanks, scallops captured but not held in the holding tanks (n=14,000) were assessed using shell damage and response codes in a similar manner to the deck held scallops. This allowed us to greatly increase the number of observations by assessing shell damage and response (HIC) in numerous additional scallops. Based on the assumption that the shell damage and response were reliable predictors of mortality, the additional observations indirectly yet substantially bolstered the size and statistical power of our estimated mortality sample. These data were also incorporated into the survival analysis (described below in Section 2.2.4) and allowed us to assess the utility of using shell damage and response as factors for the SVI. The sample sizes and number of scallops assigned to HICs are provided in Table 6.

2.2.4. Statistical Analyses

Data from scallops retained in the holding tanks (n=1,928) were used to develop HICs that would be analyzed in the statistical models. Initially, log-rank tests were used to determine if scallops with different shell damage or response codes could be combined. Results from both tests indicated significant differences between shell damage codes as well as response codes. Log-rank tests were then used to test for significant differences between response codes within shell damage codes. These log-rank tests allowed us to condense response codes by shell damage for scallops with varying levels of shell damage, resulting in 11 HICs for use in survival analyses (Table 6).

Kaplan-Meier (KM) survival analysis, Cox proportional hazard models (CPHM) and survival mixture models (SMM) were employed to evaluate HICs as predictors of scallop mortality and to estimate survival. KM and SMMs were first developed to estimate survival as a function of HIC by shell damage code (1-5). CPHMs and SMMs were also developed to estimate survival as a function of HIC and additional covariates.

2.2.4.1 Discard Mortality Estimation

KM analysis was completed to assess the appropriateness of the HICs for predicting scallop mortality and as a validation tool for goodness-of-fit model for other two types of models (CPHM and SMM) used to model scallop survival as a function of time. KM analysis is a non-parametric analysis that allows for an estimation of the probability of survival as a function of time, resulting in a survival curve based on the proportion of individuals dead and alive at different time intervals during an experiment (Kaplan and Meier, 1958).

SMMs were also developed to estimate survival after the CHD process as a function of vitality assessment (HIC). SMMs are parametric models developed for application in fisheries by Benoît *et al.* (2012). These models can be generalized to account for different types of DM and have a flexible functional form as a result of the Weibull survival function forming the basis of the model (Benoît *et al.*, 2012; Benoît *et al.*, 2015). SMMs can also model heterogeneity that exists between animals with a similar vitality assessment and accommodate censored data. A general form of a SMM is a survival function with a mixture of released animals that are harmed as a result of the CHD process and ultimately die and animals that are unaffected by this process (Benoît *et al*., 2012; Benoît *et al*., 2015). This general model is defined as:

$$S(t) = \pi \cdot \exp[-(\alpha \cdot t)^{\gamma}] + (1 - \pi)$$

where $S(t)$is the survival probability until time t, π is the probability that an animal was negatively impacted by the CHD process, α is the scale parameter and γ is the shape parameter (see Benoît *et al*., 2012 for a complete description). Benoît *et al*. (2012) developed six different SMMs with varying assumptions for the α and π parameters that allow for different interpretations of the survival function.

To model survival as a function of HIC, we applied four of these SMMs to model survival of scallops without the addition of other explanatory variables (Table 9). Four SMMs within each shell damage code were developed. The four models within shell damage code were compared with AICc values and the model or set of models with the lowest AICc or a delta AICc ≥ three were selected as the optimal model(s). SMMs survival curves with 95% confidence intervals as a function of holding time and HIC for each model were plotted against a KM survival curve to assess model fit.

Survival estimates with standard deviations were obtained with Monte Carlo simulations, model averaging and bootstrapping (Benoît *et al*., 2012). Monte Carlo simulation was employed to provide estimates of model parameters from a multivariate normal distribution using original model parameters and covariance matrices. If there was more than one preferred model, an AICc weighting approach was used to conduct model averaging to estimate the α, γ and π parameters. A total of 1,000 bootstrap samples with replacement were completed using data from tows with scallops assessed for shell damage and response codes, but not retained in holding tanks. An overall mean survival estimate and mean survival estimates by HIC within shell damage class were estimated with this approach. Mean parameters estimates for α, γ and

π were also calculated with associated standard deviations. All analyses were completed with R 3.3.2 (R Core Team, 2016).

2.2.4.2 Variables Influencing Discard Mortality

CPHMs were developed to estimate the probability of survival as a function of HIC and additional covariates (i.e. tow duration, temperature, catch volume, etc.) to determine the contribution of other factors on DM. CPHMs are semi-parametric survival models that can accommodate censored data, have traditionally been used to model survival and can be specified as fixed or mixed effect models (Cox, 1972; Benoît *et al.*, 2015). The fixed and mixed effect models are defined as, respectively:

$$\hat{h}(t) = h_0(t)\exp(X'\beta)$$

$$\hat{h}(t) = h_0(t)\exp(X'\beta + Z'b)$$

where $\hat{h}(t)$ is the hazard function estimated at time *t*, $h_0(t)$ is the baseline hazard function, *X'* is a design matrix of fixed effect covariates, β is a vector of fixed effect coefficients, *Z'* is a design matrix of random effects and *b* is a vector of random effects coefficients. Mixed effects models were explored to account for the correlation between scallops captured in the same tow (Zuur *et al.*, 2013).

Potential covariates considered for CPHM were: month, bottom type (hard or soft), tow duration, catch of scallops (number of baskets), thermal gradient (difference between bottom temperature and sea surface temperature), depth, shell height, HIC, total exposure time (the amount of time scallops were on deck from the time the dredge was emptied until scallops were put in holding tanks or released), air temperature, sea surface temperature and bottom temperature. Air temperature, bottom temperature, sea surface temperature and thermal gradient combinations were all highly correlated, resulting in thermal gradient being selected as a candidate covariate in model development. Thermal gradient was selected over the other variables because we concluded this would be representative of the thermal stress a scallop may experience during the haul back process. We also considered that month may be correlated with thermal gradient, so month was not considered further as a candidate covariate in model development as the environmental conditions across the range of the fishery in the same month could vary considerably. Log-rank tests were used to test for difference between levels of categorical variables and indicated significant differences between levels for all variables. Five final candidate covariates included in model development were: HIC, bottom type, thermal gradient, shell height and total exposure time. Table 8 provides a description of the final potential covariates. HIC level 6 was excluded from analysis because of a small sample size (n=11), following a similar approach as Benoît *et al.* (2012), to eliminate the potential for unreliable parameter estimates.

CPHMs were developed with step-wise forward selection. Covariates were added based on individual parameter CPHM model AICc values corrected for small sample sizes to an intercept-only model (Burnham and Anderson, 2002). Covariates were retained in the full model if the difference in the AICc value was reduced by a minimum of three units. The model with the lowest AICc or models with AICc within three units of each other were selected as the optimal model(s). Fixed and mixed effects models for a fully saturated model were compared for goodness-of-fit with a likelihood ratio test and results indicated a mixed effect model was more appropriate (p-value < 0.001) following the approach of Benoît *et al.* (2010). The optimal model fit was compared to a KM survival curve of the probability of survival as a function of time by HIC. All analyses were completed with R 3.3.2 (R Core Team, 2016).

3. <u>Results</u>

3.1. Laboratory Experiments

The optimal model retained all candidate covariates (shell height and air exposure) and had a significantly better fit than other models (p-value= <0.001). Parameter estimates for the optimal model are provided in Table 10. Results indicated that the odds of mortality from 15 minutes of air exposure, versus 0-5 minutes, increased by 12.38 and after being subjected to 30 minutes of air exposure increased by 161.85. For the parameter shell height, the odds of mortality decreased by 0.66 for every unit increase in shell height across all air exposure levels (Figure 4). The probability of mortality increased from 1 to 68 percent as the total amount of air exposure time increased (Table 11).

3.2. Discard Mortality Assessment

3.2.1. Discard Mortality Estimation

Based on the KM survival curves and comparisons between KM survival curves and SMMs curves, using a vitality assessment centered on HIC values appears to be an appropriate method for assessing scallop DM. KM curves by HIC as well as shell damage and response codes exhibited differential declines in the probability of survival as a function of hold time (Figures 5 - 6). All curves also reached an asymptote. One issue identified by examining the KM survival curves was the ranking of response codes. Response code values were assigned to represent of the degree of health/vigor of scallops. Higher response code values indicated a less healthy scallop. The KM curve for response indicated response code 3 has the greatest probability of survival and response code 5 has a greater survival rate than response code 4. It should be noted that there is no intrinsic assumption of survival rates as a function of the numerical scores associated with HIC (i.e. HIC 1 has higher survival than HIC 2). The possible misspecification of response codes is reflected in the bootstrapped survival rates estimates calculated from the SMMs by HIC.

Results for model selection for the SMMs by shell damage code are provided in Table 12. The number of optimal models varied by shell damage code; shell damage codes 1 and 4 had one optimal model, while shell damage codes 3 and 5 had three and four optimal models, respectively. For the optimal model types, the mixture models generally performed better than the Weibull model across shell damage codes. Plots of KM survival curves with 95% confidence intervals and SMMs survival curves used to assess SMMs model fit are provided in Figures 7 - 11. For shell damage code 1, the optimal Mixture Model 3 (MM3) overestimated survival for HIC 2 as holding time increased. The model slightly underestimated or overestimated survival compared to the KM curve for HICs 2, 3, and 4, although all MM3 curves were within the 95% confidence intervals of the KM estimate (Figure 7). Mixture Models 2 (MM2) and 3 fit the KM survival curve for shell damage code 2 very well. There were no visible deviations from the KM curve (Figure 8). The Mixture Model fits for shell damage code 3 were variable for both HICs (Figure 9). For HIC 7, MM2 did not reach an asymptote. The fit for HIC 8 for the same MM was better, with a slight overestimation of survival at holding times between 40 and 60 minutes. MM3 had a similar overestimation issue for the same holding time period for HIC 8. The fit for HIC 7 for MM3 was improved. The MM curve reached an asymptote, but had a minor overestimate of survival at longer holding times. Mixture Model 4 (MM4) had the best fit out of the three optimal models. The one optimal MM (MM2) for shell damage code 4 had a good fit compared to the KM curve for both HICs (Figure 10). The 95% confidence intervals for the KM curves overlapped for the two HICs. For shell damage code 5, all four MM were considered optimal models. All four MM curves had s similar fit to the KM curve that resulted in a slight overestimation of survival at shorter holding times and an underestimation of survival as holding times increased (Figure 11).

Bootstrapped mean survival estimates are provided in Table 13. The overall estimated mean survival rate for scallops regardless of HIC was 81.62 percent. Mean survival rates ranged from 97.35 percent to 2.41 percent by HIC. The survival rate by HIC generally declined as the severity of shell damage increased and response to stimuli degraded or as HIC value increased. HIC 2, a higher HIC value, which would indicate that the survival rate should be lower, but this HIC has the highest estimated survival. HIC 4 has a lower estimated survival rate compared to HIC 3 and HIC 5. This is a function of response code survival rates; HIC 2 includes response code 3 and HIC 4 includes response code 5 (Table 6). As discussed, examination of KM survival curves for response codes indicated the ordinal coding applied to this semi-quantitative assessment parameter may not properly represent a decline in the health as of a scallop. Bootstrapped parameters estimates for α (alpha) and γ (gamma) are provided in Tables 14 and 15.

3.2.2. Variables Influencing Discard Mortality

Individual variable models and AICcs are provided in Table 16. Three models satisfied the model selection process (i.e. a reduction in AICc of ≥ 3 units with the addition of a covariate) during model development (Table 17). Model 4 (M4) was selected as the optimal model; the model had the lowest AICc compared to M2 and M3 and the difference in the AICc value between M4 and the other models was greater than three units.

M4 included the variables HIC, shell height, exposure time and scallop catch as covariates affecting scallop DM. The variables HIC, exposure time and scallop catch were significant terms in the model (Table 18). All levels of HIC were significant, with the exception of HIC3, compared to HIC1 (the reference level). Positive coefficient estimates indicated that as the HIC value increased (scallop health declined), the risk of mortality generally increased. The exception was for HIC2, which had a negative coefficient, indicating the risk of mortality declined compared to HIC1. HIC5 also had a lesser increase in the risk of mortality compared to other HICs. The sign for the shell height and scallop catch coefficients were also negative, indicating that as shell height and scallop catch increased the risk of mortality declined. The hazard ratio (column Exp(Coefficent) in Table 18) is the effect size of the coefficient and specifies the amount of change in the hazard of mortality associated with a specific coefficient. If a coefficient is negative than the hazard ratio indicates the amount the hazard of mortality is reduced and vice versa for positive coefficients. The hazard ratio for the HIC covariates ranged from 1.53 to 39.09 for HIC levels with positive coefficients and also increased as HIC value increased. For HIC 2, the reduction in the risk of death was relatively minor compared to HIC 1. The hazard ratios for shell height and scallop catch also indicated moderately minor decreases in the risk of mortality. Exposure time had the greatest effect size outside of the HIC coefficients, with a 1.03 rise in the risk of morality as a function of exposure time.

Model goodness-of-fit was assessed by plotting the predicted survival curves from M4 against the KM survival curves for the probability of survival as a function of HIC (Figure 12). The predicted M4 survival curves were predicted with the mean shell height, total exposure time and scallop catch by HIC. Sensitivity of the M4 model fit was also assessed by plotting the KM curves against the predicted fit with the minimum and maximum values for shell height, total exposure and scallop catch (not included). Goodness-of-fit for the minimum and maximum predicted curves were similar to those for the mean predicted fit. Overall, the predicted M4 fit was comparable to the KM survival curves for all HICs. Only a minor underestimation was observed for the fit of HIC 1 at shorter holding times. The HIC 2 fit also had a slight underestimation of survival, but only for holding times of 100 minutes and greater. The fit for HIC 3 a minor underestimated survival at holding times between 30 and 100 minutes. Fits for HIC 4, HIC 7 and HIC 10 had a similar underestimation of survival at shorter holding times and slightly overestimated survival at longer holding times. HIC 5 and HIC 8 fits had an opposite pattern compared to the fits for HIC 4, HIC 7 and HIC 10, with an overestimation of survival at shorter holding times and an underestimation of survival as holding time increased. The fits for HIC 9 and HIC 11 were also similar. There was no deviation from the KM curves at shorter holding times, but as holding times increased both fits tended to underestimate survival.

The estimated overall probability of survival was 79.16 percent and the survival probability by HIC with mean shell height, mean total exposure and mean scallop catch is provided in Table 19. Survival estimates from the CPHM were generally comparable to the SMM bootstrapped estimates, with differences between HIC survival estimates ranging from -6.82 to 11.18 (Table 13). The most noticeable differences were for HIC 7, where the CPHM estimate was 11.18 units greater than the bootstrapped estimate, and for HIC 4 were the CPHM estimate was also greater than the bootstrapped estimate by 8.27 units.

4. Discussion

4.1. HICs as Indicators of Discard Mortality

The application of HICs for estimating DM of sea scallops appears to be a valid method. The shell damage codes accurately reflect declines in scallop health as a function of increased shell damage. While response codes may not exactly represent a decline in scallop vigor, we now understand which response codes are contributing to variability in the estimated DM rates by HIC. The issue of a potential mis-specified response code for code 3 may be a result of a small samples size observed for this response (n= 77) compared to sample sizes for the other responses that ranged from 198- 1,022. Based on the understanding of HIC values, using HICs to populate a SVI that can be employed across broad temporal and spatial scales as well as by different organizations and fishery observers in the future is appropriate for estimating DM. The HICs can be rapidly assessed, as demonstrated by collecting shell damage and responses from an additional 14,000 scallops during the course of the project that were not held in the holding tank system.

4.2. Discard Mortality Assessment

Discard mortality was assessed using SMMs to estimate a mean overall survival probability as well as survival probabilities by HIC. The overall mean survival estimate was similar to the current DM rate used in the stock assessment of 20 percent or 80 percent survival. While the overall mean was similar to the assessment value, there was considerable variability in the survival estimates by HIC. Scallops with the best HIC values (HIC 1 and HIC 2) had predicted survival rates of 89.7 and 97.35 percent, respectively. Scallops in these two HIC classifications made up the majority of the scallop catch. For scallops retained for the holding tank study, 49 percent of the scallops were classified as either HIC 1 or HIC 2. For the 14,000 other scallops assessed, these scallops made up a larger portion of the catch at 79 percent. The least healthy scallops, classified as HIC 9, HIC 10 or HIC 11, had much lower survival rates of 14.95 (HIC 9 and 10) and 2.41 (HIC 11) percent. The catch of unhealthy scallops was substantially lower than scallops assigned to heathy HIC classes (8 percent for scallops not retained in the holding tank study and 18 percent for scallops in the holding tank study). Due to the greater probability of survival and higher catch rates of healthy scallops, the assessment DM rate of 20 percent may be too conservative. An approach that estimated DM as a function of the percentage of discarded scallops in each HIC classification may provide more robust DM rates for use in the assessment and management of the resource. One possibility would be to leverage the coverage of the resource provided by the observer program to accurately assess animals across the range of the fishery in both time and space. This approach may also allow for spatial and temporally explicit DM rates to be calculated that more accurately captures the manner in which the fishery is persecuted.

Results from the CPHM were similar to the survival rates estimated from the SMMs for both the overall survival rate and individual HIC survival rates. Having similar survival estimates from different models allowed us to have greater confidence in the estimated survival rates. Results indicated that HIC classification had the largest impact on scallop survival, with other covariates having a minor impact on the probability of mortality. Of the covariates that were demonstrated to have an impact on survival, areal exposure was shown to be the most significant operational/environmental factor. Slightly surprisingly, thermal gradient was not a significant predictor of survival. This may have been a result of limited observations during times when the gradient was large. Even though some trips were conducted in the Mid-Atlantic Bight during the summer, a portion of the observed tows were at night when the gradient was reduced and there simply may not have been enough information to detect an effect. Since HIC is the greatest predictor of scallop survival, having a robust SVI based on HIC classification is critical and we have determined that the use of HICs to assess scallop vitality/vigor is a valid approach.

4.3. Best Practice Guidelines

Based on results from the laboratory experiments and CPHM, some generalized best practice guidelines can be developed for the industry. Results indicated that exposure time and shell height contributed to increased mortality. The probability of mortality was greater as exposure time increased and as shell height decreased. The CPHM results also indicated that scallop catch was an important factor in scallop survival, with greater catches of scallops improving survival.

To improve the survival of discarded scallops, industry should look to minimize exposure time, especially for small scallops. This may mean decreasing deck loading where small scallops may not be culled and discarded in a timely manner. Survival may be improved by sorting the catch and discarding undesirable or unmarketable scallops after every tow instead of decking loading. Increasing the volume of catch may also improve survival of scallops. The greater catch volume may limit movement of scallops within the dredge and decrease damage caused by interacting with other animals in the dredge or with the dredge itself, as some damage occurs during the dumping procedure.

4.4. Future Work

There are several areas of interest on this issue that have not been addressed and will require future work. Future work will include development of SMMs with additional covariates. This work may allow us to have a better performing model to understand how other variables effect scallop mortality. Another area of interest is to use the estimated survival rates and apply these rates to the fishery as a whole to calculate fishery-wide DM rates in a similar manner to work completed recently for some groundfish stocks in the Northeast region (Capizzano *et al.*, 2016; Mandleman *et al*., 2016). We hope to extend these results into a predictive model that can be used in concert with forward projection models and estimate the level of discards as a function of the temporal and spatial partitioning of fishing effort.

5. Presentations

The following presentations were given:

- Discard Mortality Rate of Sea Scallops Following Capture and Handling in the Commercial Dredge Fishery, Dr. Rudders, 20th International Pectinid Workshop, April 2015, Galway, Ireland
- Estimating the Discard Mortality Rate of Sea Scallops Following Capture and Handling in the Commercial Dredge Fishery, Dr. Rudders, 2016 Annual American Fisheries Society Conference, August 2016, Kansas City, Missouri
- Discard Mortality of Sea Scallops Following Capture and Handling in the Sea Scallop Dredge Fishery, Ryan Knotek, 2015, Northeast Association of Fish and Wildlife Agencies Conference, April 2015, Newport, Rhode Island

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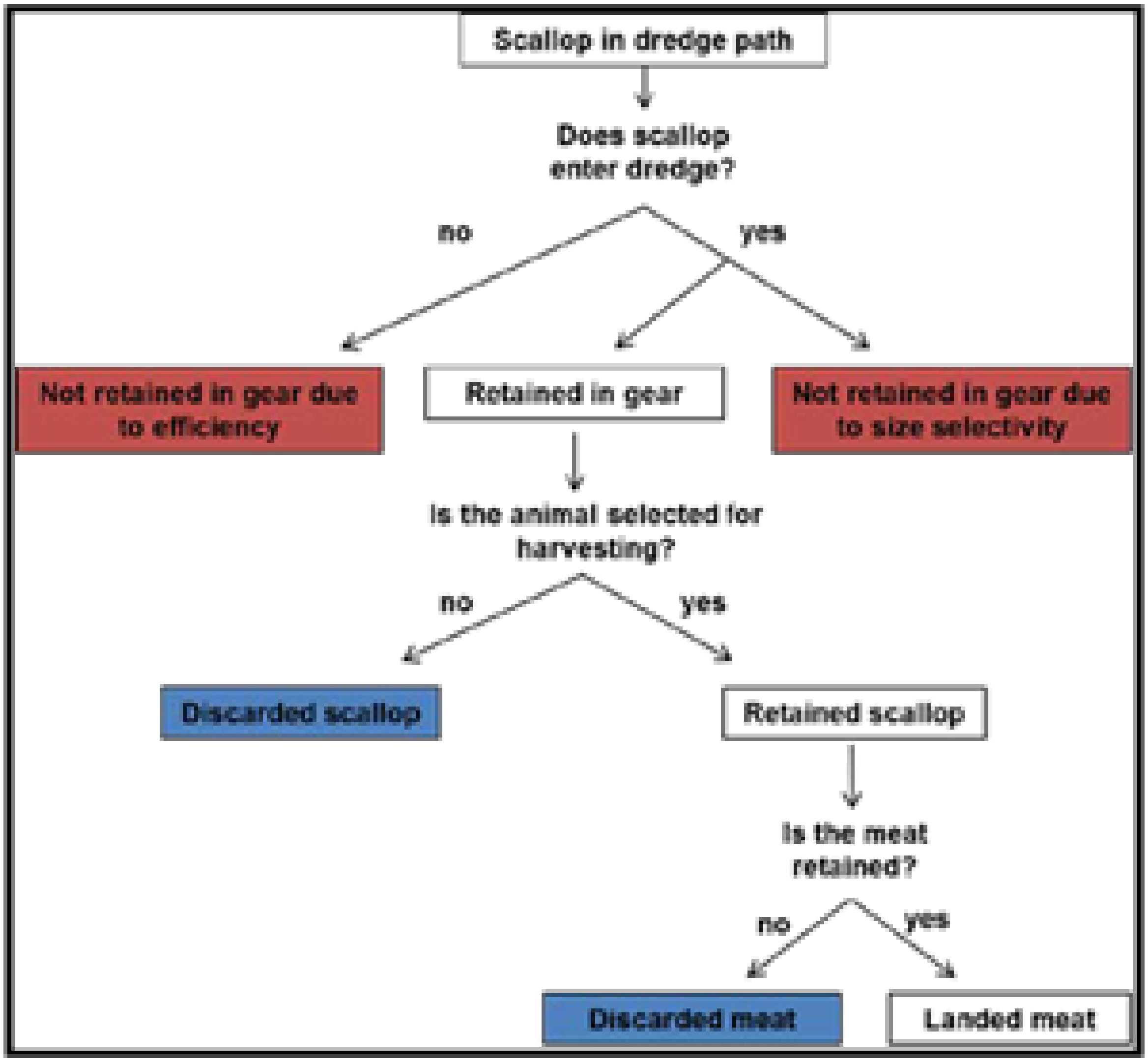

Figure 1. Schematic of the dredge capture process highlighting the various components of non-harvest mortality. Blocks shown in red represent sources of incidental mortality, while those in blue represent discard mortality. Each colored block is associated with a probability of mortality attributed to each process.

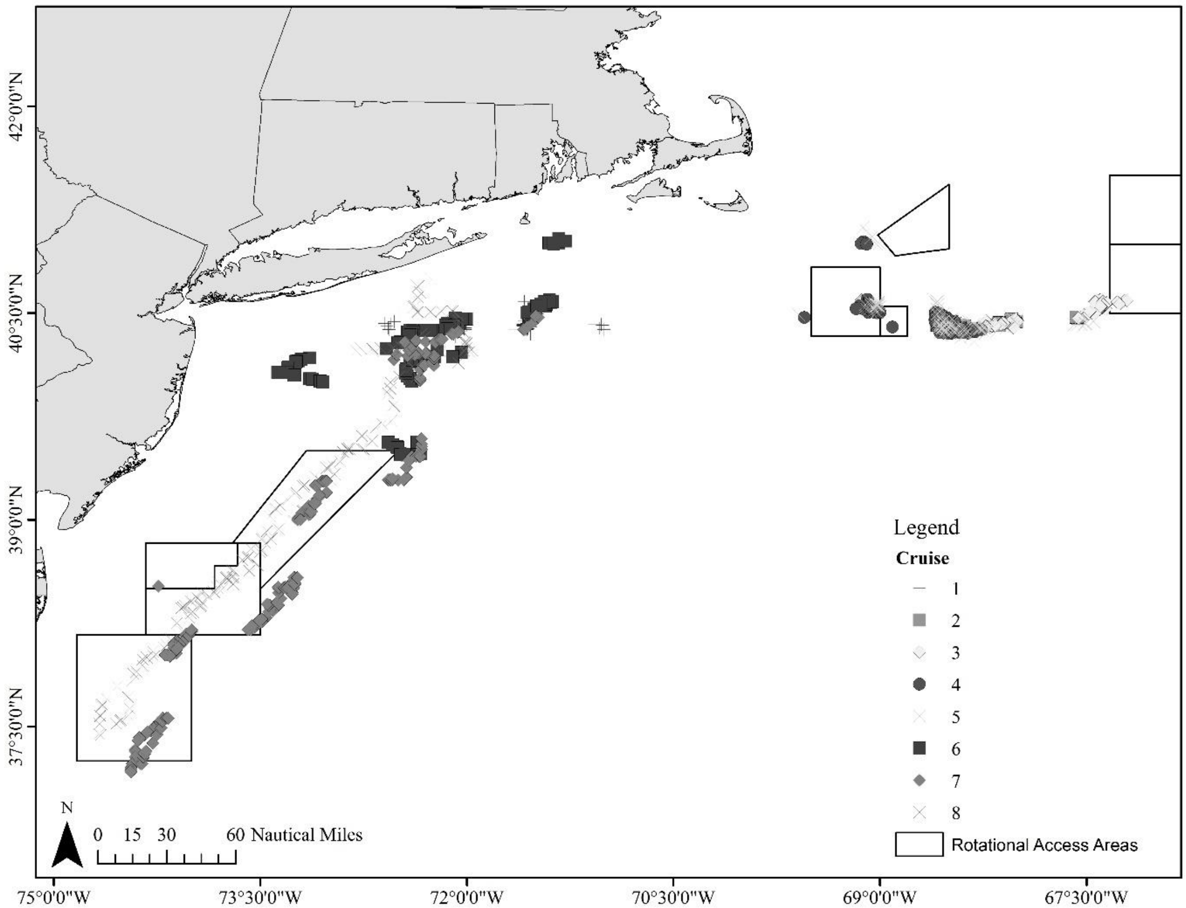

Figure 2. Sampling locations by cruise with sea scallop rotational access areas.

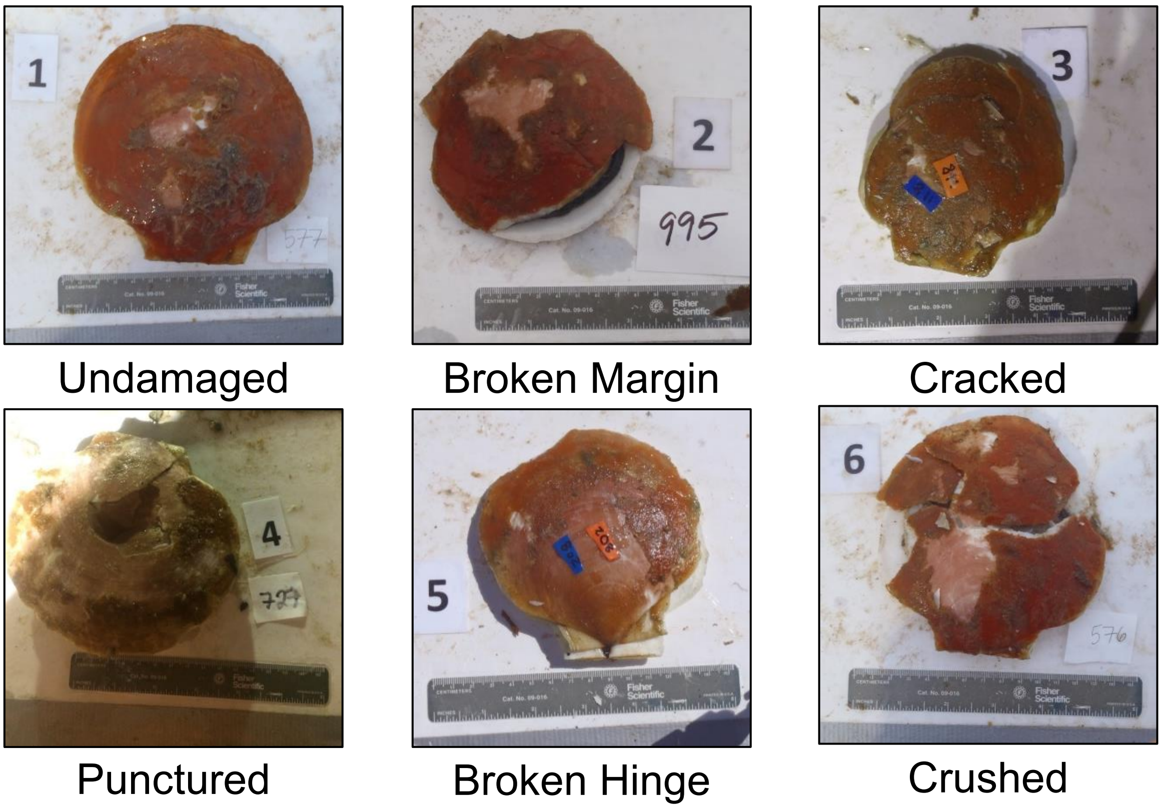

Figure 3. Examples of sea scallop shell damage by shell damage condition code. For our study Conditions 5 and 6 were combined into one category that represented wither a damaged hinge or being crushed.

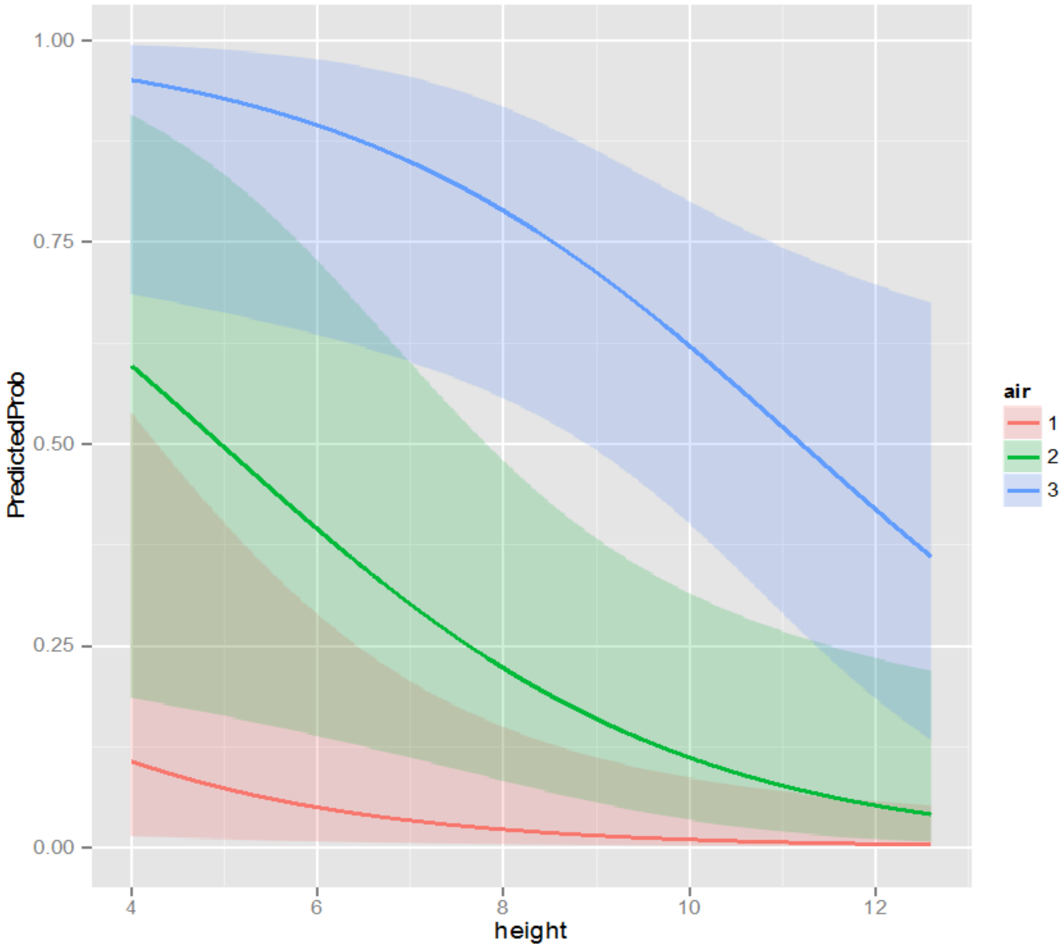

Figure 4. Predicted probabilities (lines) for mortality of animals varying in size and subjected to different air exposure durations (red=0-5 min; green=15 min; blue=30 min). 95 percent confidence intervals are shaded in colors for respective air exposure groups.

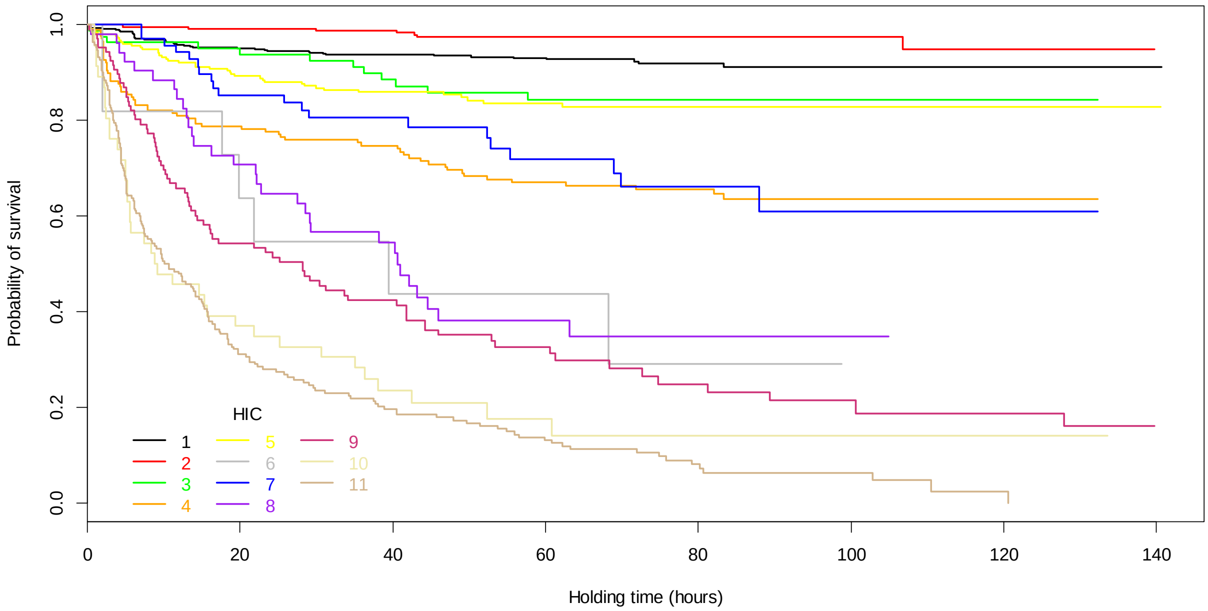

Figure 5. KM survival curves for HICs.

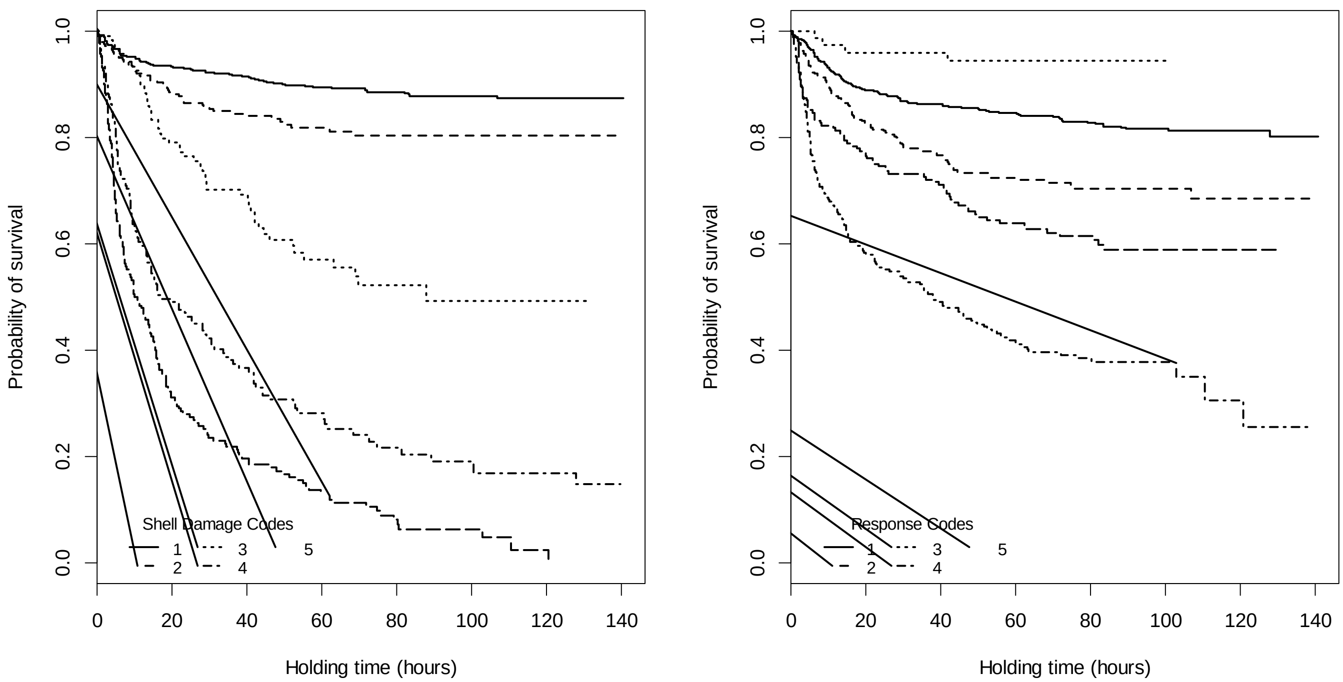

Figure 6. KM survival curves for shell damage codes and response codes.

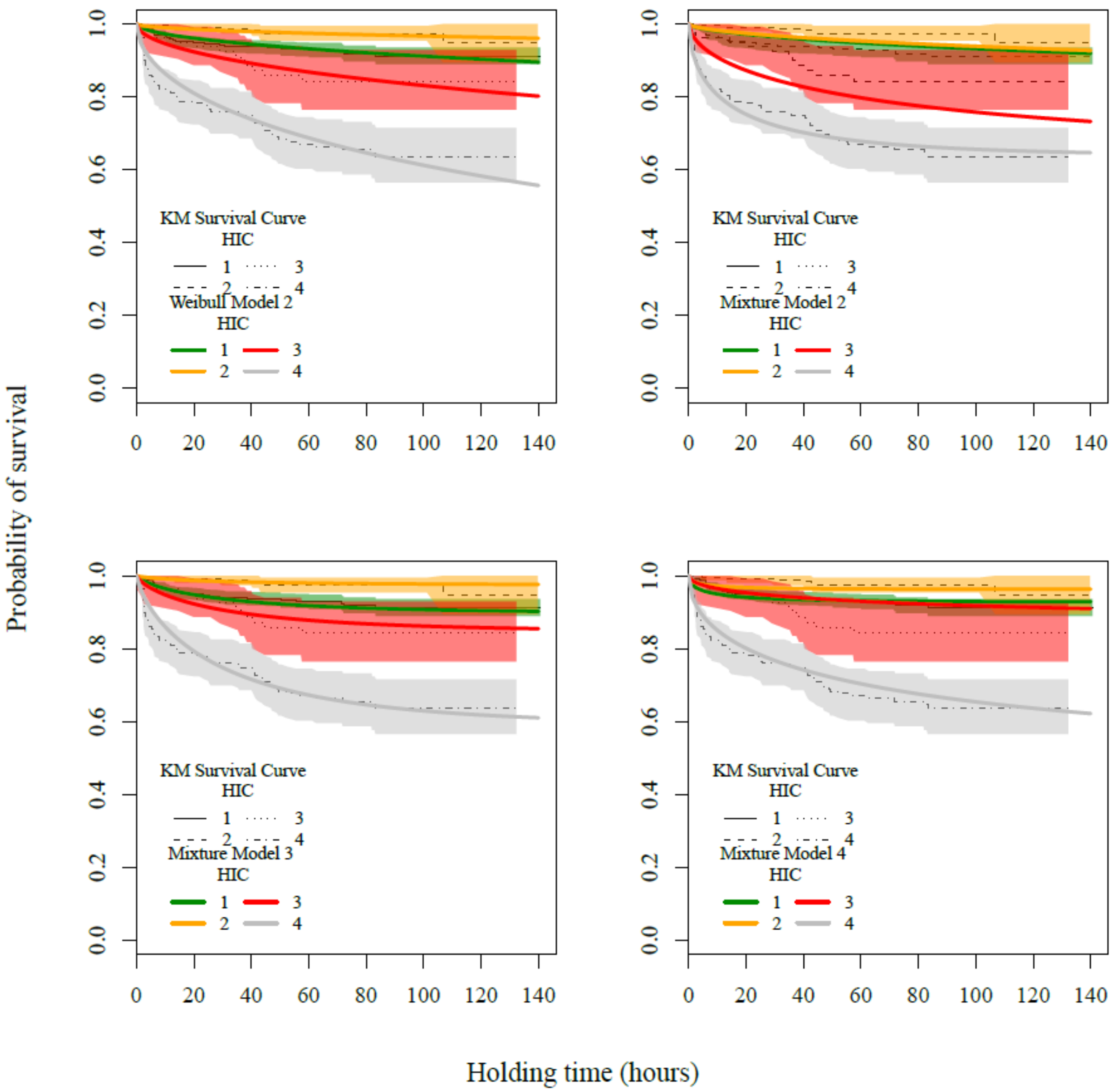

Figure 7. KM survival curves with 95% confidence intervals (shaded regions) and survival mixture model curves modeling the probability of survival as a function of HIC for shell damage 1 models.

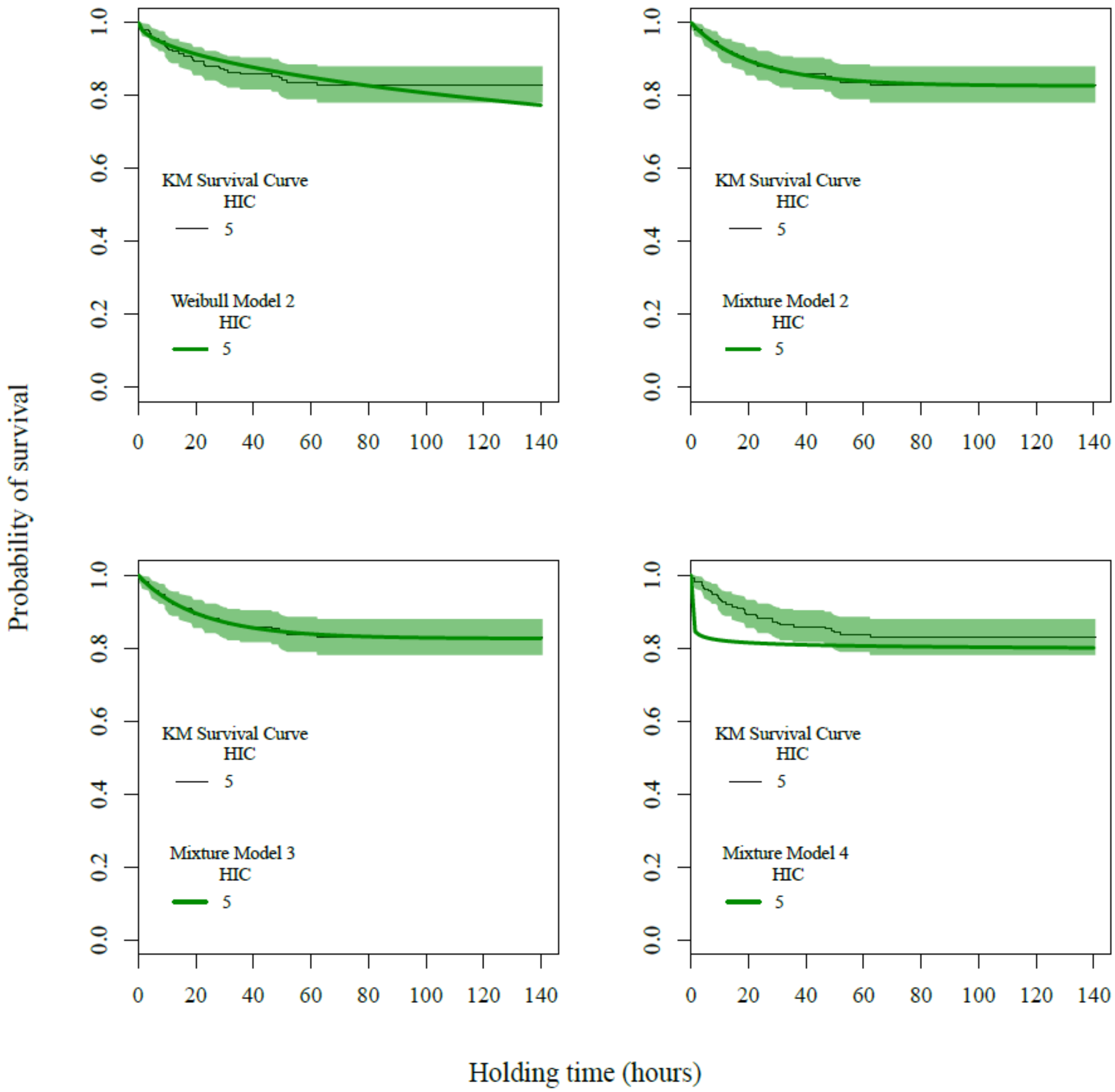

Figure 8. KM survival curves with 95% confidence intervals (shaded regions) and survival mixture model curves modeling the probability of survival as a function of HIC for shell damage 2 models.

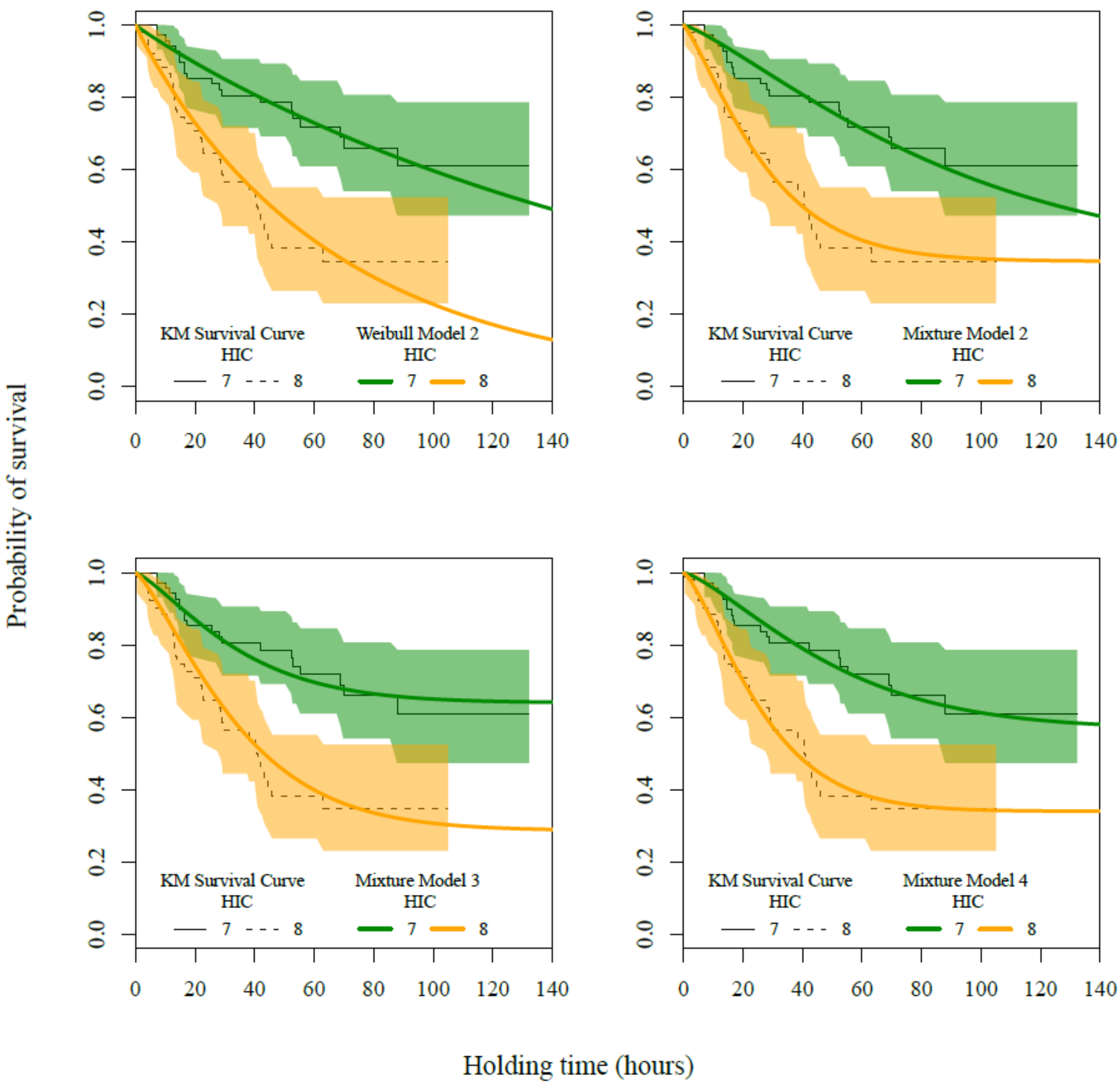

Figure 9. KM survival curves with 95% confidence intervals (shaded regions) and survival mixture model curves modeling the probability of survival as a function of HIC for shell damage 3 models.

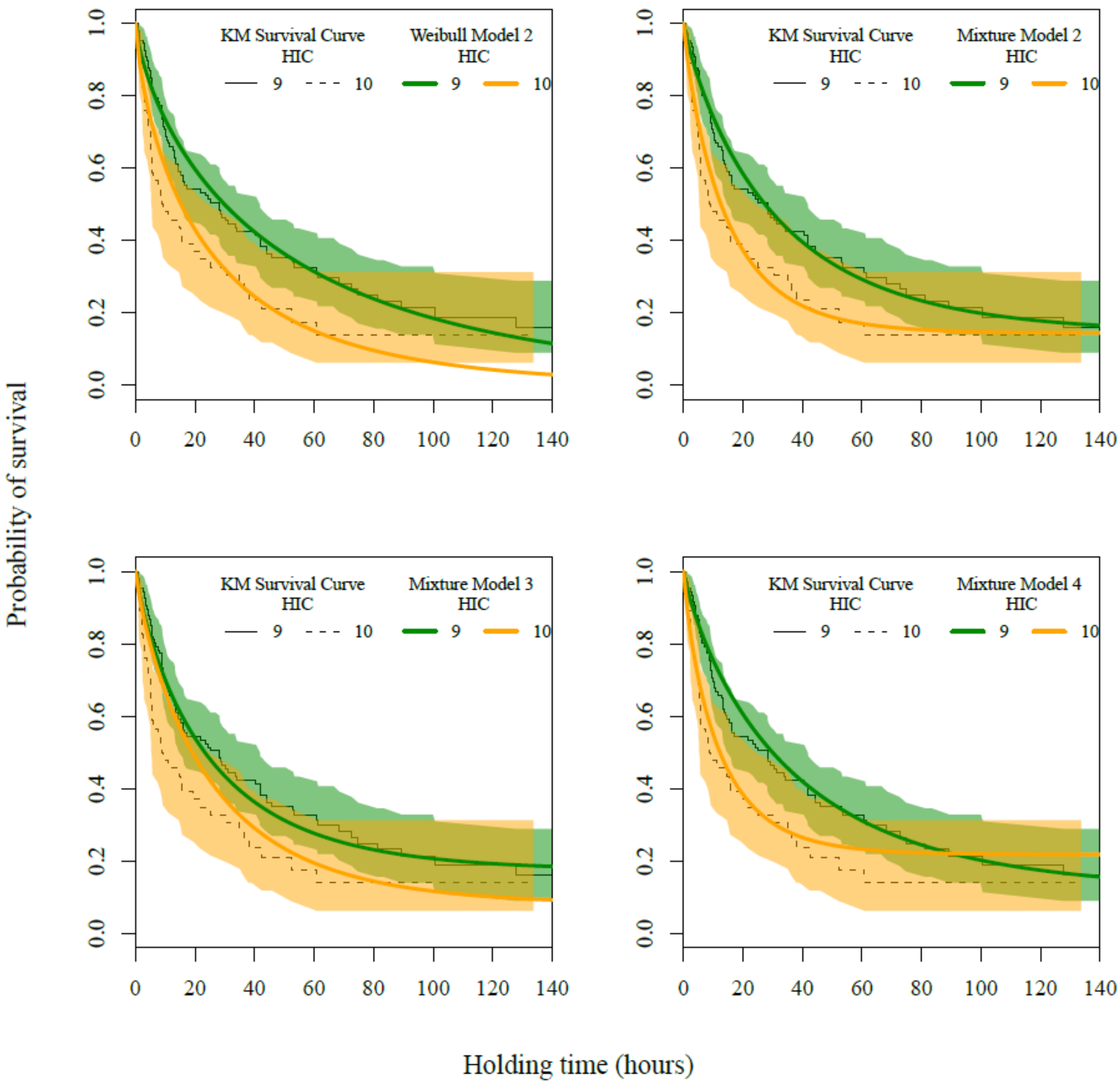

Figure 10. KM survival curves with 95% confidence intervals (shaded regions) and survival mixture model curves modeling the probability of survival as a function of HIC for shell damage 4 models.

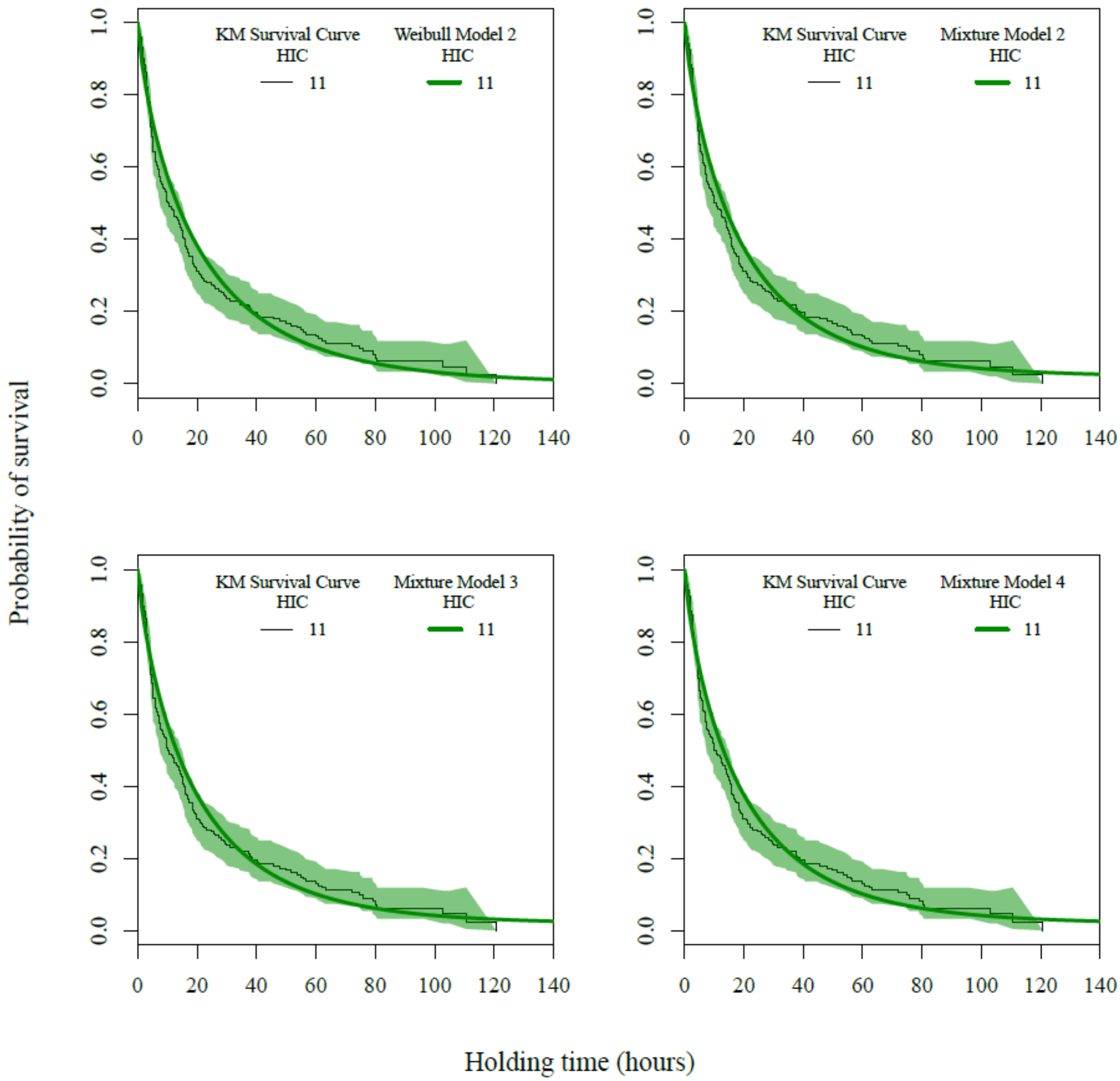

Figure 11. KM survival curves with 95% confidence intervals (shaded regions) and survival mixture model curves modeling the probability of survival as a function of HIC for shell damage 5 models.

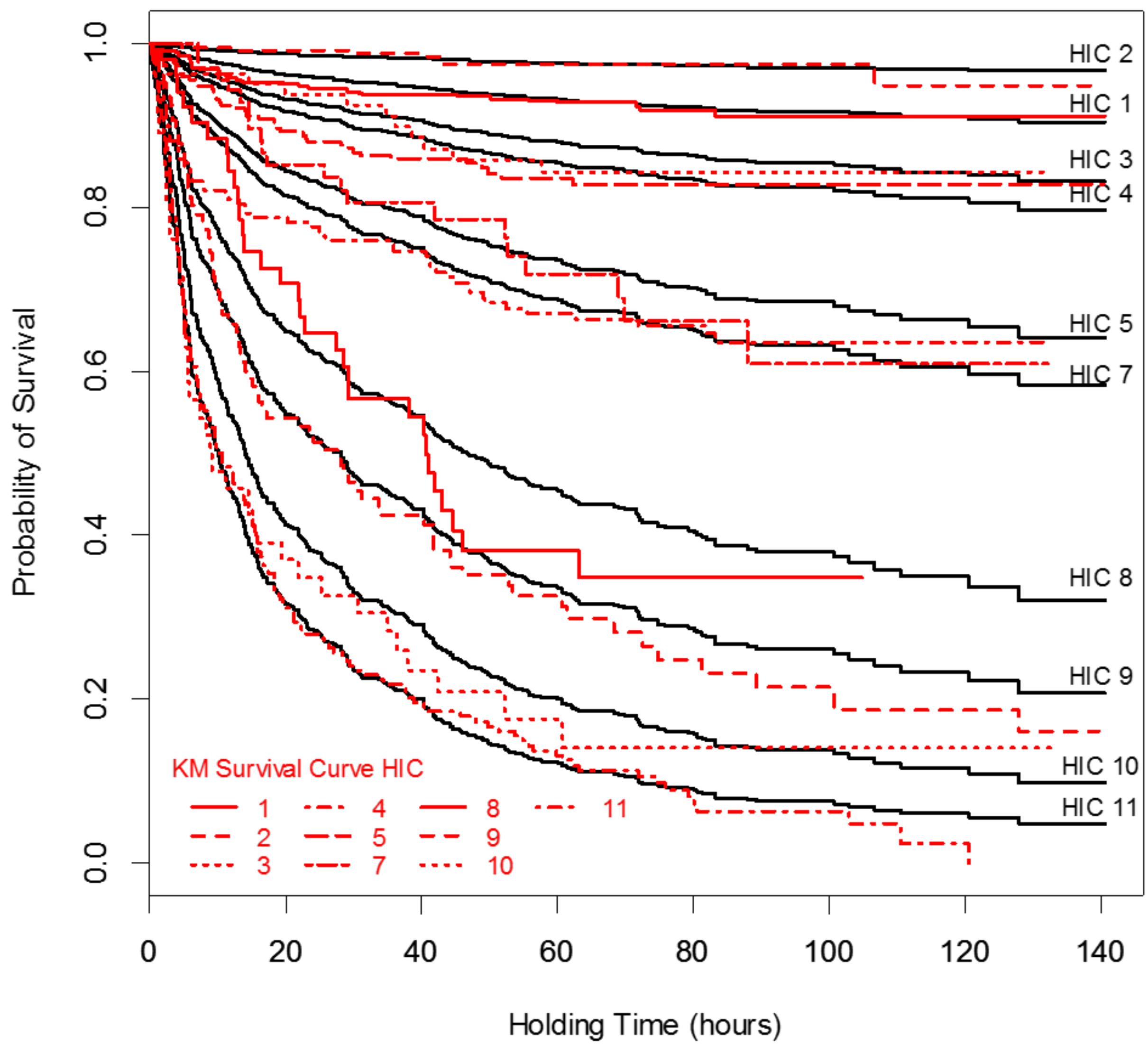

Figure 12. Predicted Cox proportional hazard model survival curves by HIC (solid black lines with HIC level above the line) for models with additional covariates plotted with KM survival curves by HIC (red lines).

Table 1. Replicate and air exposure treatment group observed sample sizes. Size classes represented as S (small): < 6.8 cm, M (medium): 6.8-9.7 cm and L (large): > 9.7 cm.

	Air Exposure Treatment Groups											
	0 min			5 min			15 min			30 min		
Replicate 1	1	2	3	1	2	3	1	2	3	1	2	3
Replicate 2	1	2	3	1	2	3	1	2	3	1	2	3
Replicate 3	1	2	3	1	2	3	1	2	3	1	2	3
Replicate 4	1	1	4	1	1	4	1	1	4	1	1	4
	S	M	L	S	M	L	S	M	L	S	M	L

Table 2. Dates, duration and vessel for the eight cruises completed for the project.

Cruise	Dates	Duration	Vessel
1	August 5 -12, 2014	8	F/V Røst
2	August 27 - September 2, 2014	7	F/V Røst
3	October 20 - 26, 2014	7	F/V Røst
4	May 16 - 22, 2015	7	F/V Horizon
5	June 15 -21, 2015	7	F/V Horizon
6	July 13 - 19, 2015	7	F/V Horizon
7	August 12 - 18, 2015	7	F/V Horizon
8	December 1 - 7, 2015	7	F/V Røst

Table 3. Number of tows completed by cruise.

Cruise	Number of Tows
1	26
2	18
3	61
4	69
5	93
6	69
7	68
8	56
Total	460

Table 4. Shell damage conditions codes and descriptions.

Condition Code	Description
1	Undamaged
2	Broken Margin
3	Cracked
4	Punctured
5	Broken hinge/Crushed

Table 5. Response description, codes and stimulus used to elicit response and time period during the capture/handling process when response was elicited.

Response	Response Code	Stimulus	Response Time Period
Clapping prior to contact	1	NA	Prior to handling
Closed shell that will not open	1	Probe	Handling
Clapping during handling	2	NA	Handling
Clapping in response to probing the mantle	3	Probe	Handing/Probe Stimulus
No clapping, but mantle slightly retracts in response to probing the mantle	4	Probe	Handing/Probe Stimulus
No response to probing the mantle	5	Probe	Handing/Probe Stimulus

Table 6. Health indicator codes (HIC) with corresponding shell damage condition code and response codes used to populate the SVI. The number of scallops in each HIC are scallops from the holding tank studies assessed for vitality scores and the percent is the percentage of scallops in each HIC.

HIC	Shell Damage Condition Code	Response Code	Number of Scallops	Percent
1	1	1	687	35.63
2	1	2-3	252	13.07
3	1	4	81	4.20
4	1	5	179	9.28
5	2	1-4	253	13.12
6	2	5	11	0.57
7	3	1	70	3.63
8	3	2-5	52	2.70
9	4	1-3	107	5.55
10	4	4-5	46	2.39
11	5	1-5	190	9.85

Table 7. Health indicator codes (HIC) with corresponding shell damage condition code and response codes. The number of scallops in each HIC are scallops from the field trails that were assessed for vitality scores but released and the percent is the percentage of scallops in each HIC.

HIC	Shell Damage Condition Code	Response Code	Number of Scallops	Percent
1	1	1	9,046	64.61
2	1	2-3	2,075	14.82
3	1	4	389	2.78
4	1	5	583	4.16
5	2	1-4	549	3.92
6	2	5	26	0.19
7	3	1	100	0.71
8	3	2-5	102	0.73
9	4	1-3	181	1.29
10	4	4-5	90	0.64
11	5	1-5	859	6.14

Table 8. Candidate variables, along with units and summary information, considered in Cox proportional hazard models analyses that included additional explanatory variables.

Variable	Mean	SD	SE	Range	Number of Observations
Tow Duration (minutes)	55.16	0.49	0.49	5 - 99	1,917
Scallop Catch (number of baskets)	13.02	0.42	18.5	0 - 133	1,917
Thermal Gradient (°C)	8.67	0.17	7.56	-6.2 - 21.1	1,917
Depth (m)	63.77	0.16	7.19	36.6 - 89.6	1,917
Shell Height (cm)	9.01	0.06	2.61	3 - 17.5	1,917
Exposure Time (minutes)	22.36	0.34	14.91	1 - 93.02	1,917

Table 9. Survival mixture models types with assumptions for parameters α and π. Taken from Benoît *et al*., 2012.

Model	α	π	Interpretation
Weibull 2	$\exp(-X'\beta)$	1	Common survival function within each vitality class
Mixture 2	$\exp(-X'\beta)$	Constant	Common survival function within each vitality class for a fixed proportion of affected animals
Mixture 3	Constant	$[1 + exp(-X'\beta)]^{-1}$	Common survival function for affected animals, with the proportion affected dependent on vitality class
Mixture 4	$\exp(-X'\beta_1)$	$[1 + exp(-X'\beta_2)]^{-1}$	Common survival function within each vitality class, where the proportion of affected individuals also depends on vitality class

Table 10. Optimal logistic regression model parameter estimates. * indicates in P-value column indicates parameter is significant.

Parameter	Estimate	Std. error	Z value	P-value	Odds ratio
(Intercept)	-0.48	1.62	-0.30	0.77	0.62
Air (15 min)	2.52	1.20	2.10	0.04 *	12.39
Air (30 min)	5.09	1.21	4.21	2.61e-05 *	161.85
Shell height	-0.41	0.17	-2.36	0.02 *	0.66

Table 11. Probability of mortality occurring as a function of air exposure time.

Air Exposure Level	Probability
0-5 min	1%
15 min	14%
30 min	68%

Table 12. Survival mixture models for discard mortality analysis listed by shell damage code and model based on AIC and ΔAIC ($model_{AIC}$ - $model_{minAIC}$). Models in **bold** were selected as the optimal model(s) based on model selection criteria.

Shell damage	Model	AIC	ΔAIC
1	**Mixture Model 3**	**1,827.59**	
	Weibull Model	1,834.31	6.72
	Mixture Model 2	1,847.36	19.76
	Mixture Model 4	1,897.44	69.85
2	**Mixture Model 3**	**531.74**	
	Mixture Model 2	**531.74**	**0.00**
	Weibull Model	540.28	8.54
	Mixture Model 4	648.90	117.15
3	**Mixture Model 2**	**574.11**	
	Mixture Model 4	**574.24**	**0.13**
	Mixture Model 3	**574.98**	**0.86**
	Weibull Model	577.55	3.44
4	**Mixture Model 2**	**1,075.34**	
	Mixture Model 4	1,079.92	4.58
	Mixture Model 3	1,081.73	6.38
	Weibull Model	1,082.76	7.41
5	**Weibull Model**	**1,439.16**	
	Mixture Model 2	**1,440.62**	**1.45**
	Mixture Model 3	**1,440.62**	**1.45**
	Mixture Model 4	**1,440.62**	**1.45**

Table 13. Bootstrapped mean survival estimates by HIC and overall mean survival with standard deviations.

Survival	Estimate	S.D.
Overall Survival	81.62	1.22
HIC 1	89.7	1.47
HIC 2	97.35	1.2
HIC 3	84.04	4.84
HIC 4	58.95	5.11
HIC 5	82.45	1.88
HIC 7	50.52	5.54
HIC 8	33.47	4.86
HIC 9	14.95	4.39
HIC 10	14.95	4.39
HIC 11	2.41	2.07

Table 14. Bootstrapped mean alpha parameter estimates by HIC with standard deviations.

Alpha Parameter Estimate	Estimate	S.D.
HIC 1	0.03	0.01
HIC 2	0.03	0.01
HIC 3	0.03	0.01
HIC 4	0.03	0.01
HIC 5	0.05	0.01
HIC 7	0.03	0
HIC 8	0.02	0
HIC 9	0.03	0.01
HIC 10	0.07	0.01
HIC 11	0.05	0

Table 15. Bootstrapped mean gamma parameter estimates by HIC with standard deviations.

Gamma Parameter Estimate	Estimate	S.D.
HIC 1 - 4	-0.28	0.09
HIC 5	-0.04	0.11
HIC 7 - 8	0.26	0.08
HIC 9 - 10	-0.12	0.08
HIC 11	-0.21	0.03

Table 16. Individual candidate Cox proportional hazard models listed by AICc and ΔAICc ($model_{AICc}$ - $model_{minAICc}$).

Model	AIC	ΔAIC
HIC	6,682.79	0
Shell Height	7,447.14	764.35
Exposure Time	7,487.90	805.11
Scallop Catch	7,502.49	819.70
Tow Duration	7,509.26	826.48
Bottom Type	7,509.95	827.17
Thermal Gradient	7,512.72	829.93
Depth	7,512.98	830.19

Table 17. Forward-selection Cox proportional hazard model development listed by model, AICc and ∆AICc ($model_{AICc}$ - $model_{minAICc}$ except for M1 and M2). ∆AICc for M1 and M2 is M1 AICc – M2 AICc. Models with * satisfied model selection criteria: a reduction in AICc ≥ 3 units with the addition of a covariate. M4 in **bold** was the as the optimal model based on lowest AICc and difference in ∆AICc.

Model	Parameters	AIC	∆AIC
M1	Intercept	7,511.01	
M2*	~ 1 + HIC + Shell Height	6,684.47	826.54
M3*	~ 1 + HIC + Shell Height + Exposure Time	6,629.77	-54.70
M4*	**~ 1 + HIC + Shell Height + Exposure Time + Scallop Catch**	**6,609.20**	**-20.57**
M5	~ 1 + HIC + Shell Height + Exposure Time + Scallop Catch+ Tow Duration	6,609.35	0.15
M6	~ 1 + HIC + Shell Height + Exposure Time + Scallop Catch + Bottom Type	6,611.00	1.80
M7	~ 1 + HIC + Shell Height + Exposure Time + Scallop Catch + Thermal Gradient	6,609.41	0.21
M8	~ 1 + HIC + Shell Height + Exposure Time + Scallop Catch + Depth	6,611.23	2.02

Table 18. Summary output from the optimal Cox proportional hazard model. * in the P-value column indicates significance of the covariate.

Fixed Coefficients	Coefficient	Exp(Coefficient)	SE(Coefficient)	Z	P-Value
HIC 2	-1.10	0.33	0.40	-2.72	0.01*
HIC 3	0.43	1.53	0.33	1.30	0.19
HIC 4	1.35	3.88	0.20	6.62	0.00*
HIC 5	0.94	2.56	0.21	4.39	0.00*
HIC 7	1.60	4.96	0.27	5.97	0.00*
HIC 8	2.65	14.15	0.24	11.19	0.00*
HIC 9	2.87	17.67	0.19	15.46	0.00*
HIC 10	3.40	30.10	0.23	14.97	0.00*
HIC 11	3.67	39.09	0.18	20.76	0.00*
Shell Height	-0.01	0.99	0.02	-0.29	0.77
Exposure Time	0.03	1.03	0.00	8.96	0.00*
Scallop Catch	-0.02	0.98	0.00	-4.39	0.00*

Table 19. Predicted survival probability from the optimal Cox proportional hazard model by HIC with mean shell height, total exposure and scallop catch.

HIC	Shell Height	Total Exposure	Scallop Catch	Survival
1	8.41	21.02	11.73	90.27
2	8.43	21.98	15.37	96.54
3	7.71	30.49	14.04	86.31
4	7.20	34.79	16.68	67.22
5	10.04	21.38	15.02	78.63
7	10.37	17.82	9.86	61.70
8	10.44	19.60	12.54	29.40
9	9.83	19.00	8.76	19.60
10	9.58	21.50	16.33	8.13
11	11.34	18.35	10.92	3.66