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By

**Matthew J. Lotti**

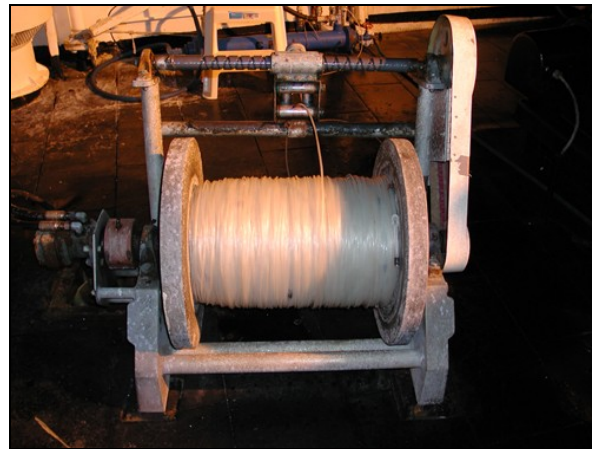


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## **Factors influencing at-vessel shark mortality during fishery-independent bottom longline surveys in the U.S. Gulf of Mexico and the western North Atlantic Ocean.**

Matthew J. Lotti, Bradley M. Wetherbee, Mark A. Grace, and William B. Driggers

### Abstract:

Many elasmobranchs have life histories and reproductive strategies that make them vulnerable to fisheries overexploitation. The U.S. commercial bottom longline fishery utilizes gear soak times up to or in excess of 12 hours and this soak period has been shown to correlate to at-vessel mortality for many shark species, especially those that use obligate ram ventilation. The NOAA/NMFS/Southeast Fisheries Science Center, Mississippi Laboratories bottom longline survey utilizes only 1 hour soak times per set, however, even with this soak time at-vessel mortality still occurs. The purpose of this research was twofold: 1. To determine mortality rates for seven shark species commonly-caught by commercial bottom longline fisheries in the Gulf of Mexico and western North Atlantic: tiger shark *Galeocerdo cuvier*, nurse shark *Ginglymostoma cirratum*, bull shark *Carcharhinus leucas*, scalloped hammerhead *Sphyrna lewini*, spinner shark *Carcharhinus brevipinna*, blacktip *Carcharhinus limbatus*, and Atlantic sharpnose *Rhizoprionodon terraenovae*; 2. Investigate specific biological, technical, and/or environmental factors correlated to at-vessel mortality. At-vessel mortality after 1 hr soak time was found to be >11% for *S. lewini*, *C. limbatus*, and *R. terraenovae* and >25% for *C. brevipinna*. In addition, the probability of at-vessel mortality was found to increase with decreasing DO (ppm) content among these species. At-vessel mortality was negatively correlated with fork length for scalloped hammerhead, blacktip, and Atlantic sharpnose. The probability of at-vessel mortality was found to be greater in male scalloped hammerhead sharks than females. The probability of at-vessel mortality in blacktip sharks was found to be higher among individuals caught on J hooks rather than circle hooks, except among small juveniles, where the opposite was shown. Within Atlantic sharpnose, the probability of at-vessel mortality was found to increase with rising bottom water temperature. At-vessel mortality and correlated factors are expected to occur more frequently with increased soak times. Considering commercial soak times are several times greater than the survey soak time used in the NOAA/NMFS study, reducing soak times and avoiding areas of low dissolved oxygen in commercial shark fisheries would decrease shark at-vessel mortality in the commercial bottom longline fishery. Use of circle hooks over J hooks is recommended to reduce mortality among blacktip sharks. Fishing in lower temperature areas may also reduce at-vessel mortality among Atlantic sharpnose. From a conservation standpoint, the distinctions found between relationships to mortality among these species could facilitate future species-specific management for sharks. One such example is the current petition to place scalloped hammerhead sharks onto the Endangered Species List. If this occurs and *S. lewini* is made a protected species, managers form policies accounting for the likely increase of discard mortality among individuals caught and released by the commercial fishery.

## Introduction:

Many species of elasmobranch are vulnerable to fishing overexploitation due to K-selected life histories and low rates of reproduction (Musick *et al*, 2000a; Cortes, 2002; 2004). Sharks typically have slow digestive rates and growth (Wetherbee and Cortes, 2004), late maturity, and low fecundity, and while certain species may be sustainably harvested (Burgess *et al*, 2005), fisheries must be conservative both in landings and discards, whether targeted or bycatch. There is concern over whether current catch-rates of elasmobranchs within the Gulf of Mexico and Southeast United States exceed sustainable limits for certain species (Baum *et al*, 2003; Burgess *et al*, 2005; Jiao *et al*, 2009; Morgan *et al*, 2009).

The targeted shark fishery within the United States began to grow throughout the 1980's and early 1990's (Morgan *et al*, 2009; Morgan and Carlson, 2010.), in-part coinciding with an international rise in demand for shark fin (Clarke *et al*, 2006). Current US federal (NMFS, 1999) and interstate regional (ASMFC, 2008) management of targeted shark fisheries is primarily centered on bottom longline efforts in the Gulf of Mexico and Southeast United States coast. Due to lack of species-specific population data, most species of shark are assessed via demographic modeling (Cortes, 2004), and assembled into complexes rather than managed as individual species. Sharks caught by US bottom longline fisheries usually fall into the Small Coastal Complex or Large Coastal Complex categories (NMFS, 1999; Morgan and Burgess, 2007; Morgan *et al*, 2009; Morgan and Carlson, 2010). Although such management measures conserve shark populations through gear restriction, catch quotas, and seasonal closures, the varying biological characteristics of species within a complex may limit the protection such

efforts provide (Burgess *et al*, 2005; Morgan *et al*, 2009). In order for future management to take such characteristics into account, further species-specific information related to shark mortality within the US commercial bottom longline fishery is needed.

However, collection of data for population modeling and stock assessment is often challenging for fisheries scientists. Historically, most data used to model shark populations prior to 2003 was derived from commercial coastal and pelagic longline logbooks (Burgess *et al*, 2005; Morgan *et al*, 2009). The gear and protocols used by commercial fishermen can vary from vessel to vessel, so logbook data must often be standardized prior to use in models (Punt *et al*, 2000). Within these data, there is concern over accurate reporting by fishermen. Under-reporting, over-reporting, and/or misidentification of species can skew resulting population models and thus management efforts. For example, Morgan *et al* (2009) notes that many Atlantic sharpnose *Rhizoprionodon terraenovae* caught by US commercial bottom longline vessels from 1994-2003 were used as bait for subsequent sets and not recorded either as landings or discards. The mandatory placement of trained observers aboard commercial longline fishery vessels starting in 2002 helps alleviate these issues, but currently covers only 4-6% of the overall fleet (Hale *et al* 2007; 2010; 2011). Thus, catch estimates projected from the observer coverage may not reflect that of the entire shark bottom longline fishery.

Fisheries-independent surveys assure that data is collected by trained scientists, and biological information recorded, but is often limited due to funding (ASMFC, 2008; Morgan *et al*, 2009). Aside from using standardized gear and protocols, fisheries-independent surveys often reduce soak times in order to limit mortality of caught sharks (Morgan and Carlson, 2010). Soak time is defined as the time from the first baited longline hook entering the water to the time that

hook is retrieved (Morgan *et al*, 2009). Commercial longline vessels typically use soak times ranging from 12-20 hours (Hale *et al*, 2007; 2010).

Soak time has been shown to influence at-vessel mortality among commonly-caught species in the US bottom longline fishery. Many sharks caught in the bottom longline fishery use obligate ram ventilation (Carlson *et al*, 2004). Longline fishing often prevents these sharks from properly ventilating when hooked. Morgan and Burgess (2007) and Morgan and Carlson (2010) found increasing soak times to positively correlate with mortality for blacknose *Carcharhinus acronotus*, sandbar *Carcharhinus plumbeus*, blacktip *Carcharhinus limbatus*, scalloped hammerhead *Sphyrna lewini*, and great hammerhead *Sphyrna morkarran*. Further, Morgan *et al* (2009) observer reports found that Atlantic sharpnose mortality rates increased over 80% when commercial soak times exceeded 8 hours, and scalloped hammerhead mortality exceeded 65% after only four hours commercial soak time.

However, while prolonged soak times understandably relate to higher mortalities among caught sharks, soak time alone does not cause mortality. Soak time is a temporal variable (Morgan *et al*, 2009) representing the time sharks could potentially be caught and tethered to the longline. Passage of time on a hook alone does not cause mortality, but rather mortality is more directly linked to the negative pressures associated with being hooked over that time period. When deprived of oxygen, sharks that obligate ram ventilate are likely to attempt faster swimming (Carlson and Parsons, 2001) while hooked in an attempt to ventilate and/or free themselves, potentially facing further physiological stress (Carlson *et al*, 2004, Morgan and Burgess, 2007). Stress, and subsequent mortality, could also be influenced by environmental, biological, and protocol-factors related to the fishing process. In order to examine the potential

correlation of such variables to mortality among hooked sharks, soak time must be controlled for. Among commercial fisheries, soak time varies, but within fisheries-independent surveys, soak time can be standardized and minimized.

The one hour soak time used by the NMFS Pascagoula Science Center Shark Survey represents a minimal-stress scenario for caught sharks, as only a maximum one-hour window exists for sharks to remain restrained. In addition, the data provided by this survey spans over a large time frame (1995-2010) and uses standardized gear and protocols. The reduced soak time and controlled protocols allow for an in-depth investigation into species-specific factors potentially correlated to mortality among hooked sharks. Understanding factors related to at-vessel mortality in caught sharks is important for management consideration, as the current system of commercial retention limits and quotas (NMFS, 2006) functions under the assumption that sharks are released alive (Morgan and Burgess, 2007). However, in species with high at-vessel mortality, such protective measures are made null by the discard of dead sharks (Morgan and Burgess, 2007), especially if such sharks are caught as bycatch and/or losses are not recorded by commercial fishermen. As such, population numbers of species vulnerable to longline fishing at-vessel mortality could be dropping without fisheries scientists and managers being aware.

For example, recent Florida state law prohibits the landing of tiger and three hammerhead shark species in state waters, starting in 2012. However, despite the law, these species are commonly caught (Hale *et al*, 2007; 2010; 2011; Morgan *et al*, 2009), and if at-vessel mortality is high prior to release, such conservation measures offer sharks little protection. Scalloped and great hammerhead sharks are often found to have high at-vessel mortality (Morgan *et al*, 2009),

so released hammerhead sharks will often already be dead, losing an economic resource for fishermen and conflicting with the conservation of the species. An investigation into the specific factors causing at-vessel mortality in sharks stands to push for the development of protective measures designed to avoid such losses and better maintain elasmobranch conservation.

The purpose of this research is twofold: 1.) To determine mortality levels associated with minimal soak time (1hr), essentially a best-case-scenario in comparison to commercial soak times (12-20hr), for seven frequently-caught species within the commercial bottom longline shark fishery range; 2.) To explore biological, technical, and environmental variables potentially correlated to at-vessel mortality among these species. The negative effect of significant correlates is likely to be exacerbated by extended (commercial) soak times, so this research stands to provide more species-specific information in regards to vulnerability to longline fishing, and may further illustrate how protective measures provided via the Large Coastal and Small Coastal shark management complexes may be too general to grant appropriate protection to species contained therein. Thus, the results of this research will be used to make management recommendations towards species-specific conservation.

#### Methods:

Data analyzed in this research was provided by the NOAA Fisheries Service, Southeast Florida Science Center, Pascagoula MS Laboratories bottom longline surveys. From 1995-2010, the Pascagoula Science Center conducted 25 cruises from August-September within the Gulf of Mexico and off the southeastern coast of the U.S. Coordinates for the exact survey range can be found in Driggers *et al* (2008). Due to the extensive time period over which survey data was

collected, >2,000 bottom longline sets were recorded. Longlines were composed of 1852 m monofilament mainline and set with 100 ganglions, each comprised of a 3.7 m leader and baited hook (Driggers *et al*, 2008). To reduce mortality, 1 hr soak times were used during all surveys. This soak time is minimal compared to those employed by commercial bottom longline shark-directed fisheries within the Gulf of Mexico and off the US Southeast Atlantic coast (see Hale *et al*, 2007; 2010; 2011). Protocols pertaining to longline length, number of baited hooks, soak time, and gear used remained constant throughout the survey period, save for hook type. From 1995-1998, No. 3 J hooks were used for surveys, while for 2001-2010, 15/0 circle hooks were used. Surveys performed during 1999-2001 utilized both hook types (Driggers *et al*, 2008). Hook type has been shown to have differential effects on at-vessel mortality in coastal and pelagic longline, but only a few publications to date have investigated this relationship (Afonso *et al*, 2011).

Mortality (Alive = 0, Dead = 1), species (1-7), sex (m = 0, f = 1), and fork length (FL)(mm) was recorded for each individual caught. The seven species chosen for this research represent some the most commonly caught non-prohibited species by the US Atlantic commercial shark-targeted bottom longline fishery, as well as frequent bycatch species for grouper and tilefish-targeted bottom longline fisheries (Hale *et al*, 2007; Morgan and Burgess, 2007; Morgan *et al*, 2009; Hale *et al*, 2010; 2011). Of these, six species – tiger shark *Galeocerdo cuvier* (n = 670), bull shark *Carcharhinus leucas* (n = 188), nurse shark *Ginglymostoma cirratum* (n = 258), spinner shark *Carcharhinus brevipinna* (n = 707), blacktip shark *Carcharhinus limbatus* (n = 837), and scalloped hammerhead *Sphyrna lewini* (n = 162) – are managed under the Large Coastal Species Complex (NMFS, 1999). The remaining species, the Atlantic



sharpnose *Rhizoprionodon terraenovae* (n = 14,301), is managed under the Small Coastal species complex (NMFS, 1999). Fork length was recorded to the nearest millimeter (mm) by measuring a straight line along the shark lateral axis stretching from the rostrum tip to the caudal fin notch (Driggers *et al*, 2008).

Bottom depth (m) was recorded for all surveys. For each longline set, the NOAA survey measured salinity (ppt) at the water surface, mid-depth, and ocean bottom, but for this research, only the bottom salinity level was used for analysis, as this is the depth at which sharks are caught and remain on the longline. Dissolved oxygen (DO)(ppm) and water temperature (°C) were measured in a similar fashion. As with salinity, only bottom DO level and bottom temperature were used for analysis in this study.

All statistical analyses were conducted using SAS statistic software (SAS, v9.2, SAS Institute, Inc., Cary, NC). Mortality-rate (%) was calculated by dividing the #dead/#total individuals within each species. Logistic regression was used to predict the relationship between mortality (alive/dead) and fork length, sex, depth, hook type, salinity, dissolved oxygen level, and bottom temperature. All variables were considered significant at  $P < 0.05$ , and final models for each species were selected based on the Aikaike Information Criterion (AIC)(Akaike, 1974) and area under the curve (c-score). The initial logistic regression model applied to each species is as follows:

$$\text{Mortality (Alive/Dead)} = \text{Intercept} + \text{FL (mm)} + \text{sex (male/female)} + \text{depth (m)} \\ + \text{hook type (J/Circle)} + \text{salinity (ppt)} + \text{DO (ppm)} + \text{temperature (°C)}$$

Logistic regression model graphs illustrate the relationship between an independent variable and dependent variable through probability, so the resulting data line exceeds the minimum and maximum values recorded for samples used. Thus, resulting graphs from modeling the regression equation were modified using Adobe Photoshop to accurately illustrate the data range among variables recorded for each species.

Due to the large sample size of Atlantic sharpnose ( $n = 14,317$ ), data pertaining to this species had to be differentiated prior to running statistical analysis. Initial logistic regressions testing on Atlantic sharpnose showed mortality to be corrected with nearly all independent variables. This is likely a byproduct of the large sample size rather than a reflection of actual correlation (Pooler, P., personal comm.). To ensure accuracy, the initial sample of Atlantic sharpnose was broken into 20 subsets, each containing 693-780 randomly-selected individuals. Logistic regression was run for each of these subsets using the above model, and the final model for Atlantic sharpnose was based on the average of significant correlations found from the results of all subsets.

### Results:

#### *Catch composition and mortality among Tiger Sharks, Nurse Sharks, and Bull Sharks*

Tiger sharks *Galeocerdo cuvier* ( $n = 670$ ) ranged from 550 mm – 3500 mm, with an average length of 910 mm, indicating that many of the tiger sharks caught during the NOAA survey were very young (Natanson *et al*, 1999). Nurse sharks *Ginglymostoma cirratum* ( $n = 257$ ) ranged from 511 mm – 2660 mm, with an average length of 1750 mm. Bull sharks *Carcharhinus leucas* ( $n = 189$ ) ranged from 997 mm – 2500 mm, with a mean of 1680 mm. Nurse sharks did not have a single instance of at-vessel mortality (0%). Tiger sharks had two instances of at-vessel

mortality (individual lengths = 750 mm and 865 mm) and bull sharks had only a single instance of mortality (individual length = 1670 mm), making the frequency of at-vessel mortality for both species < 1%. As such, logistic regression could not be run on these species.

Table 1. – Final models and logistical regression results for scalloped hammerhead, spinner, blacktip, and Atlantic sharpnose sharks.

Factor	DF	Parameter Est.	Std. Error	Wald Chi-Sq.	P-value
<i>Scalloped Hammerhead Sphyrna lewini</i>					
Intercept	1	5.1236	1.7219	8.8539	0.0029
Length	1	-0.0033	0.00112	8.6908	0.0032
Sex	1	0.6519	0.2939	4.9206	0.0265
DO	1	-0.8614	0.2903	8.8044	0.003
<i>Spinner Shark Carcharhinus brevipinna</i>					
Intercept	1	-4.9803	1.7711	7.9075	0.0049
Salinity	1	0.1563	0.0505	9.5677	0.002
DO	1	-0.4478	0.0563	63.2347	<.0001
<i>Blacktip Shark Carcharhinus limbatus</i>					
Intercept	1	5.5567	1.4972	13.775	0.0002
Length	1	-0.0016	0.000594	7.2785	0.007
Salinity	1	-0.1056	0.0429	6.0699	0.0138
DO	1	-0.4586	0.0638	51.6463	<.0001
Hook	1	-1.7308	0.6322	7.4937	0.0062
DO*Hook	1	0.1624	0.0628	6.6896	0.0097
Length*Hook	1	0.00157	0.000572	7.4974	0.0062
<i>Atlantic Sharpnose Rhizoprionodon terraenovae</i>					
Intercept	1	0.502316	1.502205	0.71983	0.473
Length	1	-0.00582	0.001125	27.53359	<0.0001
DO	1	-0.63149	0.076005	69.26265	<0.0001
Temperature	1	0.198925	0.04202	22.75332	0.0003

*Catch composition and mortality among scalloped hammerheads*

Lengths of scalloped hammerhead sharks (n = 162) ranged from 482 mm – 2300 mm, with a mean length of 1205 mm, indicating that a potentially large number of caught hammerheads were immature (Branstetter, 1987a). The at-vessel mortality rate for scalloped hammerheads was found to be 12%. Results of logistic regression found mortality negatively correlate with length (P = 0.0032)(Fig. 1) and DO level (P = 0.003)(Fig. 2). In addition, at-vessel mortality was shown to have significant relationship with gender (P = 0.265), with males more likely to succumb than females (Parameter est. = 0.65)(Table 1)(Fig. 1,2). No interactions or instances of multicollinearity were found between independent variables within the final regressions model for *S. lewini*:

$$\text{Mortality} = \text{Intercept} + \text{Length} + \text{DO} + \text{Sex} \quad (\text{AIC} = 97.753, c = 0.815)$$

*Catch composition and mortality among spinner sharks*

Spinner shark (n = 707) lengths ranged 533 mm – 1690 mm, with a mean length of 967 mm, indicating that a large number of individuals were smaller juveniles (Branstetter, 1987). The at-vessel mortality rate for spinner sharks was found to 28%. Results of logistic regression found a negative correlation between mortality and DO content (P = <0.001)(Fig. 3) and a positive correlation between mortality and salinity level (P = 0.002)(Table 1)(Fig. 4). Approximately 10% of *C. brevipinna* were caught in areas with <1ppm DO concentration, indicating a higher number of individuals dwelling in low-oxygen areas. No interactions or instances of

multicollinearity were found between independent variables within the final regression model for *C. brevipinna*:

$$\text{Mortality} = \text{Intercept} + \text{Salinity} + \text{DO} \quad (\text{AIC} = 744.057, c = 0.73)$$

#### *Catch composition and mortality among blacktip sharks*

Lengths of sampled blacktip sharks (n = 837) ranged from 550 mm – 1750 mm, with a mean length of 1038 mm. The at-vessel mortality for blacktip sharks was found to be 19%. Results of logistic regression showed mortality to be negatively correlated with length (P = 0.0070)(Fig. 5), salinity level (P = 0.0138)(Fig. 7), and DO content (P = <0.0001)(Fig. 6). Two interactions were found: Length\*hook type and DO\*hook type, indicating that the susceptibility of blacktip sharks to J and circle hooks is also influenced by body length and DO level. Thus, the correlation found between mortality and hook type is contingent on shark fork length and the amount of DO available. Two additional regressions were run – 1.) removal of length from the model; 2.) removal of DO from the model - and found the removal of these variables had a larger effect on AIC value and c-score than a model with the sole removal of hook type. This indicates that the correlation between mortality and hook type is likely influenced by length and DO content, rather than vice versa. J hooks were shown to correspond to higher probability of mortality than circle hook for individuals > 575mm FL and caught in water with DO content > 0.5 ppm (P = 0.0062, parameter est. = -1.73)(Table 1). Among individuals < 575 mm FL and caught in areas < 0.5 ppm DO content, the probability of mortality was found to be greater on circle hooks. No instances of multicollinearity were found between independent variables within the final regression model for *C. limbatus*:

$$\text{Mortality} = \text{Intercept} + \text{Length} + \text{Salinity} + \text{DO} + \text{Hook type} \\ + \text{DO*Hook} + \text{DO*Hook} \quad (\text{AIC} = 691.983, c = 0.776)$$

### *Catch composition and mortality among sharpnose sharks*

Sharpnose sharks (n = 14,301) were found to have lengths ranging from 219 mm – 1150 mm, with a mean fork length of 735 mm, indicating a large number of mature adults (Carlson and Baremore, 2003). At-vessel mortality of sharpnose sharks was found to be 16.5%. Averaged results of the logistic regression tests run for all twenty data subsets found at-vessel mortality to be negatively correlated to both fork length (P = <0.0001)(Fig. 8) and DO (P = <0.0001)(Fig. 9). In addition, at-vessel mortality was found to be positively correlated with bottom water temperature (P = 0.0003)(Fig. 10). At-vessel mortality came very close to being correlated with hook type, with J hooks showing higher correlation to at-vessel mortality than circle hooks (Parameter est. = 0.69), but results were not found to be significant (P = 0.0503). No instances of interaction or multicollinearity were found between the independent variables within the final regression model:

$$\text{Mortality: Intercept} + \text{Length} + \text{DO} + \text{Temperature} \quad (\text{AIC} = 500.51, c = 0.809)$$

### Discussion:

Among the seven species tested, at-vessel mortality was found to be lowest (<1%) for the tiger *G. cuvier*, nurse *Ging. cirratum*, and bull *C. leucas* shark, so performing logistic regression was not possible. These results are consistent with low at-vessel mortality rates found in

literature pertaining to commercial longline fisheries and likely reflect biological and behavioral qualities. Tiger sharks, typically caught as a non-target species (Morgan *et al*, 2009), were found to have only 7% at-vessel mortality within the commercial bottom longline fishery from 1994-2003 (Morgan *et al*, 2009), and only 9% at-vessel mortality in subsequent studies on the commercial longline fishery (Morgan and Burgess, 2007). In addition, Hale *et al* (2007) found the survival rates of tiger sharks released by the shark-targeted longline fishery in the Gulf of Mexico to be >82%. Within the shark-targeted longline fishery in the Northwest U.S. Atlantic, Hale *et al* (2007) found 19% of tiger sharks to be discarded dead. Within the snapper/grouper longline fishery in the Gulf of Mexico, the release survival rate of bycatch tiger sharks was found to be 87% in 2007 (Hale *et al*, 2007). Aside from these low instances of at-vessel mortality, tiger sharks have also been found to undergo limited physiological stress and blood acidosis from longline capture, indicating potentially high degree of post-release survival once freed from longlines (Mandelman and Skomal, 2009).

Morgan *et al* (2009) found 0% mortality among caught nurse sharks from 1994-2003, and subsequent NOAA observer coverage of commercial longline shark fisheries in the Gulf of Mexico and Northwest Atlantic coast found a 100% survival rate among released nurse sharks, which are typically caught as bycatch (Morgan *et al*, 2009, IUCN, 2011). In addition, Hale *et al* (2007) found nurse sharks caught by the grouper/snapper/tilefish longline fishery to have a 96% survival rate among released nurse sharks in the Gulf of Mexico. Afonso *et al*, (2011) found 0% at-vessel mortality among nurse sharks caught in both the coastal and pelagic shark-targeted bottom longline fishery in the Southeast Atlantic, independent of whether sharks were hooked on circle or J hooks.

Bull sharks have also been shown to have low at-vessel mortality within commercial fisheries, with Morgan *et al* (2009) noting a 30% at-vessel mortality rate for bull sharks caught in the Gulf of Mexico and NW Atlantic from 1994-2003. Subsequent research found bull sharks to have only 15% at-vessel mortality for soak times ranging 4-10 hrs (Morgan and Carlson, 2010). Although Morgan and Carlson (2010) found no correlation between soak time and mortality in bull sharks, comparison of the soak time employed by their study compared to commercial soak times (up to 20 hr)(Hale *et al*, 2007; 2010; 2011) may increase average mortality rates among commercially-caught bull sharks.

Like the aforementioned tiger and nurse sharks, bull sharks are frequently caught as bycatch by commercial longline fisheries (Hale *et al*, 2007; 2010; 2011, Morgan *et al*, 2009; Morgan and Carlson, 2010; IUCN, 2011), but differ in that the species is frequently landed (Hale *et al*, 2007), possibly due to demand for fins (Clarke *et al*, 2006), considered more commercially valuable than the species' meat, skin, or oil (IUCN, 2011).

Lack of at-vessel mortality for these species is likely linked to ventilation morphology, physiology, and lifestyle. Nurse sharks primarily ventilate via buccal pumping, whereby water is drawn into the buccal cavity and passed over the gills (Carlson *et al*, 2004). Tiger and bull sharks also possess comparably large gape sizes, potentially allowing the ability to buccal pump as well (Morgan and Burgess, 2007; Morgan *et al*, 2009). For sharks caught via bottom longline, mobility is often highly restricted. Within this study, the 3.7 m leader attached to the longline provides only limited space for caught sharks to swim. Hooked sharks may also fight to free themselves, causing severe fatigue and anaerobic respiration, which leads to physiological stress (Mandelman and Skomal, 2009). Species which buccal-pump have the option to rest along the



ocean floor when fatigued to recover from such stress, likely explaining low levels of at-vessel mortality and minimal physiological change found in the blood chemistry of commercial longline-caught tiger sharks (Mandelman and Skomal, 2009).

Further, species that buccal pump, are less likely to fight for prolonged periods while hooked than those which obligate ram ventilate. Carlson and Parsons (2001) noted that Florida smoothhound sharks, a buccal-pumping species, reduced activity levels during hypoxic conditions and lowered metabolic rate. For tiger, nurse, and bull sharks, this would reduce physiological stress and prevent potential injury and/or tangling from the longline hook or leader.

By contrast, species which obligate ram ventilate may face immobility and thus impaired ventilation when caught and fight to free themselves from the longline, increasing the chance of injury and/or lethal physiological stress (Renshaw *et al*, 2011). Even in cases whereby stressed sharks are released alive, post-release recovery may still be compromised by the lack of ability to ventilate over long periods (Mandelman and Skomal, 2009; Renshaw *et al*, 2011).

Spinner and blacktip sharks were found to have the highest at-vessel mortalities (28% and 19%, respectively). Although the at-vessel mortality rates for scalloped hammerhead (12%), spinner (28%), blacktip (19%), and Atlantic sharpnose (16.5%) in this study were <30%, bear in mind that the 1 hour soak time used by the NOAA survey is a minimal stress scenario. As such, the likelihood of a shark being caught via commercial longline for sixty minutes or less is very low. In contrast to the previously discussed tiger, nurse, and bull sharks, the above species are obligate ram ventilators, requiring forward movement to properly ventilate (Carlson *et al*, 2004). Sharks that use obligate ram ventilation possess a reduced branchiostegal system and are thus unable to pump water through the buccal cavity and over the gills (Carlson *et al*, 2004). Rather,

these species must maintain forward locomotion with an open gape to ventilate. Species which use obligate ram ventilation are limited in their mobility while hooked and thus become likely to face hypoxia or anoxia after prolonged periods (Renshaw *et al*, 2011).

Such physiological stress is further exacerbated by behavior. In hypoxic conditions, obligate ram ventilating sharks respond by increasing swimming speed and metabolism in an attempt to pass more water over the gills, facilitating oxygen uptake (Carlson and Parsons, 2001). Bottom longlines, however, restrict mobility in caught animals, so a hooked shark will have only limited, if any, ability to increase forward locomotion. Hooked sharks, especially obligate-ram-ventilating species, are likely to increase forward swimming speed to both ventilate and potentially free themselves from the longline, speeding up anaerobic respiration, consuming additional oxygen in the bloodstream, and fatiguing the shark (Mandelman and Skomal, 2009). Carlson *et al* (2004) notes that obligate-ram-ventilating sharks have higher standard metabolic rates (SMR) than buccal-pumping species. Consequently, these species more active and have greater oxygen consumption rates. With ventilation hindered, these species are more likely to fight to release themselves than buccal-pumping species. This behavior may only further heighten the degree of physiological stress already experienced and increase the potential for injury.

This is illustrated through the high levels of at-vessel mortality found for obligate ram ventilating species in commercial fisheries, in which soak times are less conservative. Morgan and Burgess (2007) found >90% at-vessel mortality rates for scalloped and great hammerhead sharks, >80% at-vessel mortality for dusky sharks. Atlantic sharpnose and blacktip sharks were

found to have >85% at-vessel mortality in commercial fisheries (Morgan and Burgess, 2007; Morgan and Carlson, 2010).

Results from the logistic regressions on scalloped hammerhead, spinner, blacktip, and Atlantic sharpnose are also consistent with the idea that inability to properly ventilate is a key correlation to mortality among these species. Of the independent variables run through regression models, dissolved oxygen concentration (DO) was the only variable found to influence mortality for all tested species. Results (Table 1)(Fig. 2, 3, 6, 9) indicated that lower levels of dissolved oxygen are linked to a higher probability of at-vessel mortality among scalloped hammerhead, spinner, blacktip, and Atlantic sharpnose sharks. This is consistent with the respiratory biology and behaviors of these four species, as previously discussed above. With mobility, and in turn ability to ventilate, hindered by the longline, what little ventilation these species may be able to achieve while hooked will provide more oxygen in areas higher DO content, possibly reducing physiological stress. By contrast, hypoxic regions, of which there are many around the Gulf of Mexico (Mark Grace, personal comm.) would provide less comparable oxygen to sharks struggling to ventilate. This is in-part illustrated through the high rate of at-vessel mortality found for *C. brevipinna* coinciding with the capture of approx. 10% of individuals in areas <1 ppm DO level.

Previous research on sharks caught via commercial longline has shown at-vessel mortality to be negatively correlated with length, with smaller sharks at greater risk than larger. Lower instances of at-vessel mortality with increasing size have been found sandbar shark *C. plumbeus* (Morgan and Burgess, 2007), blacktip shark *C. limbatus* (Morgan and Carlson, 2010), and blacknose shark *C. acronotus* (Morgan and Carlson, 2010). Results of this research

complement these findings, with the probability of at-vessel mortality decreasing as fork length increased among scalloped hammerheads, blacktip, and Atlantic sharpnose (Table 1)(Fig. 1, 5, 8). Morgan and Burgess (2007) noted that scalloped hammerheads did not show a correlation between at-vessel mortality and size in commercial fisheries, but added that this is likely due to high at-vessel mortality levels across all age groups. Within this research, the reduced soak time employed by the NOAA survey reduced at-vessel mortality among hammerheads to only 12%, rather than the >90% levels within commercial longlines (Morgan *et al*, 2009). This one hour soak time not only reduced mortality among this species, but also revealed a previously-unknown correlation between at-vessel mortality and fork length.

The Atlantic sharpnose was the only species to show a correlation between at-vessel mortality and bottom water temperature (Fig. 10). Logistic regression indicated a positive relationship, so as water temperature rises, so does the probability of at-vessel mortality for sharpnose sharks (Fig. 10). An increase in water temperature can increase the metabolic rate of ectothermic elasmobranchs (Carlson *et al*, 2004), so further pressure to obtain oxygen for aerobic respiration may be imposed upon sharpnose sharks caught in warmer water temperatures. Carlson and Parsons (2001) found that the oxygen consumption rate in obligate-ram-ventilating sharks increases with water temperature. Longline-hooked sharpnose shark are already oxygen-limited and likely use up oxygen while increasing swimming speed in an attempt to ram-ventilate. Further consumption of oxygen in warmer waters would even more quickly bring about anaerobic respiration, followed by blood acidosis. The retention of less DO in water as temperature increases likely accelerates this process.

Hook type was only found to influence at-vessel mortality in the blacktip shark, with J hooks shown have a higher probability of at-vessel mortality over circle hooks for sharks caught in waters with bottom DO content  $>0.5$ ppm (Fig. 6) and at fork lengths  $> 575$  mm (Fig. 5). These results coincide with the findings of Afonso *et al* (2011), wherein circle hooks were found to show reduced lower mortality rates compared with J hooks for blue, silky, and oceanic whitetip sharks. Additionally, Pacheco *et al* (2011) found circle hooks to have lower mortality rates for oceanic whitetip, shortfin mako, blue, and crocodile sharks. The level of mortality-per-unit-effort (MPUE) for J hooks was also shown to be higher than circle hooks for blue, silky, scalloped hammerhead, and bull sharks (Afonso *et al*, 2011). Also, while hook type was not significantly correlated to at-vessel mortality for sharpnose sharks in this study ( $P=0.0503$ ), results were close to significant levels, and indicated sharpnose as more vulnerable to at-vessel mortality on J hooks, also following the findings of Afonso *et al* (2011).

While the probability of mortality on circle hooks was found to decrease with an increase in fork length, the probability of at-vessel mortality on J hooks remained independent of individual fork length (Fig. 5). Thus, *C. limbatus* of all sizes are at equal risk of death on J hooks. While it is currently unknown why *C. limbatus*  $<575$  mm would be at greater risk of mortality on a circle hook than J hook, the decreasing probability of mortality with increasing size suggests that circle hooks are more effective at reducing the risk of death. For U.S. commercial bottom longline fisheries that targeting large coastal species, use of circle hooks could decrease mortality among discarded *C. limbatus*. Retention rates for *C. limbatus* in the US bottom longline fishery targeting large sharks are typically high, exceeding 75% in 2010 (Hale *et al*, 2011), but among those blacktips discarded, the percentage discarded-dead (%DD) is three times higher than the

percentage discarded-alive (%DA)(Hale *et al*, 2011). Thus, the transition from J hooks (which made up >60% of hooks used within this fishery in 2010)(Hale *et al*, 2011) to exclusive use of circle hooks may reduce mortality among discarded blacktip sharks. This is further supported by lower probability of mortality found for *C. limbatus* caught on circle hooks in areas of low DO content compared to J hooks (Fig. 6). The design of circle hooks is thought to reduce mortality by preventing fish from swallowing the hook (Monterey, 1999; Afonso *et al*, 2011). Individuals caught via circle hook in hypoxic areas may be less prone to injury if they fight to free themselves.

Among *C. brevipinna*, salinity was positively correlated to at-vessel mortality, indicating that higher salinity levels correspond to greater probabilities of mortality (Fig. 4). These results conflict with Carlson *et al*, (2004), which note that sharks may face osmoregulatory costs associated with moving into lower salinity areas potentially increasing metabolic rate. Within this research, spinner sharks were caught in salinities ranging 28.39-36.8 ppt, with an average salinity level of 34.05 ppt. Spinner sharks are known to frequent high-saline estuaries as juveniles (IUCN, 2011), and may face fluctuations in salinity level at this time. The average size of spinner sharks in this research was 967 mm, indicating that many of the spinner sharks analyzed were relatively young (Branstetter, 1987), and thus may have only recently left nursery grounds. These nursery grounds may have had lower saline water compared to that of the coastal ocean in which these sharks were caught, and the potential osmoregulatory costs associated with the transition may have increased the physiological stress associated with capture by the NOAA survey. At-vessel mortality does not correlate to fork length in *C. brevipinna*, so even larger individuals moving through areas of fluctuating salinity may suffer as a result of the

osmoregulatory costs. While conflicting results were found for spinner sharks, the negative correlation between at-vessel mortality and salinity for *C. limbatus* follows Carlson *et al* (2004). Thus, the probability of blacktip mortality was found to decrease as salinity increased (Fig. 7). To better understand these results, future research will explore the physiological effects changes in salinity level can have on osmoregulatory costs within elasmobranchs.

Also noteworthy is the correlation between at-vessel mortality and gender for scalloped hammerheads, which indicated males to have higher probability of at-vessel mortality than females (Fig 1, 2). Upon further investigation, at-vessel mortality among males was found to be 15% (12 male deaths/82 male *S. lewini*) and at-vessel mortality among females was found to be 9% (7 female deaths/80 female *S. lewini*). Mature females could be expected to have higher mortalities due to potential costs of carrying offspring, though the probability of at-vessel mortality for both sexes was found to be very low at mature sizes (Fig. 1).

Additional testing determined the average size of male *S. lewini* = 1380.0 mm and female *S. lewini* = 1049.0 mm, which seems in contrast to the negative correlation found between length and mortality, as males had higher probability of at-vessel mortality than females, but were, on average, larger. Though no interaction between sex\*DO content was found, the average DO content among the 12 dead male *S. lewini* was found to be 3.5 ppm, while the average DO content among live male *S. lewini* = 4.73 ppm. This may imply that males perished as a result of lower DO content. Both dead and live female *S. lewini* were caught in areas of higher DO content (4.17 ppm and 4.58 ppm, respectively) than dead males. Klimley (1987) noted that sexual segregation among immature *S. lewini* could affect habitat choice, with females moving into pelagic waters at an earlier age than males. Within this research, the probability of mortality

was found to be greatest among small males (Fig. 1). With the 3.5 ppm average DO content among waters where male *S. lewini*, as opposed to the 4.73 ppm average DO content found in areas where females perished, both genders of scalloped hammerhead may have been caught in different areas, supporting Klimley (1987). If males were more commonly caught in lower DO content areas than females, higher probability of mortality among males could be expected, as less oxygen would be available for males during the stressful and ventilation-impaired conditions on the longline.

Potential management recommendations in light of this research could involve restricting commercial fishing in hypoxic/anoxic areas, as at-vessel mortality was negatively correlated to DO (Fig. 2, 3, 6, 9). By identifying hypoxic areas throughout the Gulf of Mexico and Northwest Atlantic, fisheries managers could set area closures ceasing longline capture of sharks in these areas and potentially reduce at-vessel mortality. This may be of less importance for species which buccal-pump, as they have been shown to cope with hypoxia through increased activity and buccal pumping (Mendelman and Skomal, 2009). However, for species in which ventilation is impaired by longline-hooking, higher DO content may allow for longer periods of aerobic respiration and delay the onset of physiological stress. The probability of mortality among *C. limbatus* caught in hypoxic areas was shown to be lower when caught on circle hooks than J hooks (Fig. 6), supporting the use of circle hooks as a mean to reduce at-vessel mortality among this species, which could in turn reduce the amount of blacktip sharks discarded dead.

In addition, as mentioned in Morgan and Carlson (2010), noting correlation between at-vessel mortality and fork length should be considered when evaluating size limits among targeted species. Increased size limits may result in greater numbers of sharks being released alive, as



larger individuals appear to have greater probability of longline survival in this (Fig. 1, 5, 8) and other research (Morgan and Burgess, 2007; Morgan and Carlson, 2010). Increased fork length was also found to correspond to lower probability of mortality for blacktip sharks caught on circle hooks (Fig. 5). Thus, the use of circle hooks over J hooks stands to reduce mortality among discarded *C. limbatus*, especially at greater lengths. Sharpnose sharks were also shown to have great probabilities for survival in areas of cooler water temperatures (Fig. 10), so fishing in areas of lower temperature may also help reduce at-vessel mortality in this species. Also, the occurrence of 12-28% mortality among species modeled in this study, with reduced soak time to a minimal level, indicates that a reduction in commercial soak times would further reduce at-vessel mortality. This research centers on sharks within the Gulf of Mexico and Northwest Atlantic coastal oceans, but the management recommendations made above could have application towards pelagic shark fisheries as well. Pelagic longlines also inhibit movement of hooked sharks, putting them under similar negative pressure.

The Gulf of Mexico and Northwest Atlantic Ocean have been shown to be a global hotspot of species richness and functional diversity among elasmobranchs (Luciforna *et al*, 2011). With the high biodiversity of species commercially-caught in this region (Hale *et al*, 2007), management measures protecting elasmobranchs would likely be improved by species-specific management. Granted, for species that are targeted, and thus, often landed, preventing at-vessel mortality is of less concern, as these sharks will be killed regardless.

The biodiversity among elasmobranchs in the Gulf of Mexico and Northwest Atlantic (Luciforna *et al*, 2011), makes the likelihood of elasmobranch bycatch high. The feeding plasticity and subsequently large dietary range of many elasmobranchs (Wetherbee and Cortes,

2004) also increases the chance of non-target species biting the mackerel bait used on longlines, as many targeted and bycatch species share feeding habits. For bycatch with high at-vessel mortality, this could mean a large number of sharks are dying and discarded dead, potentially without being recording by commercial fishermen.

As indicated by the results of this and other studies, even species with close taxonomic relationships can have different responses to longline fishing pressures (Mandelman and Skomal, 2009), illustrated here by the 0% at-vessel mortality rate found for *C. leucas* compared to the 28% at-vessel mortality rate found for *C. brevipinna*. However, while behavioral and biological parameters differ between these species, and in turn, so do their vulnerabilities to longline mortality, both species are managed under the Large Coastal Species complex. Thus, despite these differences, they are fished with similar quotas and limits. This may be of little importance in species that are largely landed by fishermen, such as the spinner shark. However, as mentioned earlier, species that are typically discarded but suffer high degrees of at-vessel mortality will not count against quotas but still face losses to population numbers. In that way, management measures designed to foster conservation among these species grant little protection. For example, fear over loss of Atlantic hammerhead populations, thought to have declined by 70% (Jiao *et al*, 2009), was likely a driving factor in the new law prohibiting landing of hammerhead sharks in Florida state waters. While fishermen may no longer be able to land hammerheads under this law, they will still catch *Sphyrna sp.*, only now as bycatch that must be discarded. For *S. lewini* populations, this may not matter if at-vessel mortality is high and all caught hammerheads are discarded dead. There are concerns about decreasing populations around the globe (Jiao *et al*, 2009; IUCN, 2011). *S. lewini* is recognized as Endangered on the

IUCN Red List, and NMFS is currently petitioning to have the species recognized as threatened or endangered under the Endangered Species Act to offer more specific protection (Jiao *et al*, 2009; IUCN, 2011; Rauch, 2011). With the exception of Florida, *S. lewini* is still managed under the Large Coastal Species complex in the US. In order to provide more appropriate protection, additional life history and population data is necessary (Rauch, 2011), and the information pertaining to at-vessel mortality in this and other research reveals a threat to *S. lewini* populations (Morgan and Burgess, 2007; Morgan *et al*, 2009; IUCN, 2011).

For these reasons, a push towards species-specific management of elasmobranchs is likely one of the best ways to offer full protection to all species (Burgess *et al*, 2005; Morgan and Burgess, 2007). One of the challenges in implementing that management shift is a lack of information pertaining to elasmobranch life history characteristics across species. The results of this research stand to provide more species-specific information related to vulnerability to bottom longline fishing practices. In doing so, species analyzed in this research are further characterized, and the results of this study could enhance specific elasmobranch management.

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Figures:

Figure 1: *S. lewini* probability of mortality as influenced by fork length (mm). Sex 0 = Male (Blue), 1 = Female (Red).

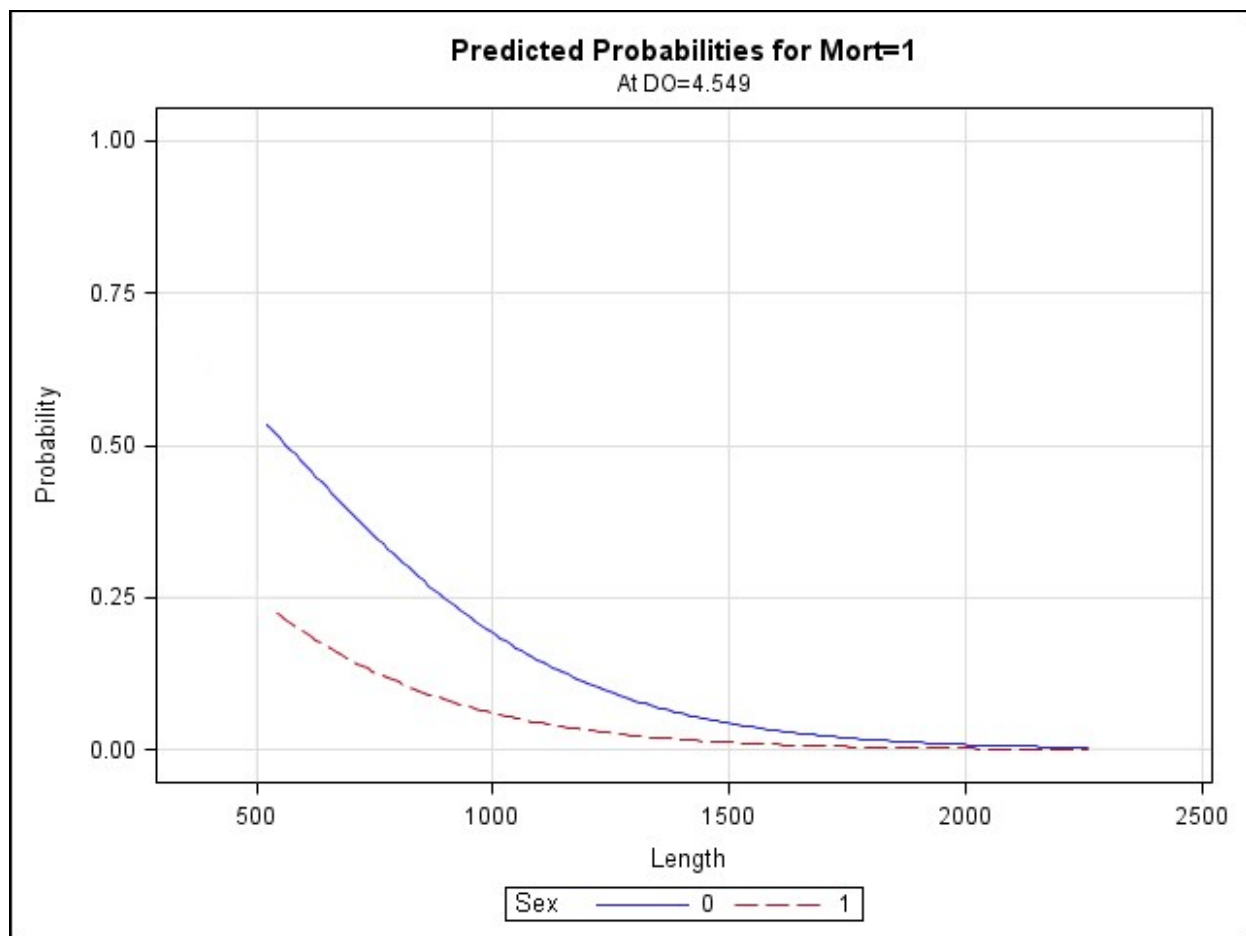




Figure 2: *S. lewini* probability of mortality as influenced by bottom DO content (ppm). Sex 0 = Male (Blue), 1 = Female (Red).

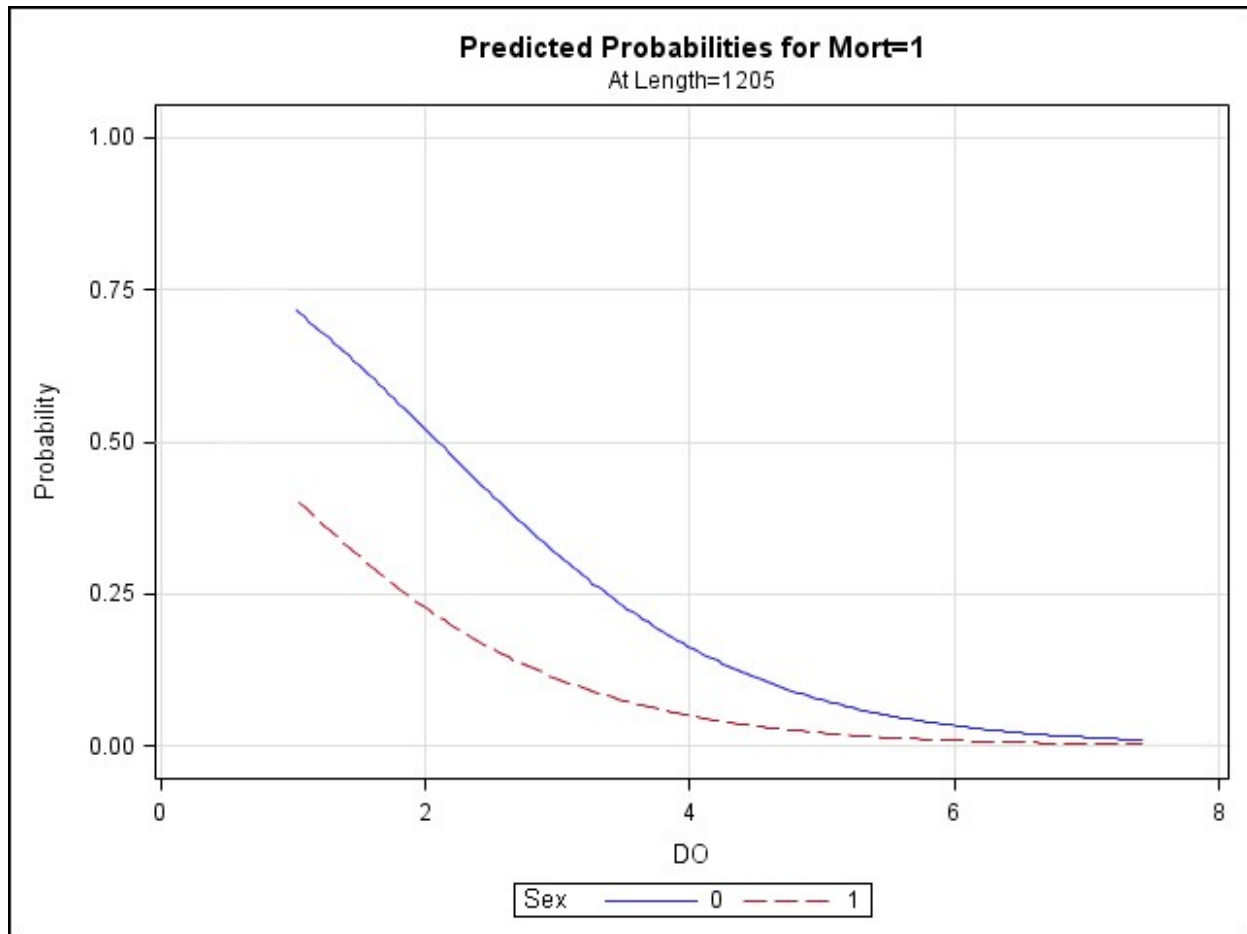


Figure 3: *C. brevipinna* probability of mortality as influenced by bottom DO content (ppm).

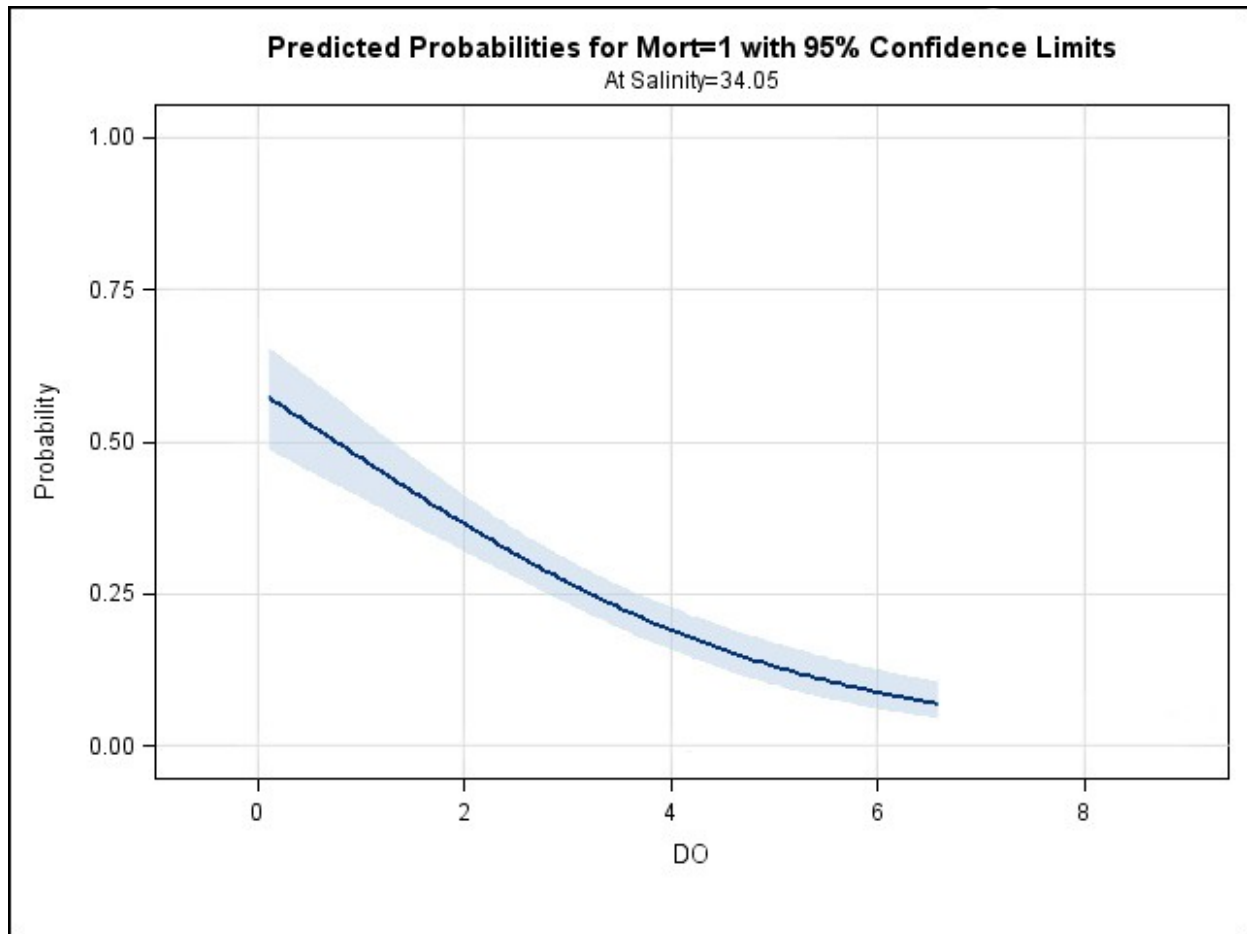


Figure 4: *C. brevipinna* probability of mortality as influenced by bottom salinity level (ppt).

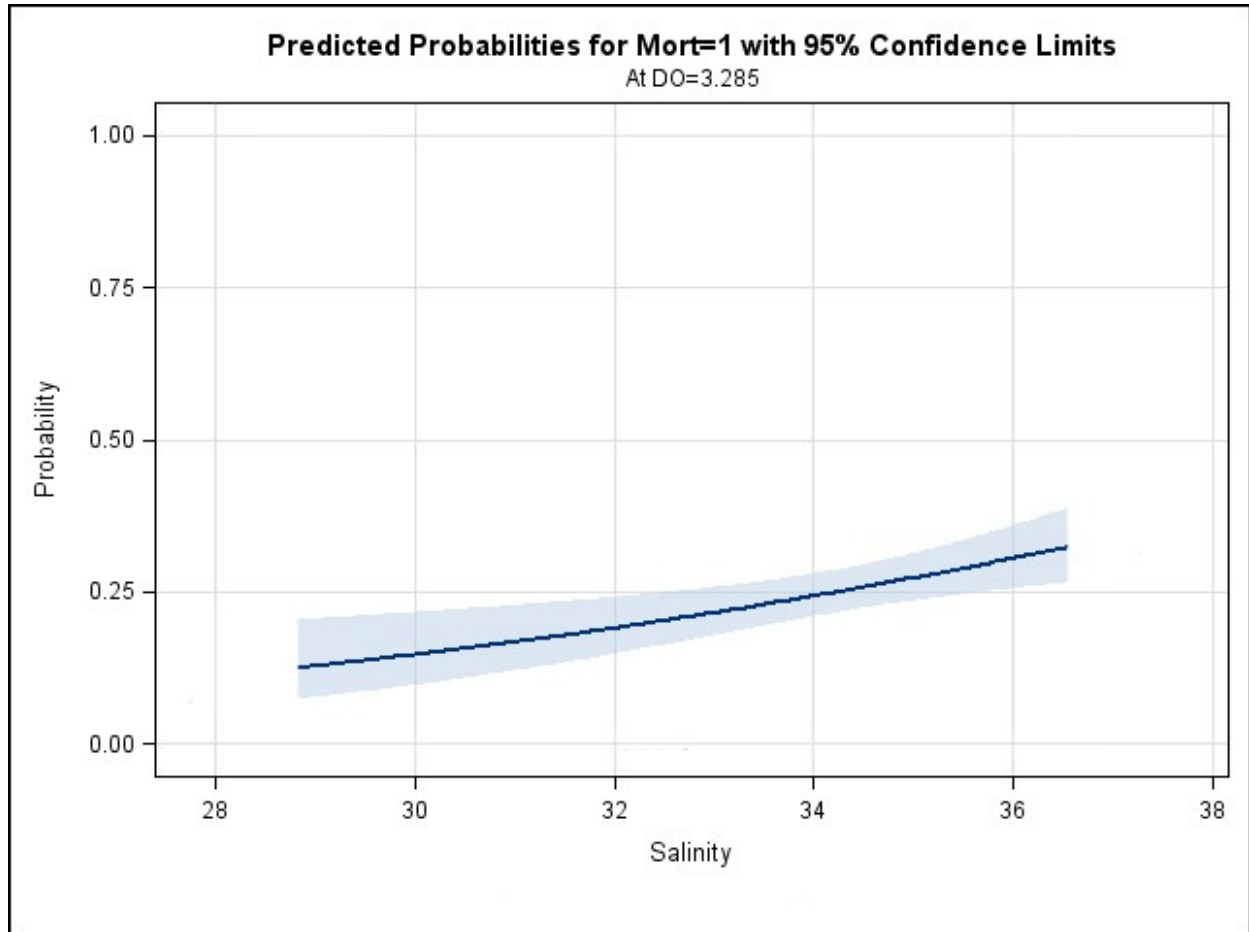


Figure 5: *C. limbatus* probability of mortality as influenced by fork length (mm). Hook 0 = J hook (Blue), 1 = Circle hook (Red).

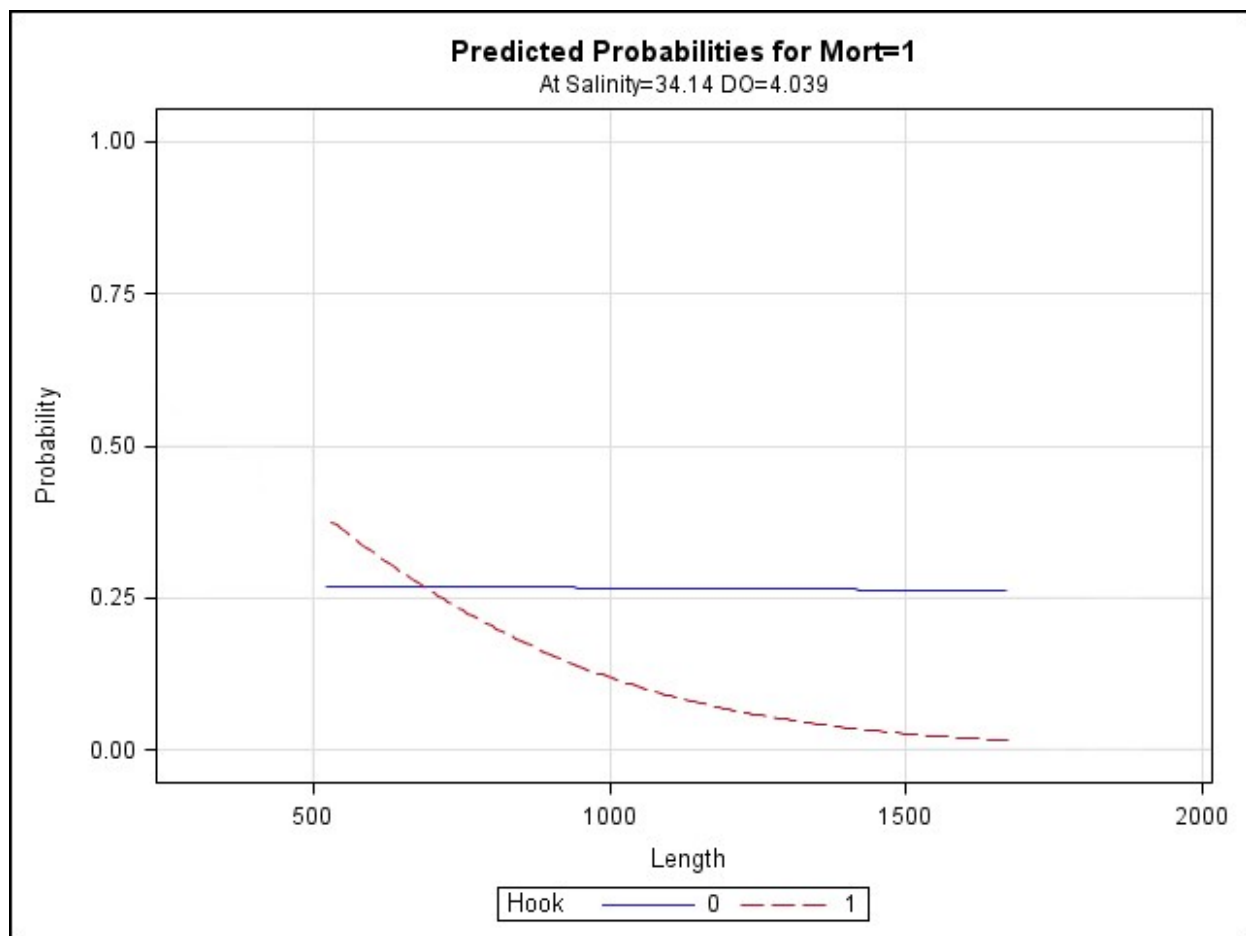


Figure 6: *C. limbatus* probability of mortality as influenced by bottom DO content (ppm). Hook 0 = J hook (Blue), 1 = Circle hook (Red).

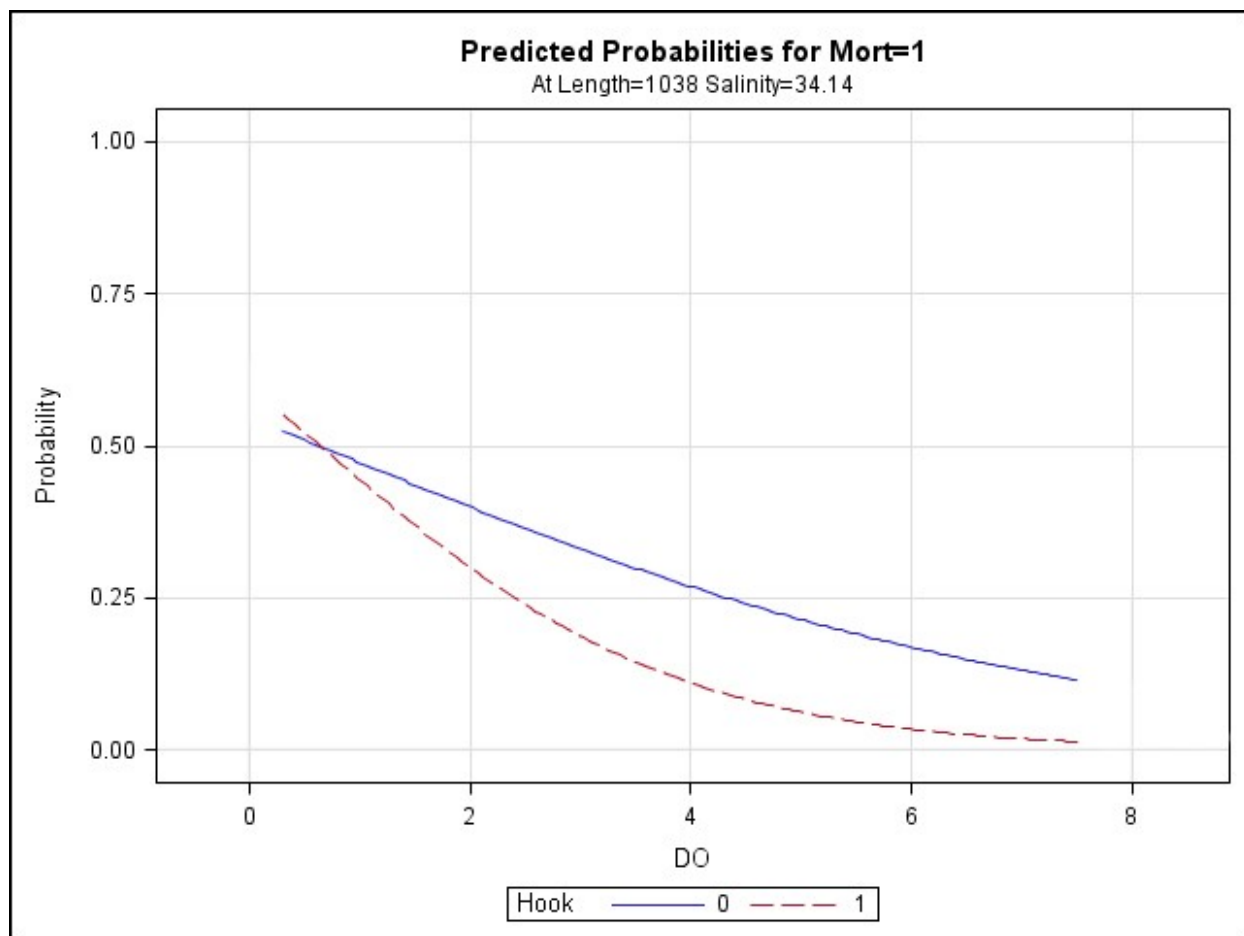


Figure 7: *C. limbatus* probability of mortality as influenced by bottom salinity level (ppt). Hook 0 = J hook (Blue), 1 = Circle hook (Red).

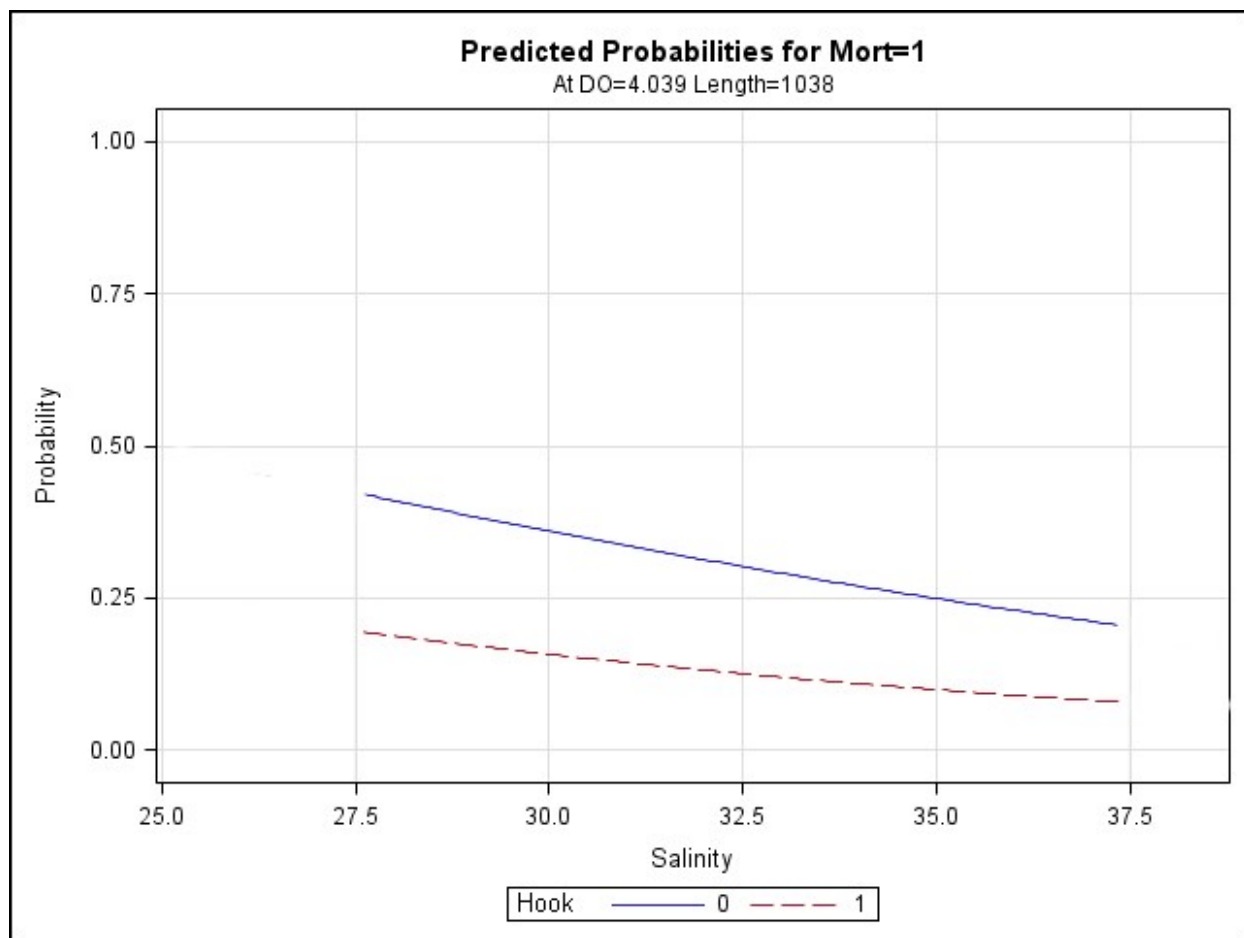


Figure 8: *R. terraenovae* probability of mortality as influenced by fork length (mm).

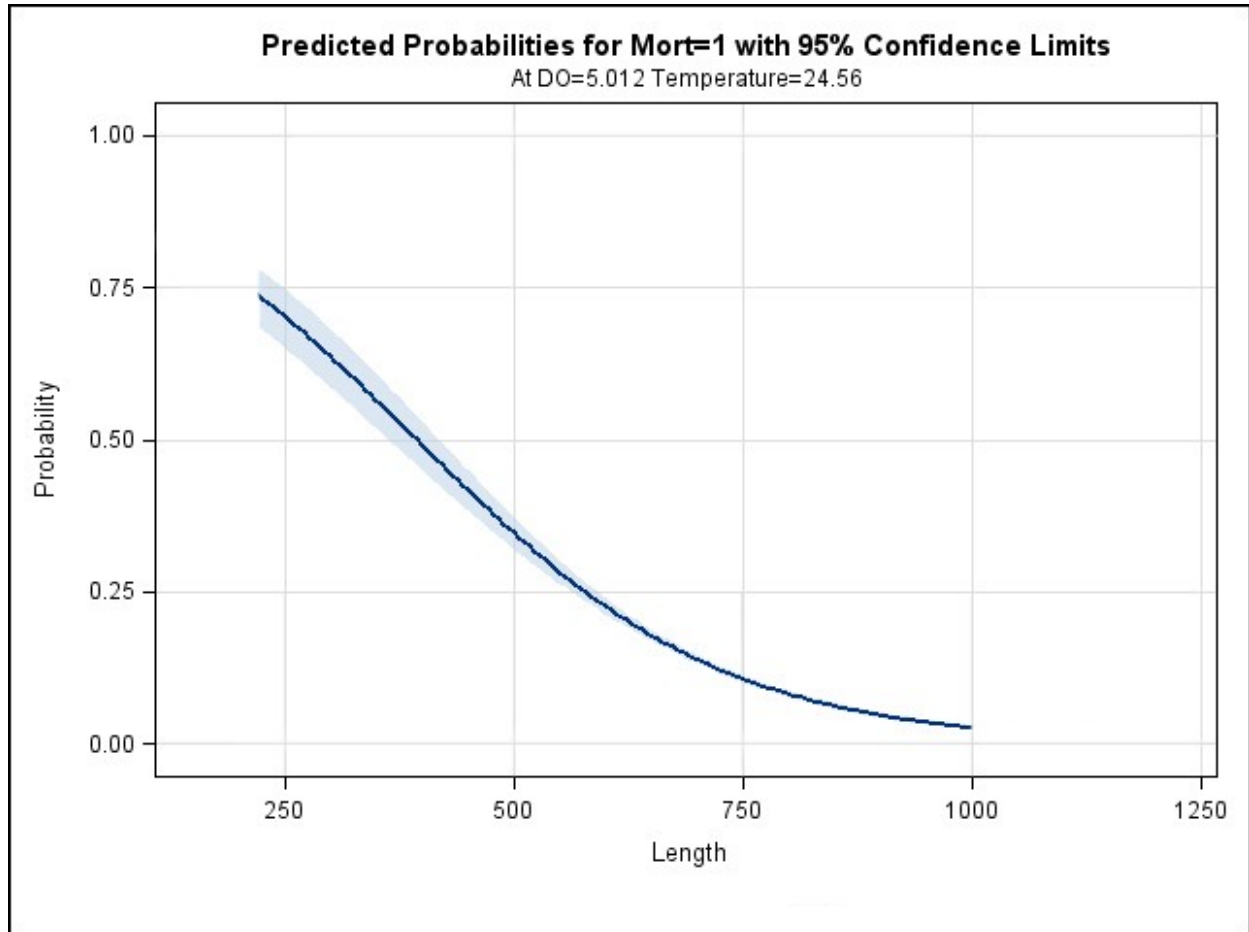


Figure 9: *R. terraenovae* probability of mortality as influenced by bottom DO content (ppm).

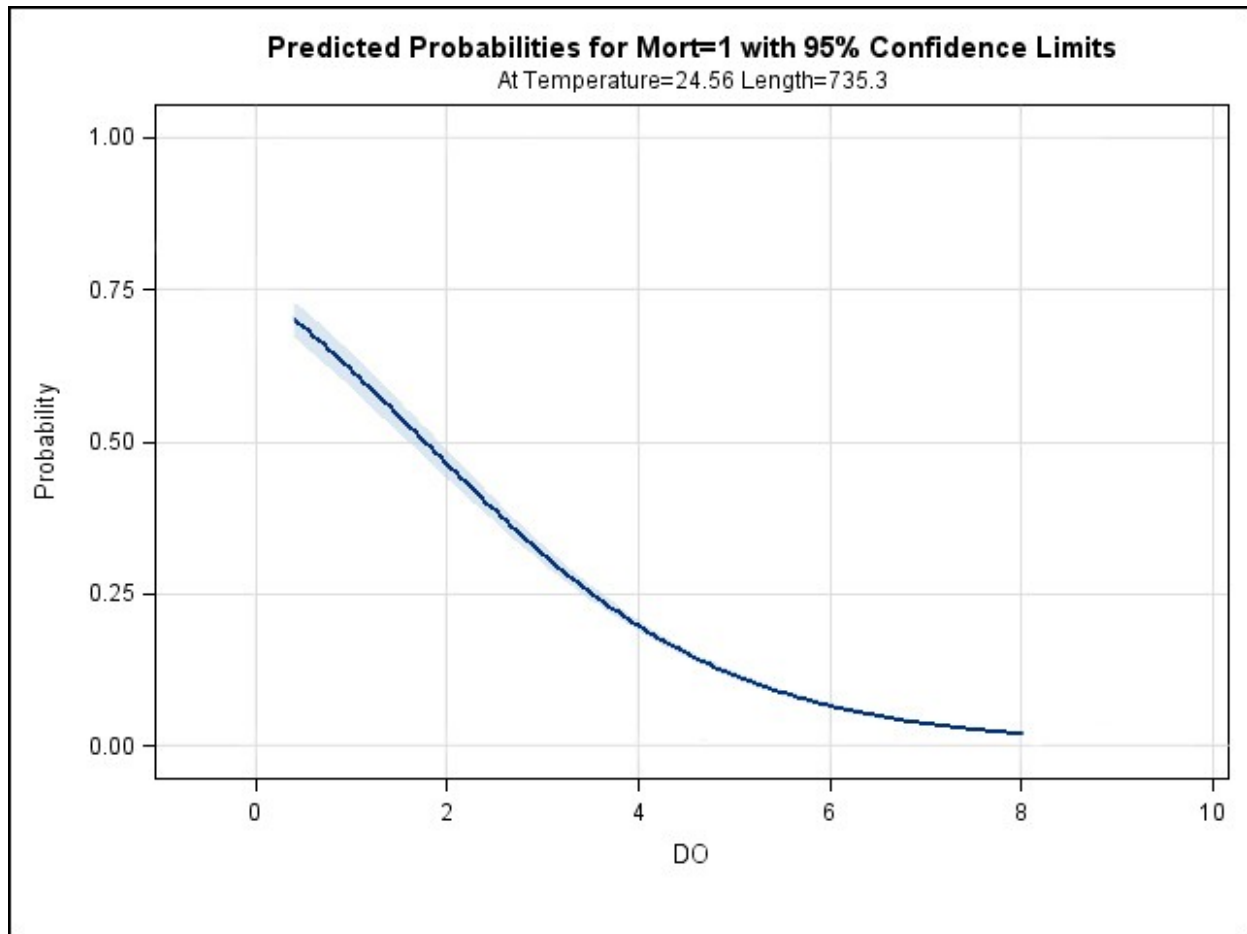




Figure 10: *R. terraenovae* probability of mortality as influenced by bottom water temperature (°C).

