INTERSTATE FISHERIES MANAGEMENT PROGRAM IMPLEMENTATION
FOR
NORTH CAROLINA

By

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Completion Report
for
Cooperative Agreement No.
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Study II

DOCUMENTATION AND REDUCTION OF BYCATCH IN NORTH CAROLINA FISHERIES

J**OB 3**: **Hooking Mortality of Spotted Seatrout** (*Cynoscion nebulosus*), **Weakfish** (*Cynoscion regalis*), **Red Drum** (*Sciaenops ocellata*), and Southern Flounder (*Paralichthys lethostigma*) in North Carolina

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ABSTRACT

Short-term (72-h) release mortality was determined for 109 spotted seatrout (*Cynoscion nebulosus*), 180 weakfish (*Cynoscion regalis*), 191 red drum (*Sciaenops ocellata*), and 316 southern flounder (*Paralichthys lethostigma*) caught with both natural and artificial baits from low (8-14 ppt) and high (18-29 ppt) salinity sites within Core, Roanoke, and Pamlico Sounds, North Carolina during the 2000 and 2001 fishing seasons. Fish were captured independently during all seasons of the year and held in pens at the fishing sites. Jaw/lip hooked fish were used as controls. Mean observed mortalities for the low salinity sites were 19.4% for spotted seatrout, 17.6% for weakfish, 10.9% for red drum, and 19.4% for southern flounder. Mean observed mortalities for the high salinity sites were 7.3% for spotted seatrout, 10.4% for weakfish, 2.3% for red drum, and 9.5% for southern flounder. Data were pooled among sites for logistic regression analyses for each species, which identified bleeding ($P<0.0013$) and fish length ($P<0.0140$) as predictors of spotted seatrout mortality. Salinity ($P<0.0011$) and hook location ($P<0.0243$) were significant predictors of weakfish mortality. Hook removal ($P<0.0001$), dissolved oxygen ($P<0.0034$), and salinity ($P<0.0058$) were identified for red drum and hook location ($P<0.0001$) for southern flounder. Variables associated with adverse hooking locations were identified as good predictors of mortality for all species. Mortality was higher at low salinity sites for all species indicating regional differences in discard mortality. Results indicate that injury and salinity stress were the most important factors influencing mortality for all species. Management measures recommended to reduce release mortality include requiring circle hooks for cut/live bait and promoting better fishing practices through publication and distribution of fishing guides containing information on handling techniques aimed at reducing release mortality.

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INTRODUCTION

Creel limits, size limits, harvest quotas, and time/area closures are common management strategies for recreational fisheries. These management approaches often promote catch and release fishing, which results in high levels of discards. The hook and release mortality of discards varies among species with some being more tolerant than others. A review of the literature reveals that many factors influence release mortality rates including water temperature, air temperature, dissolved oxygen, salinity, depth, handling time, fight time, angler experience, terminal tackle, hooking location, and fish size (Muoneke and Childress 1994). Although, the most common mortality related parameters identified by previous research involves factors that cause both stress and injury.

Recreational anglers conducted 1,709,320 shore based and private boat trips in North Carolina during 2001 (Personal communication from NMFS, Fisheries Statistics and Economics Division, Silver Spring, MD). Spotted Seatrout (*Cynoscion nebulosus*), weakfish (*Cynoscion regalis*), red drum (*Sciaenops ocellata*), and southern flounder (*Paralichthys lethostigma*) were among the top ten species most often targeted by this group of anglers (Mumford 2002). Each of these species is managed through federal and state Fishery Management Plans (FMPs). Weakfish and spotted seatrout are managed under Atlantic States Marine Fisheries Commission (ASMFC) FMPs and are currently considered viable (ASMFC 1996, ASMFC 1984). Presently, a southern flounder FMP is being developed in North Carolina and will be implemented during 2003 (NCDMF 2002). Southern flounder are currently listed as concerned, but recent trends indicate that the stock may be overfished. Red drum are managed under both a North Carolina FMP and an ASMFC FMP and are consider overfished but the most recent stock assessment depicts improved juvenile recruitment, which is a limiting factor for this species (NCDMF 2001, ASMFC 2002). All of these species are regulated by size limits and all but southern flounder have creel limits in North Carolina. Considering the amount of directed recreational fishing effort, hook-and-line discard mortality is a major concern for each of these species.

There have been many studies conducted to determine the release mortality of these species, but the results are highly variable among studies due to differences in environmental conditions, methods and experimental design. Previous research conducted on red drum illustrates the variability associated with these types of studies. Matlock et al. (1993) reported 4.1% release mortality for red drum caught with single and treble hooks on natural baits and artificial lures. Childress (1989) reported 44.7% release mortality for red drum caught with natural or artificial lures during the summer in a freshwater reservoir. Jordan (1991) reported 16.1% mortality for red drum caught with both natural and artificial baits during the summer in a Georgia estuary. Thomas et al. (1997) reported 2.7% mortality for red drum caught with both artificial and live baits in Louisiana, while Duffy (1999) reported 9.9% mortality for red drum caught on treble hooks and 2.4% for single hooks in Alabama.

Similar studies conducted on spotted seatrout indicate that release mortality rates for this species are generally higher and more variable than those reported for red drum. Matlock and Dailey (1981) reported spotted seatrout release mortalities up to 55.6% for fish caught with artificial and natural baits, while Matlock et al. (1993) reported 7.3% in a later study. Hegen and Green (1983) reported 37%

mortality for spotted seatrout caught on natural baits and artificial lures in Texas, while Murphy et al. (1995) reported 4.6% mortality in Florida. Thomas et al. (1997) reported 17.5% mortality for spotted seatrout caught on both natural and artificial baits in Louisiana while Duffy (1999) reported 9.1% mortality for spotted seatrout caught on treble hooks and 14.6% for single hooks in Alabama.

Fewer studies have been conducted on weakfish. Swihart et al. (1995) reported 18% mortality for weakfish captured on natural baits in the lower Chesapeake Bay, while Malchoff and Heins (1997) reported 2.6% mean release mortality for weakfish captured on both natural and artificial baits in New York. No literature is available on the release mortality of southern flounder but a few studies have been conducted on summer flounder (*Paralichthys dentatus*). Lucy and Holton (1998) reported 6% mortality for summer flounder caught and released during field trials and 11% mortality for similar tank experiments. Malchoff et al. (1999) reported mean release mortality rates for summer flounder caught on natural baits in North Carolina (5.3%), Virginia (6.9%), and New York (14.7%).

The FMPs for each of these species are based on predictive stock assessments, which require the quantification of all sources of mortality including discards. Failure to account for all sources of mortality could result in inaccurate stock size estimates, which could lead to the implementation of inappropriate management measures. Currently, the number of recreational discards for each of these species is estimated through the Marine Recreational Fisheries Statistics Survey (MRFSS), but the discard mortality of each is poorly estimated. The objectives of this study were:

- To provide additional estimates of short-term (72-h) mortality for red drum, spotted seatrout, weakfish, and southern flounder following catch and release angling in North Carolina.
- Identify factors that influence hooking mortality of red drum, spotted seatrout, weakfish, and southern flounder caught by hook-and-line gear in North Carolina estuaries.
- Provide management alternatives that reduce the mortality of discarded red drum, spotted seatrout, weakfish, and southern flounder in North Carolina estuaries.

METHODS

Fishing trials were conducted at River and Outer Banks sites in Pamlico, Core, and Roanoke Sounds, North Carolina between June 2000 and August 2001. Fishing sites consisted of low salinity River sites and a high salinity Outer Banks sites (Figure 1). A minimum of 20 fish were targeted for each trial. Trials were conducted at each site throughout the year. Fish were pooled across several fishing days to complete each trial. Collection methods were fisheries independent and employed common fishing practices. Anglers used medium to heavy action rods equipped with either spinning or bait casting reels, spooled with 15-20 lb test line. Both trolling and casting methods were employed using jigs, plugs, live, and cut bait.

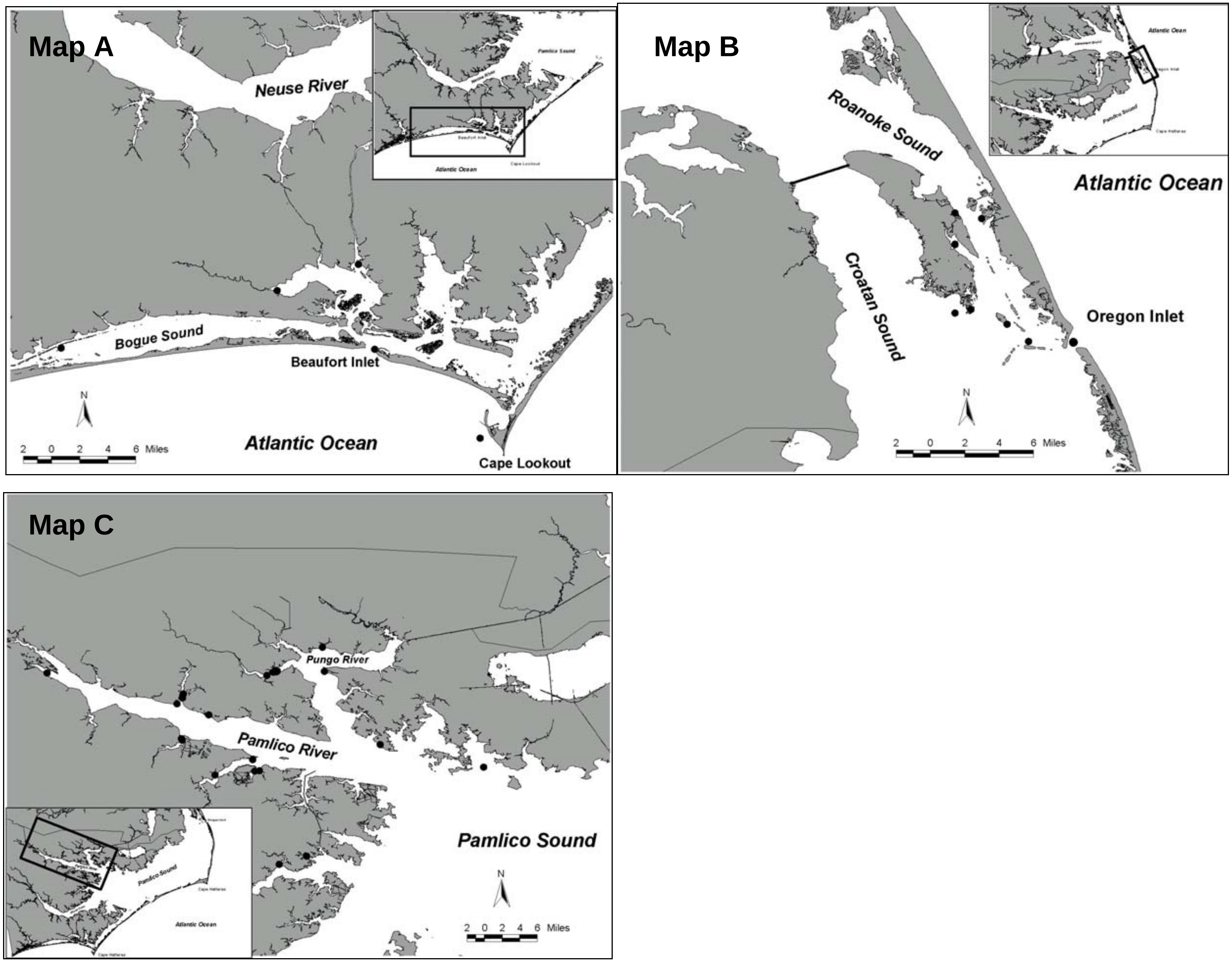

Figure 1. Map of fishing sites located in Core (Map A), Roanoke (Map B), and Pamlico (Map C) Sounds, North Carolina. Low salinity sites were located in the Pamlico and Pungo Rivers (Map C) and high salinity site were located areas along the Outer Banks (Maps A and B).

Fish were landed as quickly as possible to minimize variability between angling methods. Landed fish were tagged with numbered T-bar tags (FF-94 T-bar anchor tag, Floy Tag and Manufacturing Co., Seattle, Washington) and placed in an onboard 830-L recirculating live well. Hooks were removed by hand when possible, unless fish were deep hooked. If fish were deep hooked, the line was cut and hooks were left in place. Species, length, tag number, handling time, bait type, hook location, hook removal, and degree of bleeding were recorded for each fish landed.

After 10 fish were captured or holding time reached 30 min, fish were transferred to 0.6 m^3 cylindrical holding pens constructed of 0.5 inch (bar) coated wire mesh connected to two fiberglass hoops with wire ties. Pens were deployed at the fishing sites to facilitate fish transfer. Pen densities did not exceed 20 fish, to minimize incidental mortality caused by overcrowding. Mortality and water quality (temperature ºC, dissolved oxygen mg/l, and salinity ppt) were monitored at 24-hour intervals for three days. Dead fish were removed from the pens and identified by tag number. Jaw/lip hooked fish were used as controls, to determine pen and handling mortality.

Each variable's contribution to a linear logistic multiple regression model were examined, to investigate whether any explained 72-hour release mortality for each species. Chi Square tests were performed to determine if each independent variable's relationship to mortality was significant. All significant variables were included in a logistic regression model. Additionally, variable interactions were tested for their relationship to mortality with a General Linear Model (GLM). Interactions with significant relationships to mortality were also included in the logistic regression model. The logistic model was fit with stepwise techniques (SAS Institute 1989) and describes the probability of mortality ($P_{Mortality}$) for individual fish as

$$P_{Mortality} = e^{u} / \left(1 + e^{u}\right),$$

where u is a linear function of the independent variables. Independent variables considered in the analysis of release mortality were; location (River, Outer Banks), fish length (sublegal, legal), water temperature (<20, ≥ 20ºC), dissolved oxygen (<7, ≥ 7 mg/l), salinity (<19, ≥ 19 ppt), pen, bait type (jig, plug, cut/live), handling time (<30, ≥ 30 sec), hook removal, degree of bleeding (none, minimal, excessive), and hooking location (jaw/lip, mouth/gill, esophagus/gut). The stepwise linear logistic regression had an acceptance level based on a residual chi-square statistic of 0.10 for incorporating a variable into the model and an acceptance level of 0.10 for retaining a variable. A log-likelihood statistic was used to assess significance of the model. Factors associated with release mortality of each species were identified and estimates of release mortality provided.

PROJECT LIMITATIONS

Trials were conducted throughout the year, but availability of fish precluded trials for all species during all seasons (Tables 1-4). This resulted in unmatched seasonal trials for each species in each location with Outer Banks trials having slightly cooler water temperatures than River trials (Tables 1-4). In addition, increased control fish mortality was observed during trials with temperatures above 25ºC indicating that hooking was not the only source of mortality. Finally, both artificial and natural baits were used to varying degrees throughout the study to catch all species, which resulted in an unbalanced sampling design with respect to bait type.

Table 1. Number of individuals (n), observed mortality, pen/handling mortality, adjusted mortality (observed – pen/handling), mean water temperature (ºC), dissolved oxygen (DO mg/l), and salinity (ppt) by location for spotted seatrout release mortality trials conducted in Core, Roanoke, and Pamlico Sounds, North Carolina during the 2000 and 2001 fishing seasons.

Location	Trial	Dates	n	Observed Mortality	Control Mortality	Adjusted Mortality	Mean H_2O Temp	Mean DO	Mean Salinity
Outer Banks	1	23-Jun-00 - 20-Sep-00	15	13.3	0.0	13.3	27.1	5.9	26.0
High Salinity	2	11-Oct-00 - 6-Dec-00	27	3.8	0.0	3.8	16.2	6.7	24.9
			Mean	**7.3**	**0.0**	**7.3**	**17.9**	**6.4**	**27.6**
River	1	11-Jul-00 - 12-Sep-00	12	0.0	0.0	0.0	27.8	6.8	11.3
Low Salinity	2	9-Apr-01 - 5-May-01	27	22.2	14.3	7.9	18.7	8.0	13.1
	3	21-Jun-01 - 22-Aug-01	28	25.0	21.1	3.9	27.1	6.6	11.6
			Mean	**19.4**	**15.9**	**3.5**	**24.5**	**6.8**	**12.1**

Table 2. Number of individuals (n), observed mortality, pen/handling mortality, adjusted mortality (observed – pen/handling), mean water temperature (ºC), dissolved oxygen (DO mg/l), and salinity (ppt) by location for weakfish release mortality trials conducted in Core, Roanoke, and Pamlico Sounds, North Carolina during the 2000 and 2001 fishing seasons.

Location	Trial	Dates	n	Observed Mortality	Control Mortality	Adjusted Mortality	Mean H_2O Temp	Mean DO	Mean Salinity
Outer Banks	1	11-Jul-00 - 13-Oct-00	31	3.3	0.0	3.3	20.7	7.4	18.7
High Salinity	2	15-Oct-00 - 17-Oct-00	24	12.5	10.0	2.5	19.9	7.2	23.7
	3	15-Nov-00 - 15-Nov-00	20	0.0	0.0	0.0	13.8	4.9	29.0
	4	1-May-01 - 19-Jul-01	26	26.1	26.1	0.0	25.5	7.0	9.7
			Mean	**10.4**	**9.1**	**1.3**	**20.4**	**6.8**	**20.0**
River	1	11-Jul-00 - 12-Sep-00	26	12.0	12.0	0.0	26.5	6.6	18.2
Low Salinity	2	9-Apr-01 - 5-May-01	23	4.8	4.8	0.0	25.6	6.6	11.6
	3	21-Jun-01 - 22-Aug-01	30	32.1	19.0	13.1	25.1	5.7	12.2
			Mean	**17.6**	**13.7**	**3.8**	**25.5**	**6.6**	**16.1**

Table 3. Number of individuals (n), observed mortality, pen/handling mortality, adjusted mortality (observed – pen/handling), mean water temperature (ºC), dissolved oxygen (DO mg/l), and salinity (ppt) by location for red drum release mortality trials conducted in Core, Roanoke, and Pamlico Sounds, North Carolina during the 2000 and 2001 fishing seasons.

Location	Trial	Dates	n	Observed Mortality	Control Mortality	Adjusted Mortality	Mean H_2O Temp	Mean DO	Mean Salinity
Outer Banks	1	25-Jun-00 - 25-Jun-00	42	2.4	0.0	2.4	26.6	6.4	25.0
High Salinity	2	30-Aug-00 - 20-Sep-00	26	3.8	3.8	0.0	26.1	6.1	26.6
	3	10-Oct-00 - 11-Oct-00	19	0.0	0.0	0.0	16.6	7.5	12.3
			Mean	**2.3**	**1.7**	**0.6**	**23.7**	**6.6**	**22.3**
River	1	26-Jul-00 - 19-Sep-00	22	28.6	16.7	11.9	27.6	7.0	11.6
Low Salinity	2	9-Apr-01 - 4-Sep-01	28	14.3	4.8	9.5	26.8	6.3	10.2
	3	6-Aug-01 - 22-Aug-01	54	1.9	1.9	0.0	24.2	6.9	13.5
			Mean	**10.9**	**6.1**	**4.8**	**26.7**	**6.9**	**13.0**

Table 4. Number of individuals (n), observed mortality, pen/handling mortality, adjusted mortality (observed – pen/handling), mean water temperature (ºC), dissolved oxygen (DO mg/l), and salinity (ppt) by location for southern flounder release mortality trials conducted in Core, Roanoke, and Pamlico Sounds, North Carolina during the 2000 and 2001 fishing seasons.

Location	Trial	Dates	n	Observed Mortality	Control Mortality	Adjusted Mortality	Mean H_2O Temp	Mean DO	Mean Salinity
Outer Banks High Salinity	1	10-Jul-00 - 30-Aug-00	42	10.5	8.3	2.2	26.6	6.3	25.0
	2	31-Aug-00 - 11-Sep-00	26	16.7	8.3	8.3	26.1	7.1	26.6
	3	10-Oct-00 - 24-Oct-00	19	3.8	3.8	0.0	16.6	7.0	12.3
			Mean	**9.5**	**7.1**	**2.4**	**23.9**	**6.6**	**20.4**
River Low Salinity	1	12-Jul-00 - 9-Aug-00	30	6.7	0.0	6.7	27.9	6.7	11.4
	2	12-Sep-00 - 12-Sep-00	23	8.7	4.5	4.2	27.4	7.2	13.3
	3	13-Sep-00 - 13-Sep-00	30	13.3	0.0	13.3	27.4	7.6	12.6
	4	19-Apr-01 18-May-01	19	0.0	0.0	0.0	20.3	7.8	9.9
	5	22-May-01 29-Jun-01	24	16.7	16.7	0.0	23.9	6.5	8.1
	6	10-Jul-01 16-Jul-01	35	8.6	8.6	0.0	27.7	6.2	10.8
	7	16-Jul-01 16-Aug-01	44	22.7	8.3	14.4	26.1	6.1	9.3
	8	17-Aug-01 22-Aug-01	24	4.2	0.0	4.2	27.6	6.3	13.5
			Mean	**19.4**	**6.0**	**13.4**	**25.9**	**6.7**	**11.5**

RESULTS

Spotted Seatrout

Collectively, 109 spotted seatrout were captured and held in pens for 72 hr periods during 5 mortality trials. Two trials, consisting of 42 fish, were conducted at Outer Banks sites while three trials, consisting of 67 fish, were conducted at River sites (Table 1). Observed mortality at River sites was 19.4% and ranged from 0.0 to 25.0%, while mortality at Outer Banks sites was 7.3% and ranged from 3.8 to 13.8% (Table 1). No Pen/handling mortality was observed at Outer Banks sites, while control mortality at River sites averaged 15.9% and ranged from 0 to 21.1% (Table 1). Average adjusted mortality (observed – pen/handling) was 3.5% at River sites and ranged from 0.0 to 7.9%, while adjusted mortality at Outer Banks sites was 7.3% and ranged from 3.8 to 13.3% (Table 1).

For all trials combined, 56% of the mortality occurred within 24 hrs and 100% within 48 hrs (Figure 2). Water temperatures for River trials ranged from 18.7ºC during trial 2 to 27.8ºC during trial 1 (Table 1). Water temperatures for Outer Banks trials ranged from 16.2ºC during trial 2 to 27.1ºC during trial 1 (Table 1). The average water temperature for the Outer Banks trials was 17.9ºC while the average temperature of the River trials was slightly higher at 24.5ºC. Dissolved oxygen at River sites ranged from 6.6 mg/l during trial 3 to 8.0 mg/l during trial 2 (Table 1). Dissolved oxygen at the Outer Banks sites ranged from 5.9 mg/l during trial 1 to 6.7 mg/l during trial 2 (Table 1). Salinities at the River site ranged from 11.3 ppt to 13.1 ppt (Table 1). Outer Banks salinities were higher, ranging from 24.9 ppt to 26.0 ppt (Table 1).

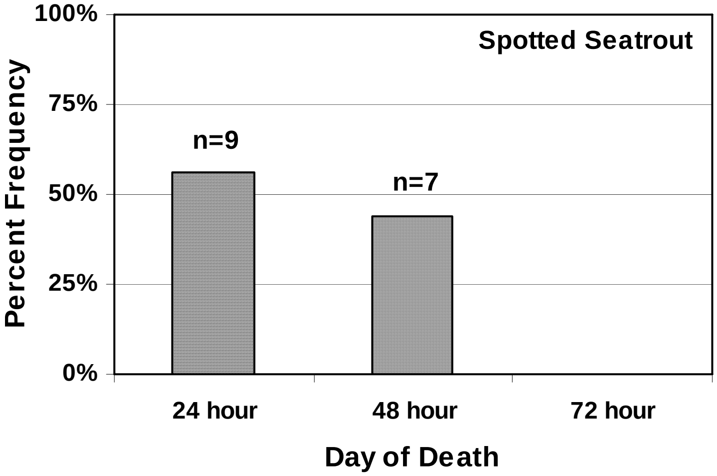

Figure 2. Day of death for all spotted seatrout mortalities observed during trials conducted in North Carolina internal waters during the 2000 and 2001 fishing seasons.

To perform the logistic regression analysis, data from each site were pooled together to determine the influence of several variables on mortality. The logistic regression analysis indicated that mortality was dependent on bleeding and fish length (Table 5). Dependent variables and interactions that were included in the model, but were not significant predictors of mortality included; location, salinity, water temperature, dissolved oxygen, hook location, hook type, hook removal, handling time, water temperature*length, hook type*hook removal and hook location*hook type. A Hosmer-Lemeshow goodness-of-fit test indicated that the model provided a good fit for the data (X^2=0.000, df=1, P<1.000, Hosmer and Lemeshow 1989). The predicted concordance or proportion of survivals and deaths correctly predicted by the model was 59.2%. Combining the intercept and parameter estimates from Table 5 allows for the estimation of mortality using the following equations:

$$P_{Mortality} = \frac{e^{-1.281+3.258(Bleed)-1.977(Length)}}{1+e^{-1.281+3.258(Bleed)-1.977(Length)}}$$

where the following discrete values have been assigned to each variable:

Bleeding	0 = None	**Length**	0 = Sublegal <12 in.
	1 = Minimal		1 = Legal $\geq$12 in.
	2 = Excessive		

Table 5. Summary of stepwise logistic regression analyses of independent variables on 72-h postrelease mortality of spotted seatrout captured by hook-and-line in North Carolina internal waters during the 2000 and 2001 fishing seasons.

Independent Variable	df	X^2	*P*	Estimate	Odds Ratio[a]
Bleeding	2	10.415	0.0013	3.258	25.999
Size	1	6.042	0.0140	-1.977	0.138

[a] Indicates the increase or decrease in odds of mortality associated with a variable; a ratio of 1.0 indicates no difference.

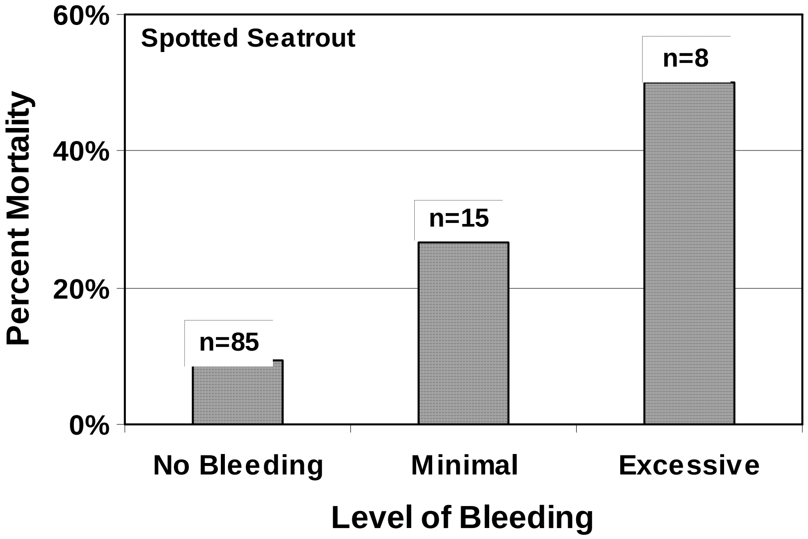

Figure 3. Mortality by level of bleeding for all spotted seatrout mortalities observed during trials conducted in North Carolina internal waters during the 2000 and 2001 fishing seasons.

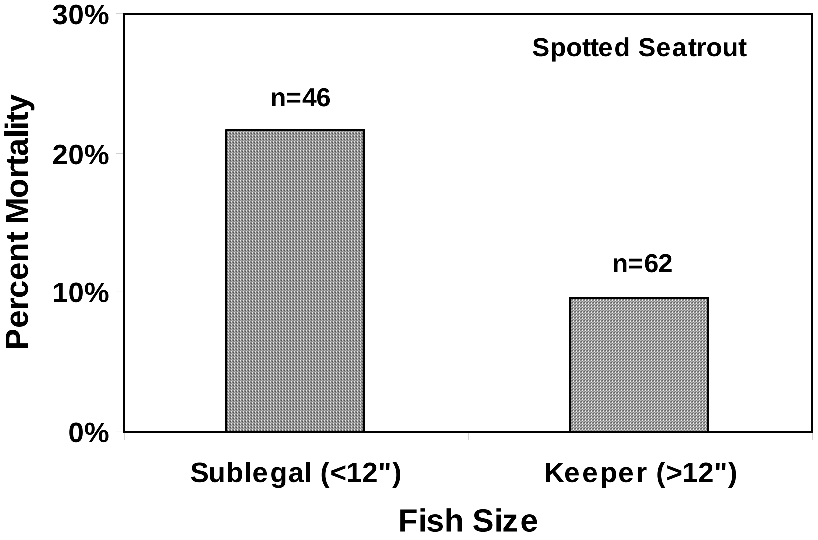

Figure 4. Mortality by fish size for all spotted seatrout mortalities observed during trials conducted in North Carolina internal waters during the 2000 and 2001 fishing seasons.

Mortality was higher for fish that were bleeding excessively (50%) when compared to those that experienced minimal (27%) or no (9%) bleeding (Figure 3). The mortality rate for fish greater than 12 inches TL was 22%, which was significantly higher than the 10% rate observed for sublegal fish (Figures 4 and 5).

In addition to the stepwise logistic model, a backward elimination logistic regression was also run to compare results between the two techniques and investigate levels of significance for those variables removed from the final model. The backwards elimination technique produced the same model, further indicating that the model provided a good fit for the data. Water temperature was the only marginally significant (P<0.1013) variable removed from the model because it did not meet the 0.10 significance level.

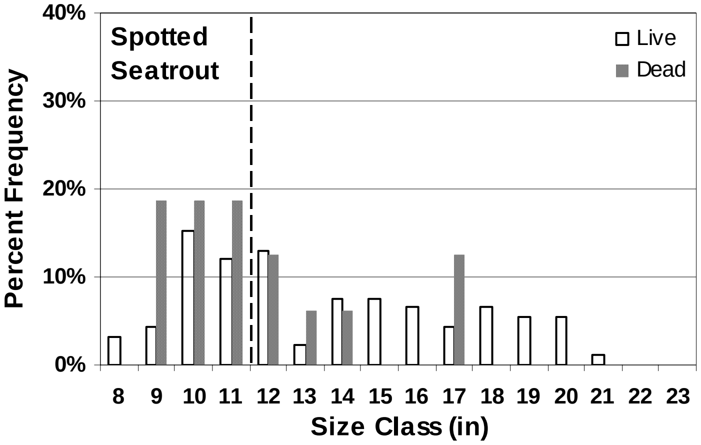

Figure 5. Length frequencies of spotted seatrout survivals (open bars) and mortalities (filled bars) observed during trials conducted in North Carolina internal waters during the 2000 and 2001 fishing seasons. Dashed line indicates the 12-inch size limit.

Weakfish

Collectively, 180 weakfish were captured and held in pens for 72 hr periods during seven mortality trials. Two trials, consisting of 101 fish, were conducted at Outer Banks sites while three trials, consisting of 79 fish, were conducted at River sites (Table 2). Observed mortality at River sites was 17.6% and ranged from 4.8 to 32.1%, while mortality at Outer Banks sites was 10.4% and ranged from 0.0 to 26.1% (Table 2). Pen/handling mortality at Outer Banks sites was 9.1% and ranged from 0.0 to 26.1%, while control mortality at River sites averaged 13.7% and ranged from 4.8 to 19.0% (Table 2). Average adjusted mortality (observed – pen/handling) was 3.8% at River sites and ranged from 0.0 to 13.1%, while adjusted mortality at Outer Banks sites was 1.3% and ranged from 0.0 to 3.3% (Table 2).

For all trials combined, 58% of the mortality occurred within 24 hrs and 79% within 48 hrs (Figure 6). Water temperatures during River trials ranged from 25.1ºC during trial 3 to 26.5ºC during trial 1 (Table 2). Water temperatures for Outer Banks trials ranged from 13.8ºC during trial 3 to 25.5ºC during trial 4 (Table 2). The average water temperature for the Outer Banks trials was 20.4ºC while the average temperature of the River trials was slightly higher at 25.5ºC. Dissolved oxygen at River sites ranged from 5.7 mg/l during trial 3 to 6.6 mg/l during trials 1 and 2 (Table 2). Dissolved oxygen at the Outer Banks sites ranged from 4.9 mg/l during trial 3 to 7.4 mg/l during trial 1 (Table 2). Salinities at the River site ranged from 11.6 ppt to 18.2 ppt (Table 2). Outer Banks salinities were higher, ranging from 9.7 ppt to 29.0 ppt (Table 2).

To perform the logistic regression analysis, data from each site were pooled together to determine the influence of several variables on mortality. The logistic regression analysis indicated that mortality was dependent on salinity and hook location (Table 6). Dependent variables and interactions that were included in the model, but were not significant predictors of mortality included; location, water temperature, dissolved oxygen, fish length, bleeding, hook type, hook removal, handling time, water temperature*length, hook type*hook removal and hook location*hook type. A Hosmer-Lemeshow good-

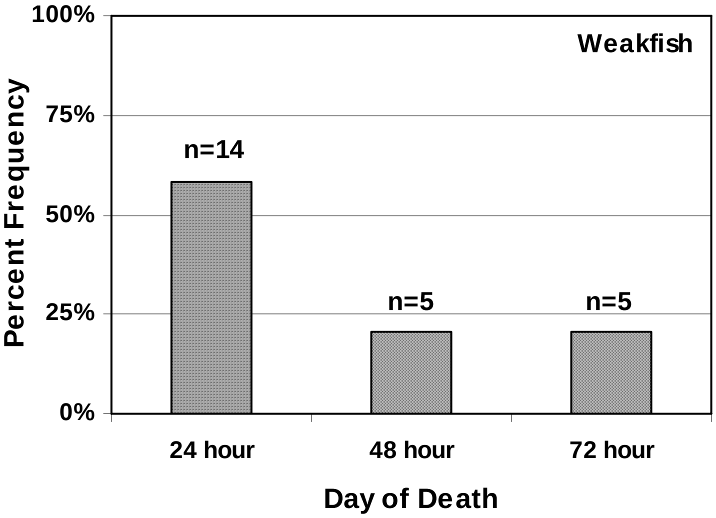

Figure 6. Day of death for all weakfish mortalities observed during trials conducted in North Carolina internal waters during the 2000 and 2001 fishing seasons.

-ness-of-fit test indicated that the model provided a good fit for the data (X^2=0.385, df=3, P<0.9434, Hosmer and Lemeshow 1989). The predicted concordance or proportion of survivals and deaths correctly predicted by the model was 62.0%. Combining the intercept and parameter estimates from Table 6 allows for the estimation of mortality using the following equations:

$$P_{Mortality} = \frac{e^{-1.462-1.778(Salinity)+0.8653(Hook\ Location)}}{1+e^{-1.462-1.778(Salinity)+0.8653(Hook\ Location)}}$$

where the following discrete values have been assigned to each variable:

Salinity	0 = <19 ppt	**Hook Location**	0 = Jaw/Lip
	1 = $\geq$19 ppt		1 = Mouth/Gill
			2 = Esophagus/Gut

Table 6. Summary of stepwise logistic regression analyses of independent variables on 72-h postrelease mortality of weakfish captured by hook-and-line in North Carolina internal waters during the 2000 and 2001 fishing seasons.

Independent Variable	df	X^2	*P*	Estimate	Odds Ratio[a]
Salinity	1	10.582	0.0011	-1.778	0.169
Hook Location	2	5.075	0.0243	0.865	2.376

[a] Indicates the increase or decrease in odds of mortality associated with a variable; a ratio of 1.0 indicates no difference.

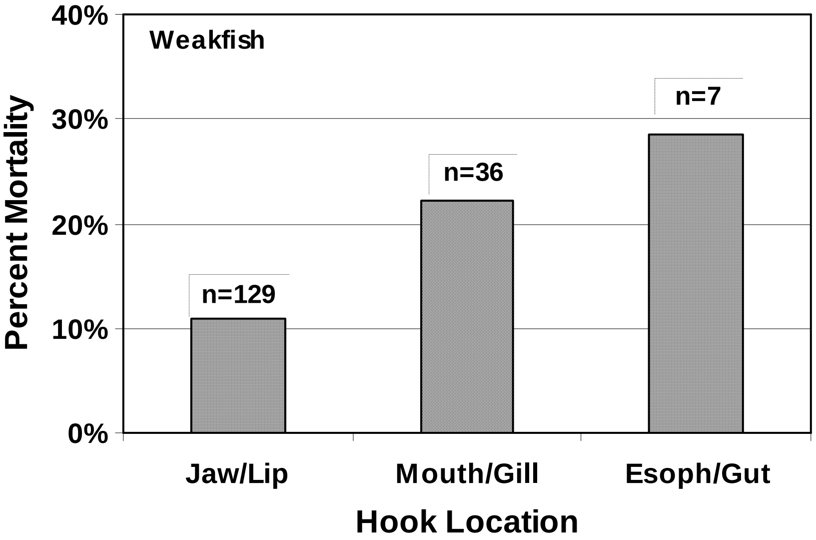

Figure 7. Mortality by hooking location for all weakfish mortalities observed during trials conducted in North Carolina internal waters during the 2000 and 2001 fishing seasons.

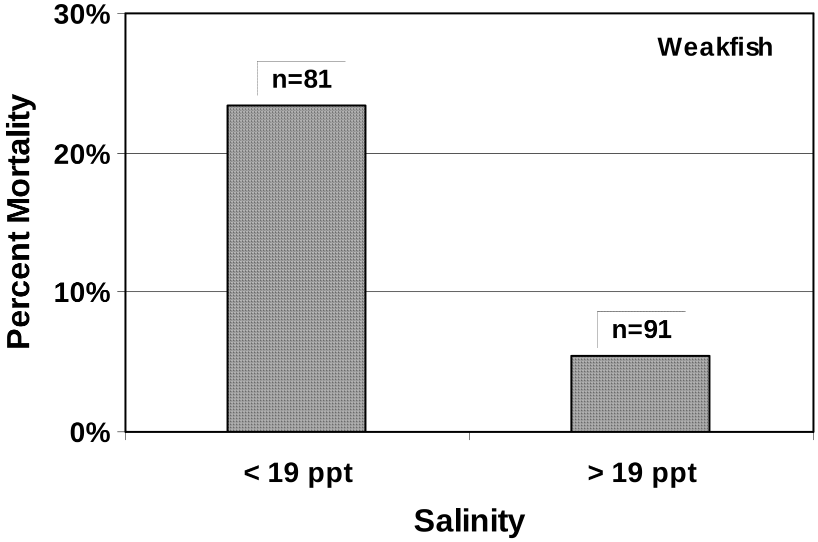

Figure 8. Mortality by salinity for all weakfish mortalities observed during trials conducted in North Carolina internal waters during the 2000 and 2001 fishing seasons.

Mortality was higher for fish hooked deeply (28%) when compared to those that were hooked in the mouth/gill (22%) or jaw/lip (11%, Figure 7). The mortality rate for fish released in low salinity water (<19 ppt) was greater (23%) than those released in high salinity water (≥19 ppt, 5%, Figure 8).

In addition to the stepwise logistic model, a backward elimination logistic regression was also run to compare results between the two techniques and investigate levels of significance for those variables removed from the final model. The backwards elimination technique produced the same model, further indicating that the model provided a good fit for the data.

Red Drum

Collectively, 191 red drum were captured and held in pens for 72 hr periods during six mortality trials. Three trials, consisting of 87 fish, were conducted at Outer Banks sites while three trials, consisting of 104 fish, were conducted at River sites (Table 3). Observed mortality at River sites was 10.9% and ranged from 1.9 to 28.6%, while mortality at Outer Banks sites was 2.3% and ranged from 0.0 to 3.8% (Table 3). Pen/handling mortality at Outer Banks sites was 1.7% and ranged from 0.0 to 3.8%, while control mortality at River sites averaged 6.1% and ranged from 1.9 to 16.7% (Table 3). Average adjusted mortality (observed – pen/handling) was 4.8% at River sites and ranged from 0.0 to 11.9%, while adjusted mortality at Outer Banks sites was 0.6% and ranged from 0.0 to 2.4% (Table 3).

For all trials combined, 100% of the mortality occurred within 24 hrs (Figure 9). Water temperatures for River trials ranged from 24.2ºC during trial 3 to 27.6ºC during trial 1 (Table 3). Water temperatures for Outer Banks trials ranged from 16.6ºC during trial 3 to 26.6ºC during trial 1 (Table 3). The average water temperature for the Outer Banks trials was 23.7ºC while the average temperature of the River trials was slightly higher at 26.7ºC. Dissolved oxygen at River sites ranged from 6.3 mg/l during trial 2 to 7.0 mg/l during trial 1 (Table 3). Dissolved oxygen at the Outer Banks sites ranged from 6.1 mg/l during trial 2 to 7.5 mg/l during trial 3 (Table 3). Salinities at the River site ranged from 10.2 ppt to 13.5 ppt (Table 3). Outer Banks salinities were higher, ranging from 12.3 ppt to 26.6 ppt (Table 3).

To perform the logistic regression analysis, data from each site were pooled together to determine the influence of several variables on mortality. The logistic regression analysis indicated that mortality was dependent on salinity, dissolved oxygen, and hook removal (Table 7). Dependent variables and interactions that were included in the model, but were not significant predictors of mortality included; location, water temperature, fish length, bleeding, hook type, hook location, handling time, water temperature*length, hook type*hook removal and hook location*hook type. A Hosmer-Lemeshow goodness-of-fit test indicated that the model provided a good fit for the data (X^2=0.980, df=3, P<0.8061, Hosmer and Lemeshow 1989). The predicted concordance or proportion of survivals and deaths correctly predicted by the model was 88.7%. Combining the intercept and parameter estimates from Table 7 allows for the estimation of mortality using the following equations:

$$P_{Mortality} = \frac{e^{2.889-3.347(\mathit{Salinity})-4.054(\mathit{Dissolved\ Oxygen})-4.476(\mathit{Hook\ Removal})}}{1+e^{2.889-3.347(\mathit{Salinity})-4.054(\mathit{Dissolved\ Oxygen})-4.476(\mathit{Hook\ Removal})}}$$

where the following discrete values have been assigned to each variable:

Salinity 0 = <19 ppt
1 = $\geq$19 ppt

Hook Removal 0 = Removed
1 = Not Removed

Dissolved O_2 0 = <7 mg/l
1 = $\geq$7 mg/l

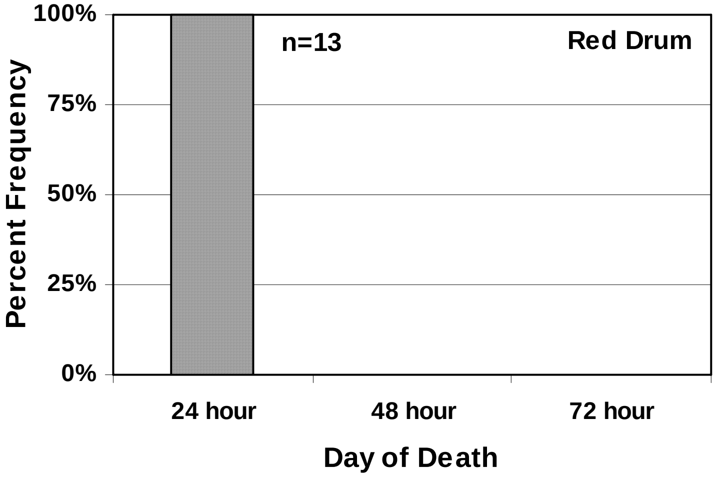

Figure 9. Day of death for all red drum mortalities observed during trials conducted in North Carolina internal waters during the 2000 and 2001 fishing seasons.

Table 7. Summary of stepwise logistic regression analyses of independent variables on 72-h postrelease mortality of red drum captured by hook-and-line in North Carolina internal waters during the 2000 and 2001 fishing seasons.

Independent Variable	**df**	**X^2**	***P***	**Estimate**	**Odds Ratio**[a]
Hook Removal	1	14.574	0.0001	-4.476	0.011
Dissolved Oxygen	1	8.562	0.0034	-4.054	0.017
Salinity	1	7.617	0.0058	-3.347	0.035

[a] Indicates the increase or decrease in odds of mortality associated with a variable; a ratio of 1.0 indicates no difference.

The mortality rate for fish released in low salinity water (<19 ppt) was greater (9%) than those released in high salinity water (≥19 ppt, 3%, Figure 10). Similarly, the mortality rate was higher (12%) for fish released in water with low dissolved oxygen content (<7 mg/l) when compared to those released in water with higher dissolved oxygen content (≥7 mg/l, 1%, Figure 11). Mortality was also higher for fish with hooks left in (58%) compared to fish with hooks removed (3%, Figure 12).

In addition to the stepwise logistic model, a backward elimination logistic regression was also run to compare results between the two techniques and investigate levels of significance for those variables removed from the final model. The backwards elimination technique produced the same model, further indicating that the model provided a good fit for the data. Water temperature was the only marginally significant (P<0.1472) variable removed from the model because it did not meet the 0.10 significance level.

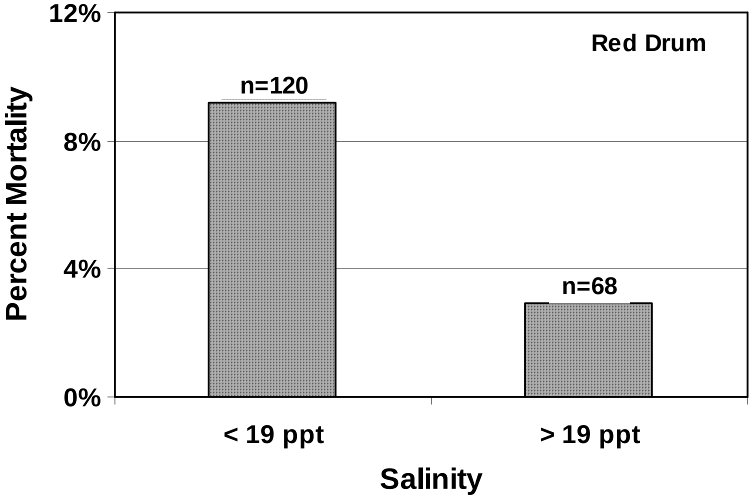

Figure 10. Mortality by salinity category for all red drum mortalities observed during trials conducted in North Carolina internal waters during the 2000 and 2001 fishing seasons.

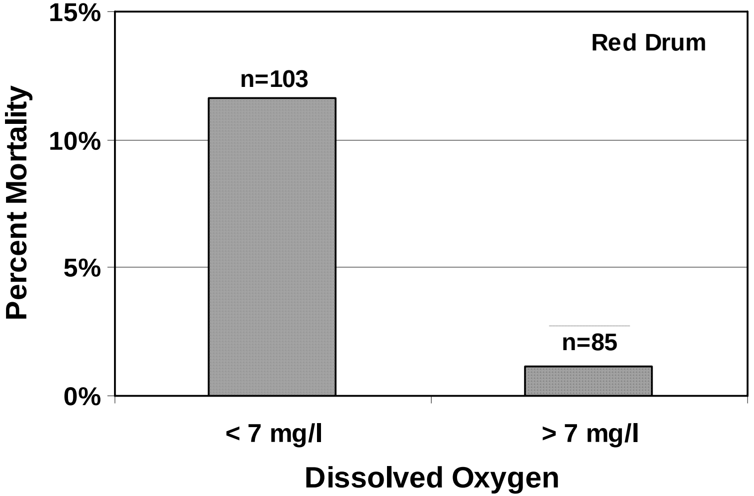

Figure 11. Mortality by dissolved oxygen category for all red drum mortalities observed during trials conducted in North Carolina internal waters during the 2000 and 2001 fishing seasons.

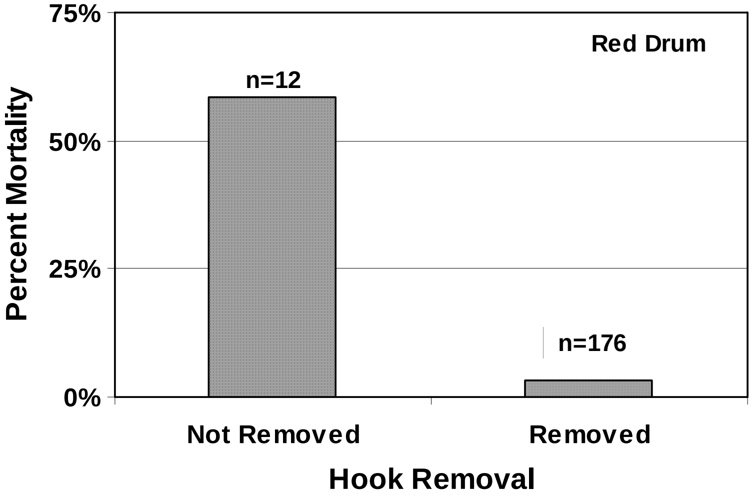

Figure 12. Mortality by hook removal for all red drum mortalities observed during trials conducted in North Carolina internal waters during the 2000 and 2001 fishing seasons.

Southern Flounder

Collectively, 316 southern flounder were captured and held in pens for 72 hr periods during 11 mortality trials. Three trials, consisting of 87 fish, were conducted at Outer Banks sites while eight trials, consisting of 229 fish, were conducted at River sites (Table 4). Observed mortality at River sites was 19.4% and ranged from 0.0 to 22.7%, while mortality at Outer Banks sites was 9.5% and ranged from 3.8 to 16.7% (Table 4). Pen/handling mortality at Outer Banks sites was 7.1% and ranged from 3.8 to 8.3%, while control mortality at River sites averaged 6.0% and ranged from 0.0 to 16.7% (Table 4). Average adjusted mortality (observed – pen/handling) was 13.4% at River sites and ranged from 0.0 to 14.4%, while adjusted mortality at Outer Banks sites was 2.4% and ranged from 0.0 to 8.3% (Table 4).

For all trials combined, 29% of the mortality occurred within 24 hrs and 84% occurred with 48 hrs (Figure 8). Water temperatures for River trials ranged from 20.3ºC during trial 4 to 27.9ºC during trial 1 (Table 4). Water temperatures for Outer Banks trials ranged from 16.6ºC during trial 3 to 26.6ºC during trial 1 (Table 4). The average water temperature for the Outer Banks trials was 23.9ºC while the average temperature of the River trials was slightly higher at 25.9ºC. Dissolved oxygen at River sites ranged from 6.1 mg/l during trial 7 to 7.8 mg/l during trial 4 (Table 4). Dissolved oxygen at the Outer Banks sites ranged from 6.3 mg/l during trial 1 to 7.1 mg/l during trial 2 (Table 4). Salinities at the River site ranged from 18.1 ppt to 13.5 ppt (Table 4). Outer Banks salinities were higher, ranging from 12.3 ppt to 26.6 ppt (Table 4).

To perform the logistic regression analysis, data from each site were pooled together to determine the influence of several variables on mortality. The logistic regression analysis indicated that mortality was dependent on hook location (Table 8). Dependent variables and interactions that were included in the model, but were not significant predictors of mortality included; location, water temperature, dissolved oxygen, salinity, fish length, bleeding, hook type, hook removal, handling time, water temperature*length, hook type*hook removal and hook location*hook type. A Hosmer-Lemeshow goodness-of-fit test indicated that the model provided a good fit for the data (X^2=0.453, df=1, P<0.5009, Hosmer and Lemeshow 1989). The predicted concordance or proportion of survivals and deaths correctly predicted by the model was 50.6%. Combining the intercept and parameter estimates from Table 8 allows for the estimation of mortality using the following equations:

$$P_{Mortality} = \frac{e^{-2.787+1.007(Hook\ Location)}}{1+e^{-2.787+1.007(Hook\ Location)}}$$

where the following discrete values have been assigned to each variable:

Hook Location 0 = Jaw/Lip
1 = Mouth/Gill
2 = Esophagus/Gut

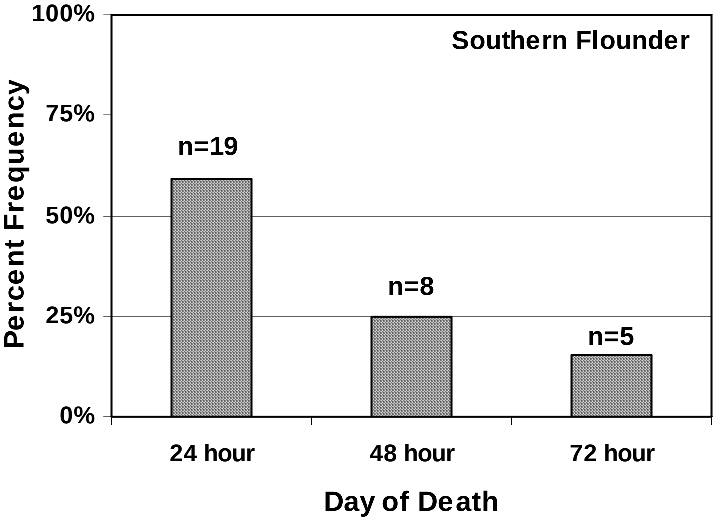

Figure 13. Day of death for all southern flounder mortalities observed during trials conducted in North Carolina internal waters during the 2000 and 2001 fishing seasons.

Table 8. Summary of stepwise logistic regression analyses of independent variables on 72-h postrelease mortality of southern flounder captured by hook-and-line in North Carolina internal waters during the 2000 and 2001 fishing seasons.

Independent Variable	df	X^2	*P*	Estimate	Odds Ratio[a]
Hook Location	2	15.629	0.0001	1.007	2.737

[a] Indicates the increase or decrease in odds of mortality associated with a variable; a ratio of 1.0 indicates no difference.

Mortality was higher for fish that were hooked deeply (35%) when compared to those that were hooked in the mouth/gill (13%) or jaw/lip (6%, Figure 14).

In addition to the stepwise logistic model, a backward elimination logistic regression was also run to compare results between the two techniques and investigate levels of significance for those variables removed from the final model. The backwards elimination technique produced the same model, further indicating that the model provided a good fit for the data. Hook removal was the only marginally significant (P<0.2721) variable removed from the model because it did not meet the 0.10 significance level.

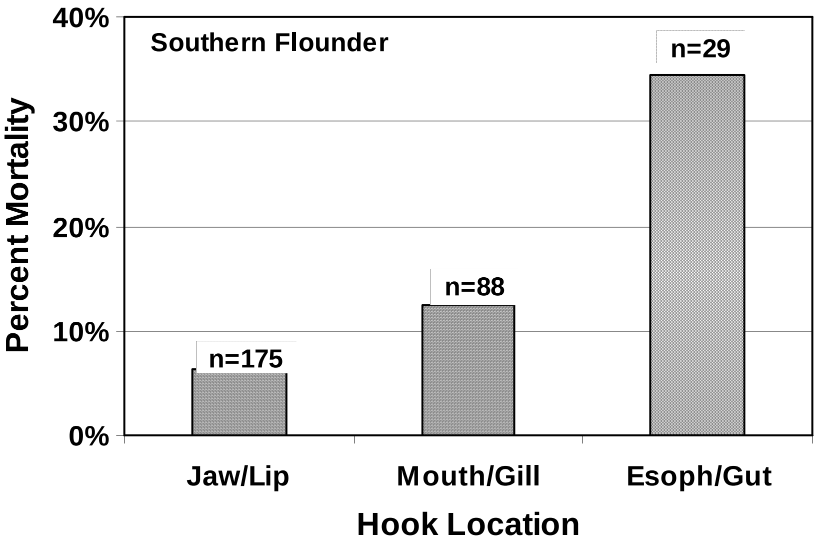

Figure 14. Mortality by hooking location for all southern flounder mortalities observed during trials conducted in North Carolina internal waters during the 2000 and 2001 fishing seasons.

DISCUSSION

During our 72-hr observation periods, the overall unadjusted hooking mortality across sites and trials was 14.8% for spotted seatrout, 14.0% for weakfish, 6.9% for red drum and 11.0% for southern flounder. These results are consistent with previous research conducted on each of these species. Recent studies on spotted seatrout reported release mortalities ranging from 4.6% to 17.5% (Matlock et al. 1993; Murphy et al. 1995; Thomas et al. 1997; and Duffy 1999). Similar rates have also been observed for weakfish with mortalities ranging from 2.6% to 18% (Swihart et al. 1995; Malchoff and Heins 1997). In addition, red drum mortalities reported in this study match those described previous studies that reported mortalities from 2.4% to 16.1%, which were generally lower than mortalities reported for spotted seatrout and weakfish (Jordan 1991; Matlock et al. 1993; Thomas et al. 1997; Duffy 1999). Finally, our southern flounder mortality rate also corresponded well with mortality rates reported for summer flounder, which ranged from 5.3% to 14.7% (Lucy and Holton 1998; Malchoff et al. 1999).

Most mortality occurred within two days for all species and exhibited an inverse relationship between mortality and holding time. This indicates that there was minimal handling stress associated with the mortality trials. Although, higher control mortality was observed for all species except southern flounder at low salinity River sites compared to higher salinity Outer Banks sites indicating an enhancing effect of salinity on mortality.

The ameliorating effect of salinity on release mortality was evident for all species with higher observed mortality at low salinity River sites compared to higher salinity Outer Banks sites. However, logistic regression analyses identified salinity as a significant predictor of mortality for weakfish and red drum. These findings are in agreement with the results of other studies designed to test the effects of salinity on release mortality, which suggest that release mortality is lower in brackish versus freshwater. RMC (1990) held striped bass in three salinity ranges 0.0 ppt, 0.5-4.2 ppt, and 7.7-8.3 ppt and reported striped bass mortalities of 74%, 39%, and 3% respectively. Cech et al. (1996) measured physiological changes in subadult striped bass after brief handling and 5-min intense swimming stress in freshwater and subsequent recovery at 25ºC in four different environments; freshwater, buffered freshwater (10 mM $NaHCO_3 \cdot L^{-1}$), brackish water (10 g $NaCl \cdot L^{-1}$), and seawater (30 g $NaCl \cdot L^{-1}$). The conclusion drawn from this study was that postexercise acidoses were corrected and ionic imbalances were minimized by recovery in brackish water (Cech et al. 1996). These studies confirm the effects of brackish water on release mortality but more work needs to be done to clarify this relationship.

Additionally, predictors of mortality for each species in this study were also identified by other researchers further validating our results. Similar to this study, Thomas et al. (1997) found mortality differences between sublegal (< 305 mm) and legal spotted seatrout. Spotted seatrout length was marginally significant in the Murphy et al. 1995 Florida study, but was not discussed. Furthermore, we identified bleeding as a significant predictor of mortality for spotted seatrout, while hook location was identified for weakfish. Bleeding is often an indicator of an adverse hook location in the gills, esophagus, or gut. Murphy et al. (1995) identified hook location as a significant predictor of spotted seatrout mortality and other researchers have investigated mortality differences between treble and single hooks and reported higher mortalities for spotted seatrout captured on single hooks due to adverse hooking locations associated with single hooks (Thomas et al. 1997; Duffy 1999). Similarly, Swihart et al. (1995) drew the same conclusions for weakfish hooked in sensitive areas. We identified hook removal as a significant predictor of mortality in red drum, which was closely associated with adverse hooking locations. In our study, hooks were only left in fish that were hooked in sensitive areas. Jordan (1991) reported similar results with mortality increasing with depth of hooking. Finally, hook location was identified as a significant predictor of mortality for southern flounder, which agrees with results of other studies on summer flounder. Lucy and Holton (1998) reported that deep hooked summer flounder accounted for 95% of the mortalities observed in tank experiments and 93% of mortalities in field trials and was the only variable identified as a significant predictor of release mortality. While Malchoff et al. (1999) also identified hook location as a significant predictor of mortality in three state-based analysis for North Carolina, Virginia, and New York.

Finally, the mortality rates observed among species in this study are comparable to trends in the literature. Spotted seatrout and weakfish experienced similar mortalities at 14.8% and 14.0% respectively. Similarities were expected for these closely related species and further validate our results. Red drum release mortality was much lower (6.9%) than the mortality rate observed for spotted seatrout and weakfish. This trend has been observed by many researchers investigating angler induced mortality for these species. Thomas et al. (1997) observed 17.5% mortality for spotted seatrout and 2.7% mortality for red drum in single and treble hook comparisons in Louisiana. Duffy (1999) also examined the effects of single and treble hooks on these species in Alabama and observed 14.6% mortality for spotted seatrout caught on single hooks and 2.4% mortality for red drum. Matlock et al. (1993) also studied the effects of single and treble hooks on these species in Texas and observed 7.3% mortality for spotted seatrout caught on single hooks and 4.1% mortality for red drum. Discard mortality differences between these species have also been documented in gillnets (Price and Gearhart 2002). Collectively, these studies indicate that red drum have a higher tolerance for environmental, exercise, handling, injury, and confinement stress. Southern flounder release mortality observed in this study was similar to the results of other studies on summer flounder, which were generally lower than those observed for spotted seatrout or weakfish, but higher than those observed for red drum. Due to their relatively sedentary lie-in-wait predator lifestyle and subsequent behavior patterns, flounder respond well to confinement experiencing minimal pen related mortality in these types of studies. They also appear to have a higher tolerance for handling and environmental stress than spotted seatrout or weakfish.

CONCLUSIONS AND RECOMMENDATIONS

Considering the results of this study, which identifies hook location and associated variables as good predictors of release mortality for all species examined, managers should promote the use of fishing techniques that are less likely to hook fish in adverse locations. Previous studies on the use of single and treble hooks for red drum and spotted seatrout have mixed results. Thomas et al. (1997) found highly significant differences for red drum and spotted seatrout release mortality between fishing methods that included; treble hook artificial lure, single hook artificial lure, treble hook live bait, and single hook live bait. Treble hooks had significantly lower release mortalities for both species with both artificial and live bait compared to single hooks. However, both treble and single hooks had significantly higher release mortality when live bait was used. In contrast, both Duffy (1997) and Matlock et al. (1993) found no significant differences in red drum or spotted seatrout release mortality between treble and single hooks. These results indicate that more work needs to be conducted to clarify the relationship between hook type and release mortality for these species. In addition, research examining the use of circle hooks for these species needs to be conducted. Previous studies on inshore fish have primarily focused on the effects of circle hooks on striped bass release mortality (Lukacovic 1999; Hand 2001). Hand (2001) conducted a circle hook evaluation in North Carolina and reported that 4/0 and 5/0 non-offset hooks reduced the incidence of bleeding and deep hooking. In addition, catch efficiencies were lower for circle hooks when compared to traditional “J” hooks. Lukacovic (1999) conducted a similar study in Maryland and reported 9.1% mortality for striped bass caught on conventional hooks compared to 0.8% mortality for fish caught on non-offset circle hooks. Lukacovic (1999) also reported 17.2% deep hooking with conventional hooks compared to 3.4% for circle hooks. These results illustrate the potential reduction of deep hooking and subsequent release mortality associated with the use of circle hooks. However, these results may not be consistent across species. Malchoff et al. (1999) compared the release mortality of summer flounder caught on wide-gap and circle hooks and found no significant difference between hook types.

The effect of salinity on release mortality identified here is interesting, but may only serve to point out regional mortality differences that potentially occur within recreational fisheries directed at the species examined here. The mortality differences at low and high salinity sites could be used to adjust recreational fishing mortality estimates by regionally applying the release mortality estimates to MRFSS discard estimates for each of these species. The FMPs for each of these species are based on predictive stock assessments, which require the quantification of all sources of mortality including discards. Failure to account for all sources of mortality could result in inaccurate stock size estimates, which could lead to the implementation of inappropriate management measures.

Finally, NCDMF should strive to promote better fishing practices by publishing and distributing a guide containing fishing and handling techniques aimed at reducing release mortality. As fish stocks increase, size and creels often remain in place to prevent overfishing, which results in increases in recreational catch-and-release fishing. The number of discards associated with these fisheries can be high and the perception of “waste” produced by management regulations often hinders efforts to promote better fishing practices. To effectively change the behavior of the public, new fishing practices and techniques that reduce release mortality have to be adopted and promoted by those that can influence anglers the most, which include outdoor writers, local guides, marine extension agents, and tournament managers (Mills 2000). Lastly, the tackle industry must take the lead in developing, promoting, and making new tackle available to the public.

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