CONTRIBUTIONS TO THE BIOLOGY OF RED DRUM, *Sciaenops ocellatus*, IN SOUTH CAROLINA

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This report reflects the efforts of many individuals who either assisted in the field sampling, the processing of materials in the laboratory, the analysis of data or writing specific sections of this report. Among those who did so are the following:

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This work could not have been accomplished without the dedication and skill of those mentioned above.

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CHAPTER 1 {A}

MONTHLY STRATIFIED RANDOM TRAMMEL NET SETS IN SOUTH CAROLINA'S ESTUARINE SYSTEMS – DISTRIBUTION, RELATIVE ABUNDANCE AND AGE OF RED DRUM

BY

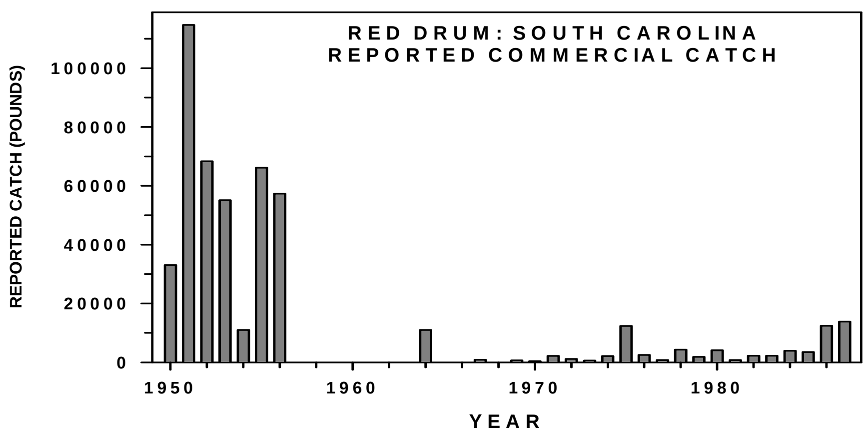
CHARLES A. WENNER

INTRODUCTION

BACKGROUND

The management of red drum in the fisheries of South Carolina's territorial waters has evolved over time. Prior to July 1, 1987, there were no restrictions on the fishery[1]. South Carolina had a small commercial fishery whose landings peaked in the 1950's, averaging ~58,000 pounds over a seven year period. The reported catch declined in the 1960's and fluctuated between zero and 13,000 pounds over the two-decade period (Figure 1). Major gear types included handlines, stop nets, gill nets, haul seines and gigs. Although no data are or were available, many felt some of the catch was sold outside of the normal market channels, and therefore went unreported.

Figure 1. Reported commercial landings in pounds of red drum in South Carolina, 1950 – 1987.



Before July 1, 1987, there were no restrictions on the recreational harvest of red drum in state waters. The law enacted on that date declared red drum as well as spotted seatrout gamefish, placed restrictions on their harvest and banned a variety of fishing gears (gill nets, trammel nets, stop nets) in state waters[2]. Initially, there was a minimum size of 14 inches total length (TL)

[1] There were some areas that were closed to netting, i.e., west of the Intracoastal Waterway as well as some very minor mesh size restrictions for gill nets.
[2] Short lengths of gill net were permitted to be fished in areas where commercial trawling for penaeid shrimp was allowed; red drum caught in such gear were to be returned to the water alive.

during July and August and a twenty-five fish per angler per day bag limit. In 1988, the minimum size restriction was extended to include September as well as the other two months.

After the passage of a cold front in winter, estuarine waters cool rapidly because of the low air temperatures and the strong northwest winds that mix the waters. The calm, cold nights when the waters settled provided the opportunity for a highly effective fishery in the estuarine shallows, generally near oyster bars. Water clarity was high and the fish were lethargic due to the low water temperatures. Flat-bottomed boats equipped with lights directed into the water were poled through the shallows while an individual, positioned in the bow, used a barbed spear or ‘gig’ to impale and harvest the slow moving fish. The method was very effective. The law also eliminated that practice during the months of January and February, the two coldest months, and applied the same harvest and size restrictions as for the hook and line fishery. Later, the month of December was included in the closed season. Subsequent regulatory changes reduced the bag limit to five fish per angler per day in a 14 to 27 inch TL slot. The harvest of large fish (older subadults[3] and adults) was stopped because of concerns about the size of the spawning population.

The additional restraints on the recreational fishery for red drum were imposed in an attempt to reduce fishing mortality on the subadult fish. The management target was to allow sufficient numbers of immature red drum to survive, become sexually mature and maintain the spawning biomass at 40% of levels present in the absence of fishing. The initial assessments of the survival of subadults were quite discouraging and indicated that the escapement rate was less than 1% in the 1980’s. After initial restrictions on the fishery, the rate increased to ~3-5% in the early 1990’s and with the implementation of the size and the lower bag limits, escapement increased to ~17% in the period from 1992-1994 (Vaughan, 1996).

THE RECREATIONAL FISHERY

Most red drum are harvested by anglers fishing from boats in estuarine waters. This is the “Private/Rental” category of the Marine Recreational Fisheries Statistical Survey. Since few businesses rent boats in coastal South Carolina, this mode is almost totally composed of small, privately owned vessels. These gain access to the estuary either from public landings, dry stack marinas, or the many private docks found in the protected creeks along the coast. The MRFSS, however, does not sample the vessels leaving from the private docks. The absence of a

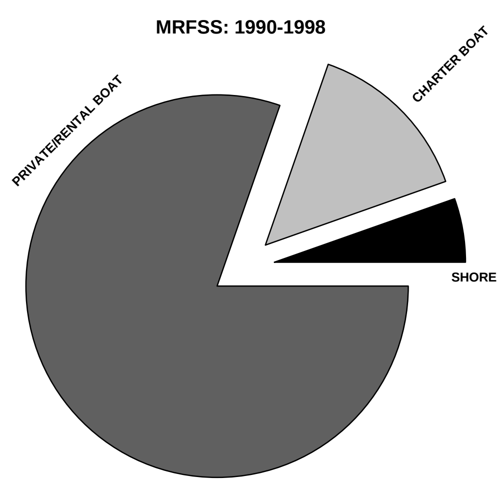
[3] Subadults are those red drum that have not attained sexual maturity and have not “escaped”, i.e., moved from the estuary to join the spawning stock.

"roaming" portion of the survey, which would intercept these anglers on the water, results in the exclusion of these catches from the data.

For the nine year period from 1990 through 1998, slightly more than 80% of the 2.6 million red drum were caught by anglers (A + B1 +B2) fishing from private boats. An additional 14% was accounted for by the charter boat fleet and 5% by shore based anglers (Figure 2 and Table 1). The latter fished from beaches, banks, bridges and piers. In the 1990's, a growing charter boat fishery developed. Fishing guides target red drum in shallow water, either on the marsh surface at high tide when that area is flooded or on the shallow flats when the marsh surface is dry. Prior to booking a charter targeting red drum, some guides inform patrons that all red drum caught during the trip will be released, regardless of size (M. Able, personal communication, 1999). Others do not permit the anglers to retain the legal bag limit of five fish per day.

Since 80% of the catch was made by small boats fishing in inland waters, the subsequent discussion of the recreational fishery will be limited to results of sampling this mode. The MRFSS does not sample Wave 1 (January-February) in South Carolina because of reduced effort and small catches during this period. Survey data indicate that fishing effort is lowest in the late winter – early spring (Wave 2: March – April), increases in subsequent waves to high levels in Waves 4 and 5 and declines in Wave 6 (Table 2).

Figure 2. Total catch of red drum (A + B1 + B2) by fishing mode in inland waters in South Carolina pooled for the nine year period from 1990 through 1998; source NMFS, MRFSS.



Because red drum are first recruited in any numbers to the recreational fishery at an age of ~ 1 year during Wave 4 of the MRFSS (Figure 3), the “red drum period” was established. This period was defined as the interval from 1 July of a year to 30 June of the following year. The MRFSS is partitioned into two-month sampling waves so the period included Wave 4 through 6 of one year and Waves 2 and 3 of the following year. After establishing this period, the effort and the catch by the Private /Rental mode fishing in inland waters was allocated to periods. With this procedure, a cohort can be followed from the time of initial catch to just before the time of recruitment of the next cohort.

Effort, the number of trips made by private boats in inland waters, though variable between years (Table 2), has shown a gradual upward trend since the early 1980’s. Total catch (A +B1 + B2) for the private/rental boat mode in inland waters peaked at over 500,000 red drum in the period from July 1987 through June 1988 (Figure 4). Lowest catches were in the early 1980’s. The catch per unit effort, CPUE, was defined as the total catch of red drum for a period divided by the corresponding number of trips made by the private/rental mode in inland waters. The CPUE ranged from a low of 0.137 to a high of 0.847 red drum per trip for the periods from 1981 through 1998.

Table 1. Total catch of red drum (A+B1+B2) by mode for the period from 1990 through 1998 from the Marine Recreational Fisheries Statistical Survey.

Year	***Shore Mode***		***Charter Boat Mode***		***Private/Rental Boat Mode***		***Total***
	Number	Percent	Number	Percent	Number	Percent	Number
1990	2,398	1.08	19,708	8.91	199,171	90.01	221,277
1991	28,147	12.46	16,303	7.22	181,352	80.31	225,802
1992	28,542	17.97	3,229	2.03	127,032	79.99	158,803
1993	18,735	7.06	62,405	23.50	184,373	69.44	265,513
1994	20,160	4.44	42,797	9.42	391,264	86.14	454,221
1995	18,074	3.31	136,010	24.06	411,191	72.74	565,275
1996	8,870	2.89	51,143	16.65	247,153	80.46	307,166
1997	12,398	4.07	33,011	10.83	259,385	85.10	304,794
1998	4,442	3.40	11,533	8.82	114,807	87.79	130,783
Total	141,766	5.38	376,139	14.28	2,115,728	80.33	2,633,633

Table 2. Estimates of fishing effort for the Private/Rental boat mode in inland waters by wave. Data from MRFSS; effort = number of trips.

Year	Wave 2	Wave 3	Wave 4	Wave 5	Wave 6	Total
1981	11,663	38,206	27,547	41,719	11,193	**130,328**
1982	19,008	61,542	79,113	126,427	81,730	**367,820**
1983	11,328	80,744	76,978	124,997	46,447	**340,494**
1984	61,163	59,822	69,767	115,934	63,930	**370,616**
1985	78,726	59,227	63,946	65,577	103,618	**371,094**
1986	26,761	126,994	62,471	137,272	112,473	**465,971**
1987	80,475	122,357	185,568	133,790	149,703	**671,893**
1988	26,714	143,890	204,918	159,899	226,820	**762,241**
1989	43,001	84,026	103,335	104,113	99,779	**434,254**
1990	77,847	55,516	158,139	127,857	60,673	**480,032**
1991	93,145	121,163	224,305	188,264	159,495	**786,372**
1992	92,988	167,983	134,697	141,880	99,875	**637,423**
1993	43,880	95,130	219,157	174,476	81,124	**613,767**
1994	111,550	207,947	205,359	255,972	69,969	**850,797**
1995	69,600	191,287	82,733	103,293	141,353	**588,266**
1996	68,276	124,974	127,051	78,742	50,025	**449,068**
1997	36,052	70,679	112,430	93,919	44,797	**357,877**
1998	13,137	43,047	96,665	68,279	37,633	**258,761**
	965,316	**1,854,537**	**2,234,183**	**2,242,415**	**1,640,643**	**8,937,094**

Previous work in South Carolina's estuaries has demonstrated that the age composition of red drum differed between trammel net catches and the recreational fishery as described by the Marine Recreational Fisheries Statistical Survey (MRFSS). The estimates of mortality were higher using the MRFSS data than those derived from the fishery-independent data. The causes of the bias were suggested as being: (1) the recreational fishery targets smaller fish; (2) decreased availability with increasing size and age; (3) the slot limits of the regulations impacted the size composition of the catch. The present study expands on the findings of a previous MARFIN project on the abundance of red drum in fishery-independent surveys in South Carolina.

Figure 3. Length frequency distribution of red drum measured by state personnel during incepts of anglers in the state of South Carolina survey. Lengths are fork lengths in inches. A few new “recruits” are seen in Wave 3, but many more are seen in the catches of the next wave.

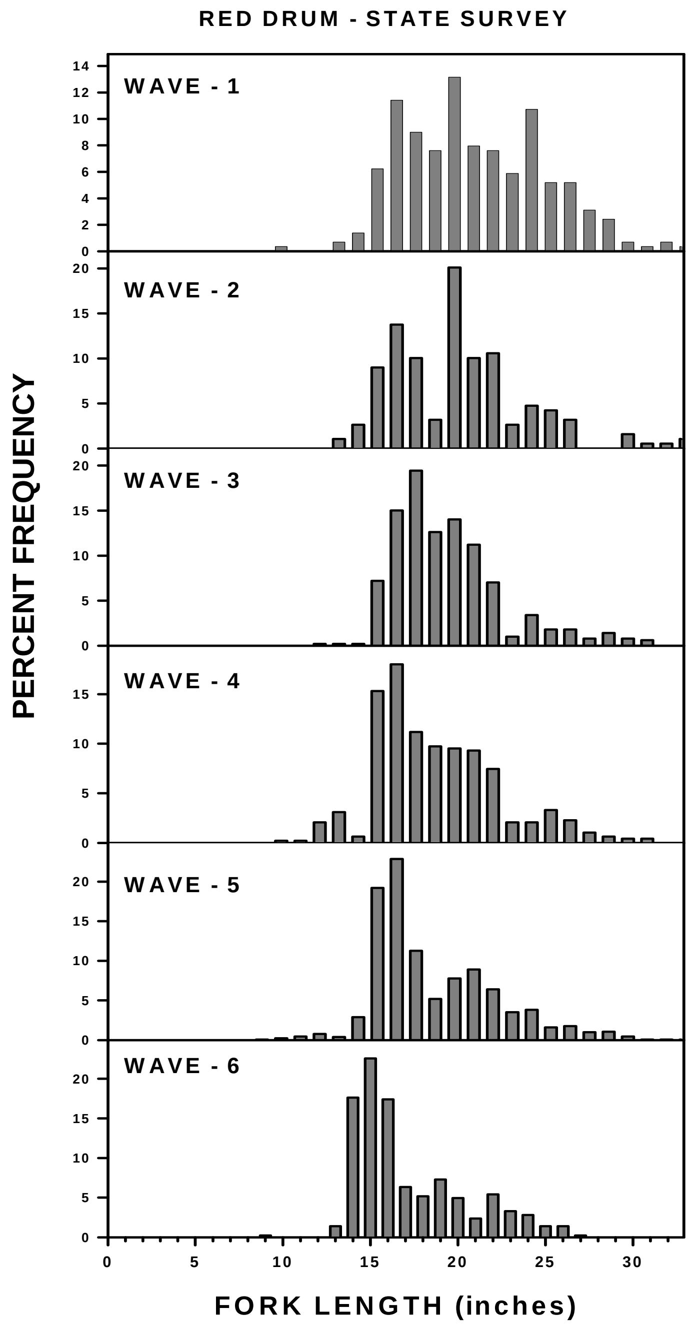
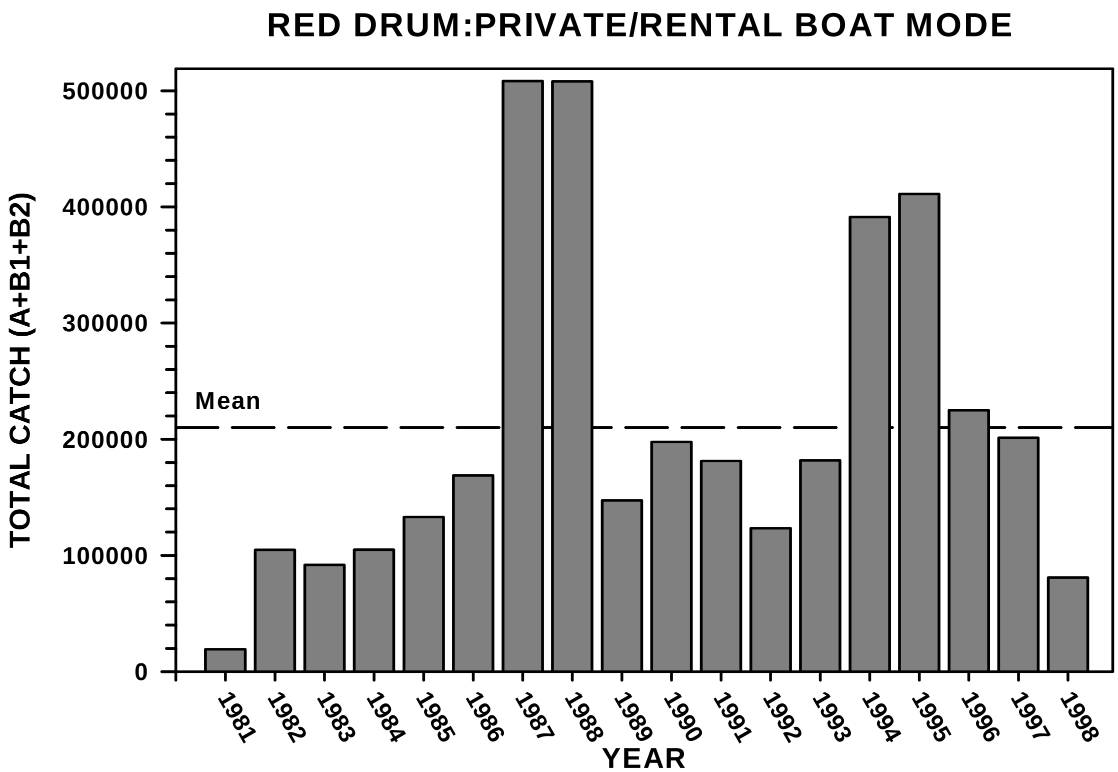


Figure 4. Estimated total catch of red drum by the Private/Rental Boat sector in South Carolina from 1981 through 1998. Dashed line is the mean for the period.

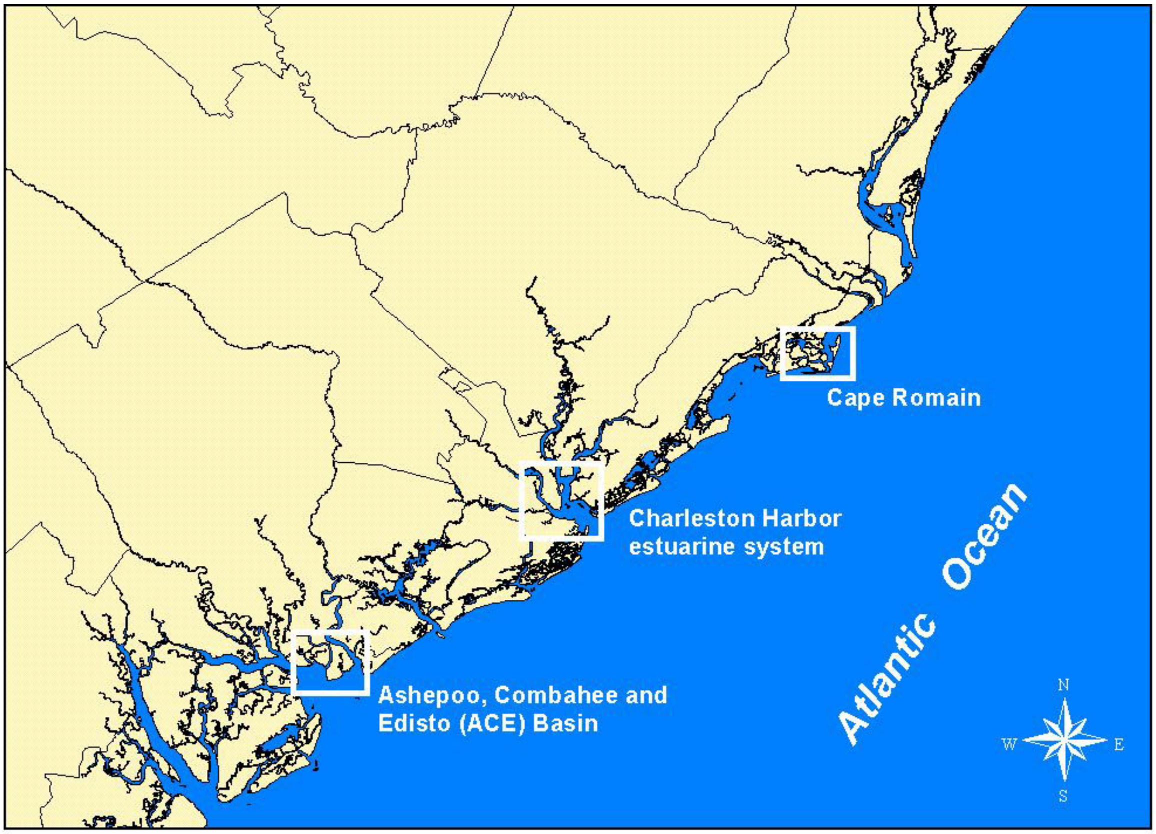


MATERIALS AND METHODS

Sampling began in 1991 in the Charleston Harbor and lower Wando River strata (Figure 5). The initial work (1991-1993) was funded by the Charleston Harbor Project[4] and Sport Fish Restoration Grants. As additional support from the National Marine Fisheries Service became available, we added four additional strata in the following locales: Ashley River, ACE Basin, Cape Romain Harbor and Whitebanks in the very northern section of Bulls Bay. Since the latter two strata were contiguous and monthly samples were in adjacent bodies of water, these strata were collapsed into a single stratum, Cape Romain, for analysis.

4 The Charleston Harbor Project was funded by the National Ocean and Atmospheric Administration of the US Department of Commerce and was administered by the South Carolina Coastal Council.

Figure 5. Strata locations for trammel net sampling along the South Carolina coast.



The shoreline in these strata was divided into 305-m long sampling sites that were assigned an identification number. Some areas were excluded from the station matrix because of physical obstructions such as docks and groins, swift tidal currents, or topography. Because the trammel net was constructed with a large amount of monofilament webbing, it had a great deal of resistance to tidal current. If the net was set in moderate or strong current, the gear's interaction with the water flow caused it to be either pulled under the surface or dragged downstream. Nets set in areas with relatively deep water adjacent to the bank did not fully enclose the site and the gear did not effectively sample the whole water column. Another topographical feature that resulted in the exclusion of an area from consideration as a sampling location was the presence of tidal creeks flowing into the site from the adjacent marshes. Their presence would provide fishes with avenues of escapement from the sampling gear.

The five strata had between 23 and 56 possible sites that could be sampled (Table 3). Prior to field operations, twelve stations were selected without replacement with a table of random numbers. An additional pair of sites were selected in the same fashion as alternate sampling locales in case one or two of the primary selected could not be sampled because of weather, tide or the presence of recreational fishermen at the station.

Table 3. Potential stations in the five strata sampled with the trammel net.

Stratum	***Number of Possible Sampling Sites***
Charleston Harbor	23
Wando River	23
Ashley River	25
Cape Romain	56
ACE Basin	27

After the initial trials when we examined the relationship of the catch of red drum in trammel net sets with tidal stage, we sampled from just after high tide to low slack water. At each randomly selected site, we set the net from a rapidly moving (~15 knots; 7.7m/sec) boat in an arc that enclosed a section of the shoreline during ebb tide. The characteristics of the trammel net were:

[1] outer walls: 17.8-cm square mesh (35.6-cm stretch mesh), eight meshes deep made from #9 monofilament;

[2] inner wall:3.2-cm square mesh (6.4-cm stretch mesh), sixty meshes deep made from #177 monofilament;

[3] headrope: 1.27-cm diameter polyfoam line tied to 0.95-cm diameter polypropylene line;

[4] footrope: 0.95-cm diameter leadcore rope weighing 38.6 kg/182.9-m;

[5] other: net hung with #9 dipped nylon twine; length = 182.9-m; depth = 2.44-m.

After the net was set and the area along the shoreline isolated, the water inside the site was disturbed by racing the engine and slapping the water's surface with poles. The net was then hauled and cleared of fishes.

Most fishes were placed in oxygenated holding tanks on the boat as they were removed from the net. Immediately after the net was retrieved, red drum were measured to the nearest mm total length (TL)[5]. Although red drum lack a defined fork in the caudal fin, we measured a subsample for "fork length". The Marine Recreational Fisheries Statistical Survey as well as some states, i.e., North Carolina, present their data on size as "fork length". In reality this measurement is a "relaxed total length", that is, the straight -line distance form the tip of the snout to the center of the caudal fin. After measurement, unmarked red drum were tagged with sequentially numbered internal anchor or stainless steel dart tags. The tag choice was based on the size of the fish. Fish less than 550-mm TL were fitted with an internal anchor whereas larger red drum had a dart tag inserted into the muscle mass between the pectoral fin and the beginning of the dorsal fin. The tags were inserted on an angle so that the streamer projected caudally and was close to the body. Individuals collected during sampling that were previously marked, were measured (TL-mm) and the tag number recorded. For newly marked as well as previously tagged individuals greater than 500-mm TL, a sample of scales was removed from behind the pectoral fin to estimate age. The re-examination of the scales from previously marked fishes gave us an indication of the repeatability of our counts.

The remainder of the catch was identified to species, counted, measured (TL, FL, SL or disc width depending on the species) and weighed. Most were released alive; however, monthly subsamples of striped mullet**,** *Mugil cephalus*, spotted seatrout, *Cynoscion nebulosus*, and southern flounder, *Paralichthys lethostigma*, were sacrificed for aging (otoliths) and reproductive samples. Diamondback terrapins were counted and these data were provided to a graduate student at the university of Charleston for her thesis. Other turtles (green and loggerhead) were measured, marked with tags provided by the National Marine Fisheries Service, and released at the point of capture. These data were sent to NMFS personnel in Miami, Florida.

[5] This measurement is the maximum total length, i.e., the straight-line distance from the tip of the snout to the end of the caudal fin.

After processing the catch, air and water temperature were measured with a stem thermometer and a sample of water was taken to the laboratory to estimate salinity with a temperature compensated index refractometer. For the past two years, we have measured water temperature, salinity and dissolved oxygen with a model number 85 YSI water quality meter[6]. Weather observations, tidal stage and sample depth were also recorded.

Data Analysis

We used chi-squared analysis to determine if there were any significant differences in the presence of red drum in trammel net sets made at different tidal stages. The stratified mean catch per set and its standard error were calculated for sets made between mid-ebb tide and low slack water by the following

[1.] $y_{st} = 3\ (N_h \text{ x } y_h)/N$

where y_{st} = stratified mean catch per set

N_h = number of possible sets in the h^{th} stratum

y_h = mean catch per set in the h^{th} stratum

N = possible number of sets in all strata

[2.] $s_{yst} = (\sum(N_h/N) \text{ x } (s_h^2 / n_h))^{1/2}$

where s_{yst} = standard error of the stratified mean catch/ set

N_h = number of possible sets in the h^{th} startum

N = total number of possible sets in all strata

s_h^2 = variance of stratified mean in h^{th} stratum

n_h = number of sets in stratum h on which variance estimate is based.

The portions of the monthly estimates of the stratified mean catch/set attributable to a specific cohort (yearclass) were obtained by applying monthly age-length keys (Ricker, 1975) to the monthly length frequency distributions for a given stratum. The birthdate was defined as September 1 which is approximately the mid-point of the spawning season. Red drum from 10 to 14 inches TL (25 to 36-cm TL) caught in September with no annuli on their hardparts were defined as 13 months of age. Larger fishes that had 1, 2 or 3 annuli on otolith sections were designated as 25, 37 or 49 months of age, respectively. If the sample was taken in September of

[6] YSI Incorporated, 1725 Brannum Lane, Yellow Springs, OH 45387

1995, the 10 to 14-in TL red drum (age = 13months) was assigned to the 1994 yearclass. The 25, 37 and 49 month-old fish were in the 1993, 1992 and 1991 cohorts, respectively. Fishes were pooled in 3-in TL intervals to produce the keys.

Since red drum otoliths are large and dense, they must be sectioned in order to count the rings. Prior to sectioning, the core was marked on the proximal surface with a soft lead pencil and the bone was embedded in epoxide resin[7] in a silicon mold. A low speed, Isomet saw[7] equipped with two 10.2-cm (4-in) diameter diamond-coated blades separated by a ~0.5-mm thick spacer made the section of the sagittae. The resulting sections were mounted on glass sides and viewed under appropriate magnification.

RESULTS

The mean catch/set (Figure 6) as well as the frequency of occurrence (Figure 7) of red drum in net samples were lowest from early flood to early ebb tide and highest in mid-ebb to low tide (Table 4). When red drum were caught in trammel net sets made from early flood to late flood tides, they were taken in low numbers. For example, the three sets with red drum, caught from one (n = 2) or three fish; mid-flood catches were comprised of one (n = 3), three (n = 1) or six (n = 1) whereas late flood sets had one (n = 5), two (n = 1) or four (n = 1) individuals. High tide sets

Table 4. Frequency of occurrence and mean catch per trammel net set with the associated standard error for various tidal stages.

tidal Stage	*n*	*Mean*	*Standard error*	*Present*	*Absent*
Early Flood	12	0.42	0.26	3	9
Mid-flood	19	0.63	0.34	5	14
Late Flood	69	0.16	0.07	7	62
High	98	0.60	0.21	22	76
Early Ebb	1153	1.33	0.14	366	787
Mid-ebb	1420	4.81	0.34	825	595
Late Ebb	876	6.67	0.62	513	363
Low	13	7.78	2.66	8	5

[7] Buehler Ltd., P.O. Box 1, Lake Bluff, IL 60044.

more frequently encountered red drum than those sets made during the stages of the flood tide. Of 22 occurrences of red drum, most had one (n = 13), two (n = 5) or three fish (n = 1); other samples had six (n = 1), eleven (n = 1) or sixteen (n = 1) red drum. As the tide ebbed, not only did the frequency of occurrence increase but also the incidence of multiple fish in the samples

Figure 6. The mean catch per set with the standard error for red drum taken in random net sets made at different stages of the tide.

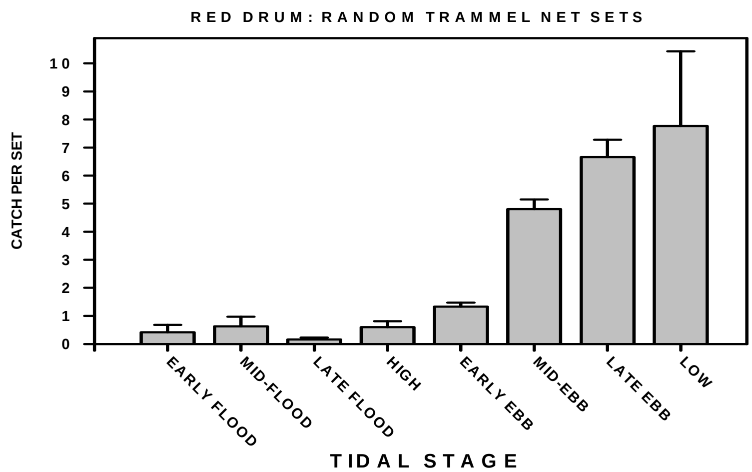
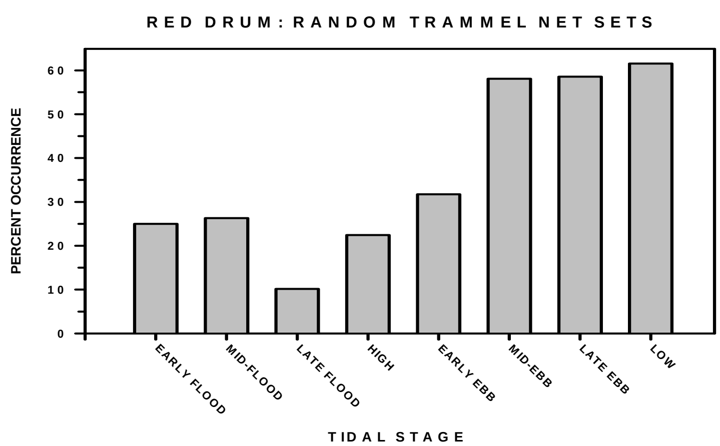


Figure 7. Frequency of occurrence of red drum taken in random net sets by tidal stage.



and the variance (Table 5). Chi-square analysis showed significant differences in the frequency of occurrence of red drum in sets made at different tidal stages (Π^2 = 291.61, df = 7, p = <0.001). Subsequent tests indicated that there were three groups that significantly differed from each other: early flood to high tide; early ebb tide and mid-ebb to low tide (Π^2 = 288.302, df = 2, p = <0.001). Red drum occurred in 37.4% to 57.1% of the trammel net sets made during all tidal stages in each year for the eight-year period (Table 5). This species was in 54.4% to 63.2% of the samples taken from mid-ebb to low tide.

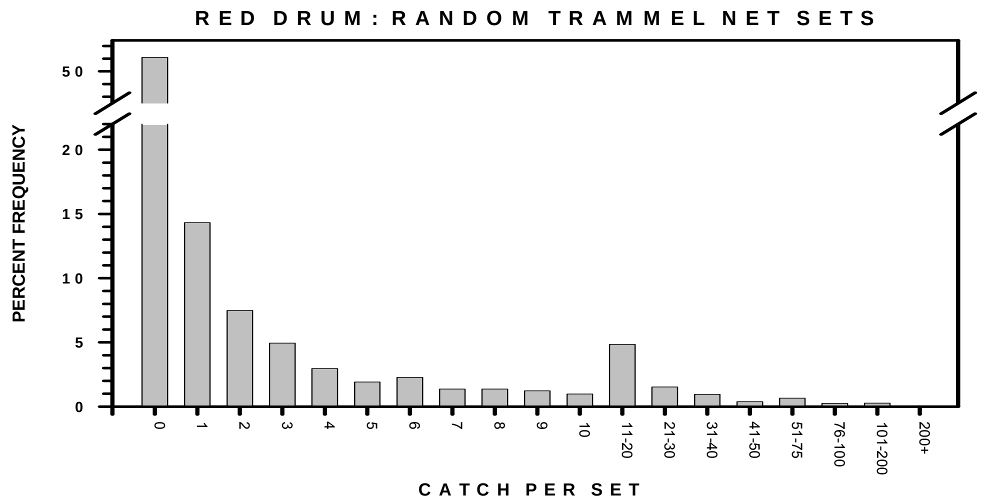
The overall frequency distribution of the number of red drum caught/set followed a negative binomial with values that ranged from 0 to 232 individuals per set (Figure 8). Over 50% of the sets caught no red drum and 39.5% had from one to 10 fish. During early flood to high tide sampling, over 80% of the 198 sets failed to capture red drum; only 1% of the samples had more than 10 fish. In the 1,153 sets made during early-ebb tide, only 3.1% had more than 10 red drum; a single set had 96 fish. Mid-ebb to low tide sampling contained red drum 58.3% of the time, and 14.1% of the total number of sets (n = 2,309) made during this interval had more than 10 individuals.

Since red drum were generally unavailable to the trammel net during incoming and high tide, we limited the analysis of the catch data to mid-ebb to low tide. The monthly values of the stratified mean catch per set ranged from less than one to more than thirty fish (Figure 9). The largest catch was in February of 1992; lowest in January of 1997. The standard error was related to the mean, i.e., as the mean catches increased in magnitude, the associated standard errors became larger. This resulted from contagious distribution of subadult red drum inside South Carolina's estuaries. The monthly catch rates showed no obvious trend; however, fewer large monthly means were seen after 1995 than in prior years. The month to month variability obscured any

Table 5. Occurrence of red drum in trammel net sets made from 1991 through 1998.

Year	***All Tidal Stages***		***Mid-ebb to Low Tide***	
	Total Sets	% Occurrence	Total Sets	% Occurrence
1991	195	37.4	84	58.3
1992	161	57.1	128	59.4
1993	229	56.3	182	58.2
1994	483	46.0	294	59.9
1995	589	50.6	372	63.2
1996	577	48.4	363	59.0
1997	681	47.1	436	56.2
1998	746	44.9	450	54.4

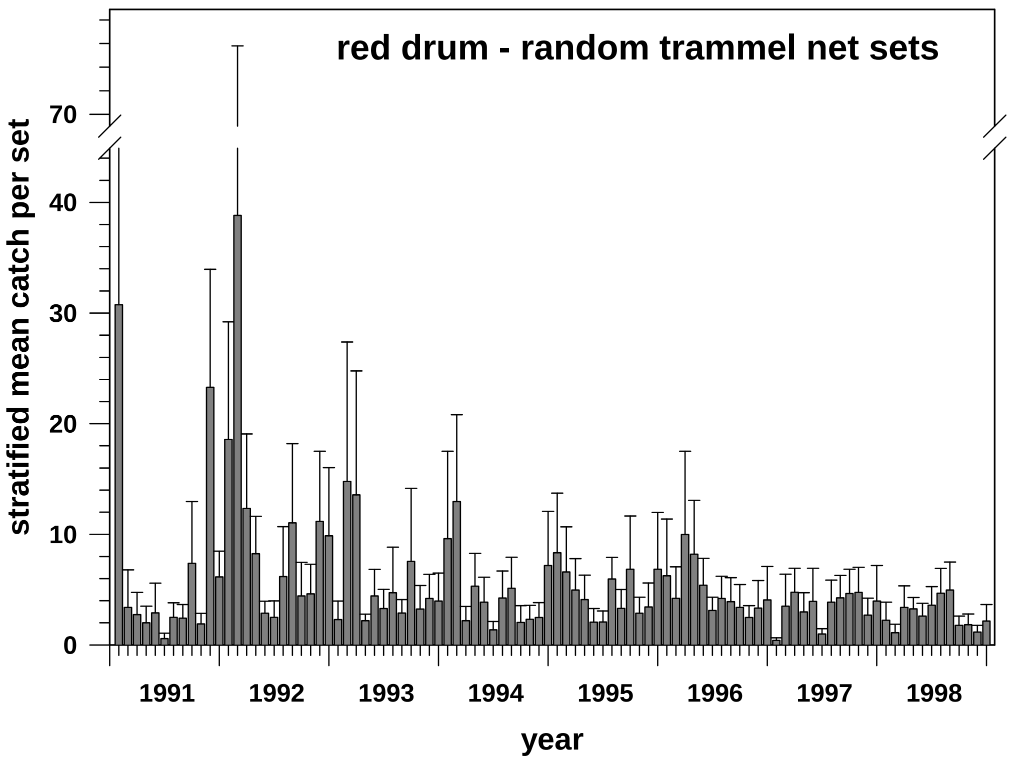
Figure 8. Frequency distribution of the number of red drum caught in stratified random trammel net sets from 1991 through 1998.



trends in the data.

To further examine these data for tendencies, the duration of the study was partitioned into periods based of the recruitment of the youngest cohort of red drum to the gear. Monthly length frequency distributions indicated that a cohort was first recruited to the trammel net in July (Figure 11). In essence, the 1999 yearclass will have moved from the nursery habitat and/or grown to a size that will be retained by the gear in July of 2000. The stratified mean catch per set for the periods from 1 July to 30 June of the following year showed a decline during the study (Figure 12). The stratified mean was significantly and negatively correlated with time ($r = -0.884$, $df = 6$, $p>0.01$) and had lowest values in recent periods. The stratified mean catch per set is an index of relative abundance of subadult red drum in coastal South Carolina, and the steady decline of its magnitude provides strong evidence that red drum are declining in abundance (Figure 11).

Figure 9. Monthly values of the stratified mean catch per set; error bars = one standard error of the mean.



To further investigate this trend, monthly length frequency data for each period were converted into monthly age frequency data and summed for that interval. The percentage of the catch represented by a specific cohort was multiplied by the stratified mean catch/set for that period. This provided an estimate of the contribution of an age group to the stratified mean (Table 6).

Figure 10. Length frequency distribution of red drum taken by random trammel net sets by month.

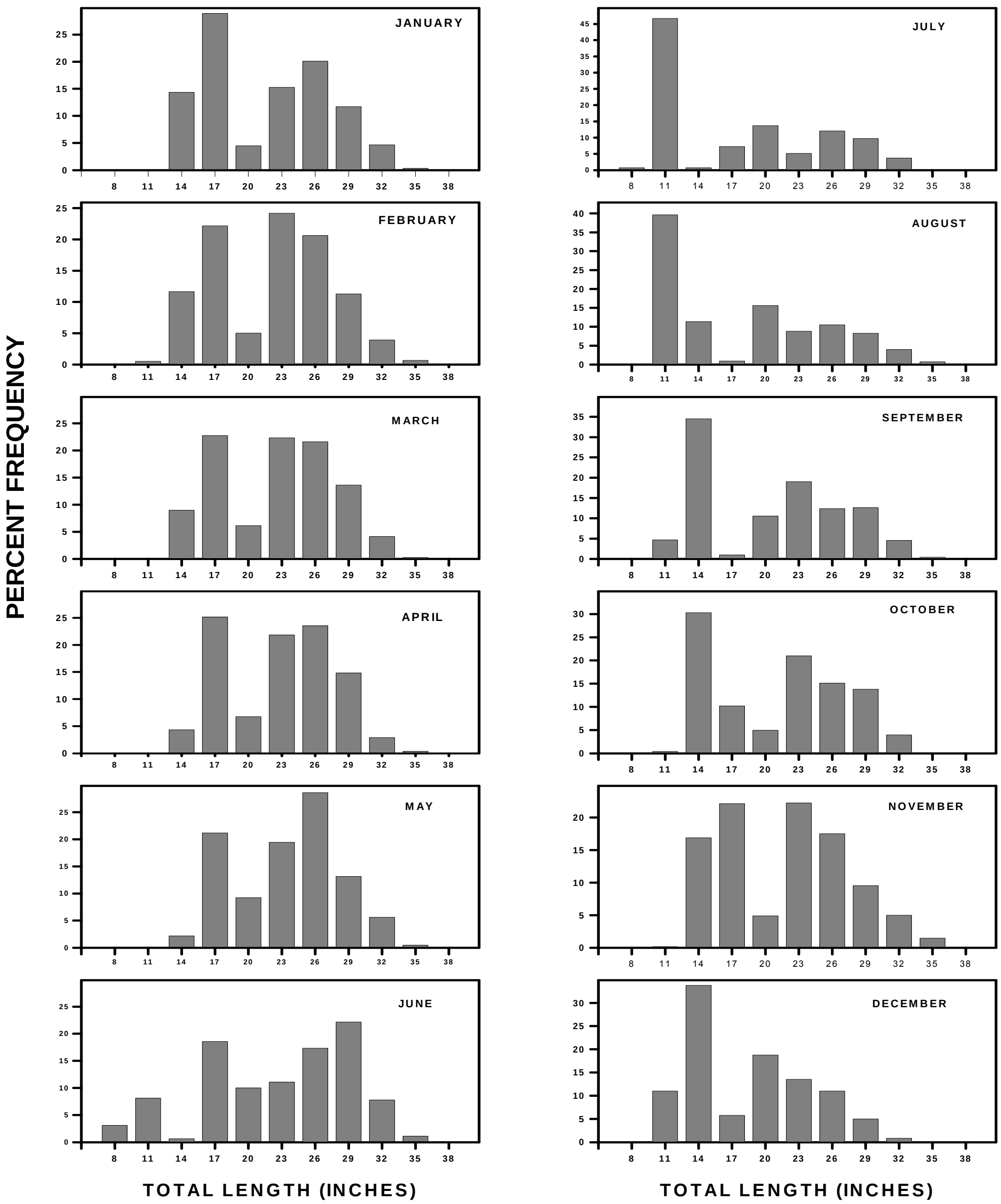
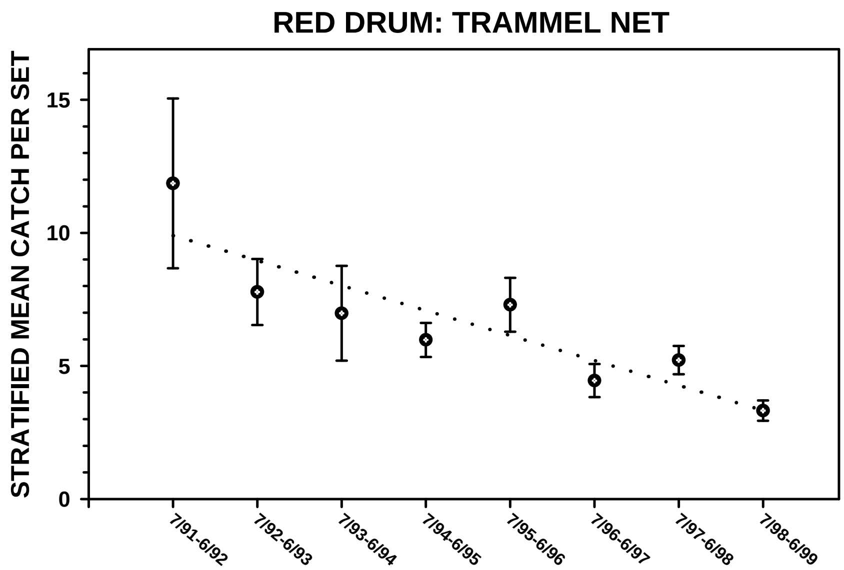


Table 6. Catches of red drum assigned to yearclasses in random trammel sets made from mid-ebb to low tide. Sampling interval was the 12 month period from recruitment to the fishing gear to one year later.

Yearclass	***Sampling Interval***	***Catch***	***Age in Months***
1989	July 1991 – June 1992	4.86	23 – 34
	July 1992 – June 1993	1.18	35 – 46
	July 1993 – June 1994	0.32	47 – 58
	July 1994 – June 1995	0.05	59 – 70
1990	July 1991 – June 1992	6.11	11 – 22
	July 1992 – June 1993	3.04	23 – 34
	July 1993 – June 1994	1.08	35 – 46
	July 1994 – June 1995	0.38	47 – 58
	July 1995 – June 1996	0.10	59 – 70
1991	July 1992 – June 1993	3.31	11 – 22
	July 1993 – June 1994	2.84	23 – 34
	July 1994 – June 1995	1.26	35 – 46
	July 1995 – June 1996	0.27	47 – 58
	July 1996 – June 1997	0.04	59 – 70
	July 1997 – June 1998	0.01	71 – 82
1992	July 1993 – June 1994	2.61	11 – 22
	July 1994 – June 1995	1.94	23 – 34
	July 1995 – June 1996	1.92	35 – 46
	July 1996 – June 1997	0.16	47 – 58
	July 1997 – June 1998	0.06	59 – 70
	July 1998 – June 1999	0.01	71 – 82
1993	July 1994 – June 1995	2.35	11 – 22
	July 1995 – June 1996	1.83	23 – 34
	July 1996 – June 1997	0.87	35 – 46
	July 1997 – June 1998	0.21	47 – 58
	July 1998 – June 1999	0.03	59 – 70
1994	July 1995 – June 1996	3.19	11 – 22
	July 1996 – June 1997	2.08	23 – 34
	July 1997 – June 1998	1.42	35 – 46
	July 1998 – June 1999	0.24	47 – 58
1995	July 1996 – June 1997	1.30	11 – 22
	July 1997 – June 1998	1.25	23 – 34
	July 1998 – June 1999	0.68	35 – 46
1996	July 1997 – June 1998	2.25	11 – 22
	July 1998 – June 1999	1.14	23 – 34

Figure 11. Stratified mean catch per trammel net set for all ages of red drum; error bars = +/- one standard error of the mean. Dotted line shows trend. Each twelve month period extends from 1 July to 30 June of the following year.



With the exception of the period from July 1995 through June 1996, the recruitment of age one fish to the trammel net has declined (Figure 12 and Table 6). The modest increase in the catch of age one red drum during this period was caused by the 1994 yearclass. This cohort was also abundant in the catches in the July 1996 – June 1997 as two-year-old and three-year-olds in the period from July 1997 – June 1998. All other estimates indicated a declining trend in the abundance of all age groups of subadult red drum.

Estimates of annual mortality of subadult red drum from cohort specific catch curves ranged from a high of 77.7% for the 1989 yearclass to a low of 27.4% for the 1995 yearclass (Table 7). The estimate for this cohort was based on only three data points and the correlation coefficient was not significant at one degree of freedom (r = 0.892). The estimate for the 1996 yearclass was calculated from two observations. With additional data points, these estimates will change. It should be pointed out, that these estimates are biased in that the loss of individuals from the various cohorts due to sexual maturity and movement to the spawning stock are not accounted for in the analysis.

Figure 12. Contribution of age-one red drum to the stratified mean catch per set; dotted line indicates trend; r is significant at the 95% level.

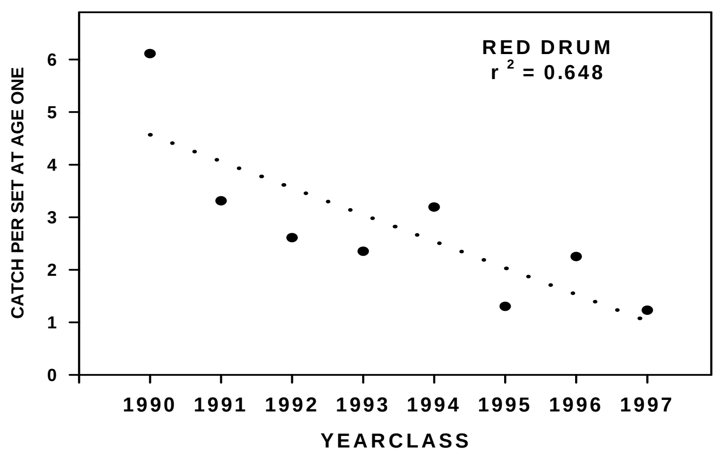


Table 7. Cohort specific estimates of the instantaneous rate of total mortality (Z), annual mortality (A) and the annual rate of survival (S). Data derived from the contributions of the yearclasses to the stratified mean catch per set for the period.

YEARCLASS	***Z***	***A***	***S***	***r^2***	***n***
1989	1.50	0.78	0.22	0.994	4
1990	1.03	0.64	0.36	0.989	5
1991	1.24	0.71	0.29	0.943	6
1992	1.16	0.69	0.31	0.906	6
1993	1.09	0.66	0.34	0.909	5
1994	0.81	0.56	0.45	0.856	4
1995	0.32	0.27	0.76	0.795	3
1996	0.68	0.49	0.51	-	2
1989-1994	**1.20**	**0.70**	**0.30**	**-**	**-**
1989-1996	**0.98**	**0.63**	**0.38**	**-**	**-**

A second approach to estimate subadult mortality was used. The basic premise was that the annual rate of disappearance of red drum from the estuarine population results from natural mortality, fishing mortality and escapement to the spawning population found in coastal and nearshore oceanic waters. Natural mortality results from predation (pelicans feed on age one fish in the winter; porpoises feed on subadults in winter), disease and environmental factors such as low dissolved oxygen in summer and very cold water temperatures during winter freezes. The sources of fishing mortality are “catch and keep” as well as handling mortality from “catch and release” fishing. Escapement can result from sexual maturity and the subsequent movement of these fish from the estuarine habitat as well as movement of subadults from the sampling areas to other estuaries along the coast. Natural mortality can be estimated indirectly by the use of one of several models available. Vaughan and Carmichael (2000) used the method of Boudreax and Dickey (1989) to calculate a mean value for red drum ages 1 through 5 (M = 0.23). We have not had a freeze in coastal South Carolina since Christmas 1989 and there are no data available on the number of red drum that succumb to low dissolved oxygen during warm water fish kills. Approximately 4% of marked subadult fish were captured outside the sampling area over the past 10 years. The percentage was so small that the movement of the subadults was not a serious source of bias in the disappearance of fish. Also, there probably was some movement of subadults into the sampling areas which would balance the losses.

Based on the examination of South Carolina red drum, less than 0.5% of the females and 3% of the males were sexually mature by age 3. Therefore, the survival, annual mortality and instantaneous mortality (Z) could be estimated for fish age 1 through 3 in the various yearclasses since escapement due to sexual maturity did not contribute significantly to the disappearance of subadults.

These estimates were obtained using the following relationships (Ricker 1975):

(a) for those yearclasses with only two age groups represented, i.e., ages 1 & 2 or age 2 & 3:

$$Z = -(\ln[n_{t+1}] - \ln[n_t])$$

(b) for those yearclasses with three age groups represented, i.e., ages 1, 2 & 3:

$$S = \{(n_{t+1}) + (n_{t+2})\} / \{(n_t) + \{(n_{t+1}) + (n_{t+2})\}$$

where Z = instantaneous rate of total mortality

S = annual survival

n_t = stratified mean number of red drum per set at age t.

Estimates of Z ranged from a low in 1992 (Z = 0.52) to a high of 1.42 in 1989 (Table 8) and averaged 0.738 for the eight yearclasses examined. Annual mortality rate for the 1989 cohort was estimated at 77.58%. Values of M for red drum (subadults = 0.23; adults = 0.21) resulted in an annual loss of 18.94 to 20.55% from natural causes.

Table 8. Estimates of the instantaneous rate of total mortality (Z), annual mortality (A) and survival (S) for various yearclasses of subadult red drum; fish aged 1, 2 or 3 included in the calculations.

Yearclass	***Z***	***A (%)***	***S (%)***
1989	1.42	77.58	22.42
1990	0.91	59.73	40.27
1991	0.59	44.67	55.33
1992	0.52	40.34	59.66
1993	0.625	46.53	53.47
1994	0.635	47.68	52.32
1995	0.525	40.25	59.75
1996	0.679	49.34	50.66

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CHAPTER 1{B}

ESTIMATES OF THE EFFICIENCY OF TRAMMEL NETS IN THE COLLECTION OF ESTUARINE FISHES WITH EMPHASIS ON RED DRUM

BY

CHARLES A. WENNER

INTRODUCTION

A major question facing any biologist who samples the nektonic community is the effectiveness of the gear used to collect the various taxa. Is the gear size selective? What is the relationship of the catch of the gear to what is present? Does the catch adequately portray the population? In several of the modern methods to assess fish populations, fishery independent surveys are utilized as "tuning" factors in the analysis. These "tuning" indices provide reference points for models such as VPA (virtual population analysis). Fishery independent surveys have become more important since the application of various size and bag limits has changed the characteristics of the catches by the recreational and commercial sectors.

Personnel of the Marine Resources Research Institute of the South Carolina Department of Natural Resources have been conducting a trammel net survey of estuarine waters since 1991. The survey is based on a stratified random sampling design, with various estuaries as strata. The purpose of this work is to generate fisheries independent indices of abundance of species of importance. These species may be of importance either to the recreational fishing community of South Carolina or the recreational and/or commercial sector in other states in the region. Although the principal target species for this work is the red drum, *Sciaenops ocellatus*, data are collected on other species such as spotted seatrout, southern flounder, spot, black drum, striped mullet and others.

In an attempt to obtain information on the sampling characteristics of the trammel net, we conducted the following study in South Carolina's estuarine habitat.

MATERIALS AND METHODS

Sites for efficiency samples were randomly selected from the pool of potential sampling locations from May 1996 through late 1999. Thirty-eight samples were included in the analysis. These were distributed throughout the year with each month having at least two observations. At each sampling location, a 183-m long, 2.4-m deep trammel net was set in an arc during ebb tide along the shoreline from a rapidly moving (~15-knots) boat. The trammel net sealed off an area approximately 15-m from shore and 150-m long. The outer walls of the net were 14-in (35.6-cm) stretch mesh monofilament and the inner wall was 2.5-in (6.4-cm) stretch mesh. After the trammel net was set, it was surrounded by a 2.4-m deep, 192-m long net constructed of the same mesh size as the inner wall of the survey net (2.5-in stretch mesh). After this net, henceforth referred to as the efficiency net, was set in place, the boat re-entered the enclosed site. The water was disturbed as during sampling for our regular survey, the trammel net was hauled and cleared of fishes. The catch was identified to species, counted and measured to the nearest mm total length (TL) or standard length (SL).

The efficiency net remained in place as the water ebbed from the site. At low tide, the fishes retained by the net were gathered from the intertidal area. These were processed in the same fashion as the catch from the trammel net. The efficiency was calculated as the percentage of the total number of fish within the site caught by the trammel net. The sizes of the different species of fishes retained by both nets were compared by analysis of variance.

EFFICIENCY RESULTS

Thirty-eight test sets were made from May 1996 through late 1999 to estimate the sampling effectiveness of trammel net strikes. These caught 2,680 fishes representing 35 species. Spotted seatrout, spot, black drum, red drum, striped mullet, southern flounder were numerous, and frequently occurring enough to elucidate gear effectiveness. The species caught by the gears are in Table 1.

Overall, random trammel net sets captured 853 of the 2,680 fishes present within the sites (31.83%). Individuals captured by the sampling gear were related to the total catch by the equation:

$$\text{Total catch} = 10.2 + 4.6((\text{trammel catch})^{1/2} (\log_e \text{trammel catch}))$$

The model accounted for 61.6% of the variability in the total catches of fishes (Figure 1). For the abundant taxa, efficiencies ranged from a high of 54.25% for spot to a low of 15.65% for black drum.

RED DRUM

The tests indicated that the sampling caught 30.48% of the red drum within a site. If our last observation, which had eight red drum in the trammel net and 47 in the efficiency net, was excluded from the analysis, the overall effectiveness increased to 52.86% for this species (Figure 2). Analysis of variance found no significant difference in the mean total lengths of red drum in the trammel and efficiency nets ($F = 2.443$, $df = 1, 264$; Table 2). This suggests that although the trammel net fails to catch all the red drum in a site, there is no size selectivity in the red drum taken by the trammel net (Figure 3). The size and age composition of red drum caught by the standardized survey reflects that of the population of subadults in the estuary, but the gear underestimates the absolute abundance by 50 to 70%. Note that these data apply only to those red drum that are large enough to be retained by the 2.5-inch stretch mesh nets.

Table 1. Estimates of the efficiency of trammel net sets by species; Trammel Net = number in regular sampling set; Efficiency Net = number in outside block net after trammel net was pulled.

Species		Trammel Net	***Efficiency Net***	***Percent***
Carcharhinus plumbeus	sandbar shark	0	2	**00.00**
Rhizoprionodon terraenovae	Atlantic sharpnose shark	0	1	**00.00**
Dasyatis sabina	Atlantic stingray	6	16	**37.50**
Dasyatis sayi	bluntnose stingray	0	1	**00.00**
Lepisosteus osseus	longnose gar	5	3	**62.50**
Elops saurus	ladyfish	2	5	**28.57**
Alosa sapidissima	American shad	0	1	**00.00**
Brevoortia tyrannus	Atlantic menhaden	1	26	**03.70**
Dorosoma cepedianum	gizzard shad	1	1	**50.00**
Ariopsis felis	hardhead catfish	1	2	**33.33**
Pomatomus saltatrix	bluefish	4	5	**44.44**
Caranx hippos	crevalle jack	3	2	**60.00**
Chloroscombrus chrysurus	Atlantic bumper	0	1	**00.00**
Selene vomer	lookdown	0	3	**00.00**
Trachinotus carolinus	Florida pompano	1	0	**100.00**
Trachinotus falcatus	permit	0	1	**00.00**
Lobotes surinamensis	tripletail	0	1	**00.00**
Archosargus probatocephalus	sheepshead	7	9	**43.75**
Lagodon rhomboides	pinfish	17	79	**21.52**
Bairdiella chrysoura	silver perch	4	1	**80.00**
Cynoscion nebulosus	spotted seatrout	172	158	**52.12**
Leiostomus xanthurus	spot	185	156	**54.25**
Menticirrhus americanus	southern kingfish	1	0	**100.00**
Micropogonias undulatus	Atlantic croaker	14	1	**93.33**
Pogonias cromis	black drum	23	124	**15.65**
Sciaenops ocellatus	red drum	82	187	**30.48**
Chaetodipterus faber	spadefish	1	0	**100.00**
Mugil cephalus	striped mullet	200	640	**23.81**
Mugil curema	white mullet	12	3	**80.00**
Peprilus alepidotus	harvestfish	1	2	**33.33**
Paralichthys albigutta	gulf flounder	0	12	**00.00**
Paralichthys dentatus	summer flounder	1	7	**12.50**
Paralichthys lethostigma	southern flounder	72	318	**18.46**
Sphoeroides maculatus	northern puffer	9	11	**45.00**
Chilomycterus schoepfi	striped burrfish	28	48	**26.84**
TOTAL		**853**	**1827**	**31.83**

Figure 1. Relationship of the total catch of fishes (TotC) with the number taken by the trammel net (TC) in thirty-eight sets.

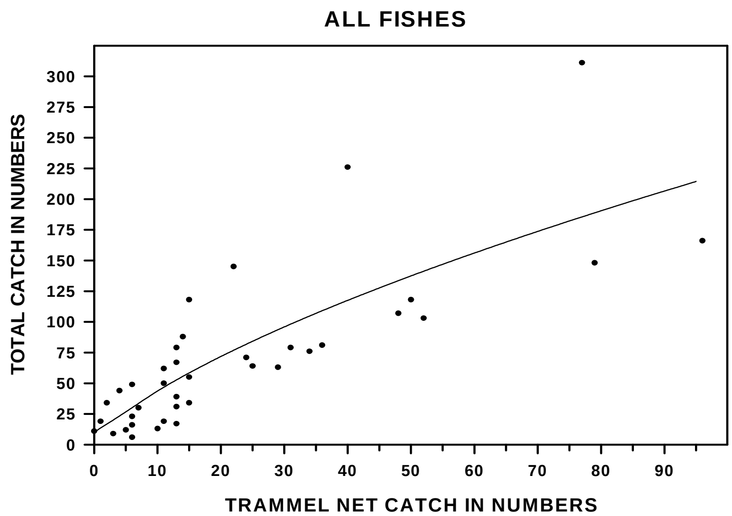


Figure 2. Scatterplot of the number of red drum in the trammel net and the total number of red drum in the site.

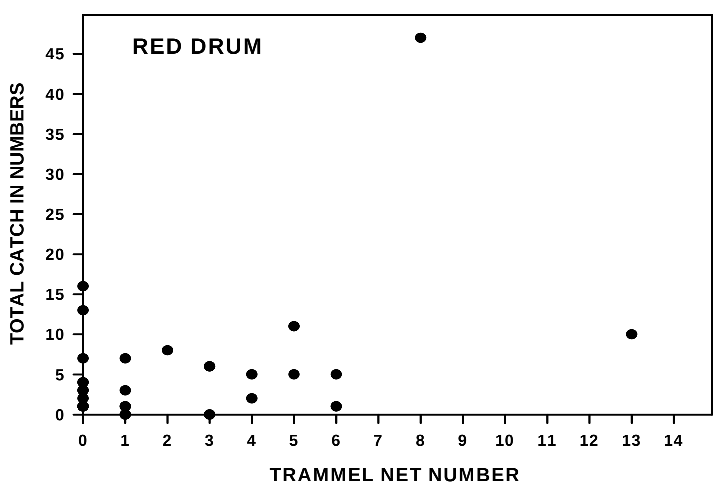
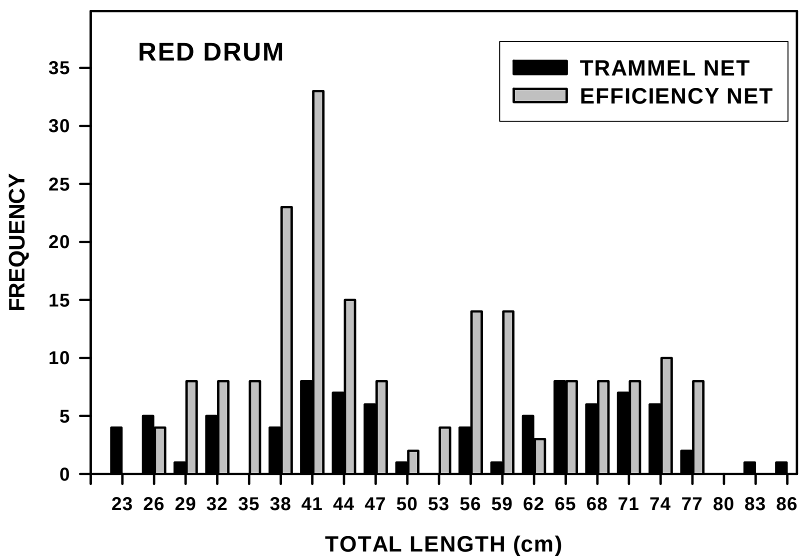


Table 2. Total length statistics for red drum captured during the efficiency study; units are mm. CL = confidence limits.

Net Type	*Number of Fish*	*Mean*	*95% CL*		*Range*
			Lower	*Upper*	
Trammel	81	531	493	569	228 – 868
Efficiency	185	499	478	520	252 - 785

Figure 3.Total length frequency distribution of red drum in the trammel net and the efficiency net in 3-cm intervals.



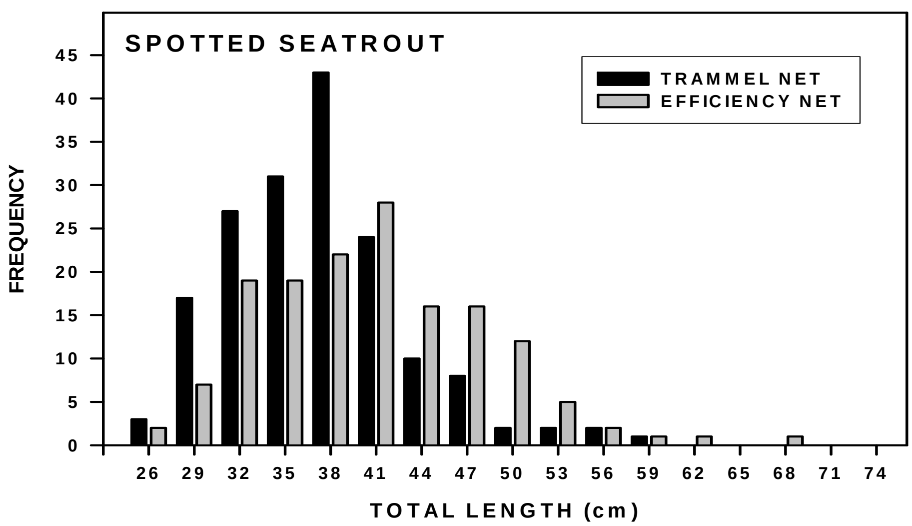
SPOTTED SEATROUT

The 38 sets caught 350-spotted seatrout. The trammel net had 172 individuals for an overall efficiency of 52.12%, i.e.; the survey gear on average took 52+% of the spotted seatrout at each site. Spotted seatrout ranged from 257-mm TL to 598-mm TL in the trammel net and 262 to 673-mm TL in the efficiency net. Analysis of variance found spotted seatrout were significantly larger in the efficiency net than in the trammel net (F = 21.875, df = 1, 319) (Table E-3). Length frequency distributions indicated that the trammel net caught more spotted seatrout less than 38-cm TL than the efficiency net (Figure 4). The cumulative frequency distributions of fishes taken by the two gears more readily demonstrated the differences in size composition between the two gear types (Figure 5). Trammel net sets caught more small fishes than the efficiency net,

Table 3. Total length statistics for spotted seatrout captured during the efficiency study; units are mm. CL = confidence limits.

Net Type	***Number of Fish***	***Mean***	***95% CL***		***Range***
			Lower	*Upper*	
Trammel	170	376	367	385	257 – 598
Efficiency	151	411	399	423	262 – 673

Figure 4. Length frequency distributions of spotted seatrout caught by the trammel and efficiency nets in 3-cm intervals.



whereas the efficiency net had more large fishes than the trammel net. The impacts of these findings on the size and age composition of spotted seatrout in South Carolina's estuaries will be more fully evaluated in the future. After excluding the zero catches from the analysis, i.e., those sets that had no spotted seatrout in either net type, the total number of spotted seatrout in the site was related to the number in the trammel net by the linear model:

$$\text{Total Catch} = 1.89(\text{Trammel Catch}) + 4.79$$

The model explained over 90% of the variability of total catch ($r^2 = 0.92$, $n = 24$) (Figure E-6).

Figure 5. Cumulative length frequency distributions of spotted seatrout taken in trammel and efficiency net sets.

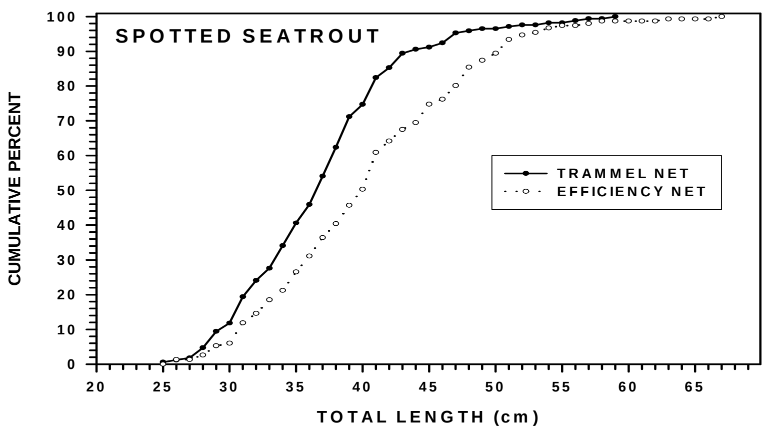
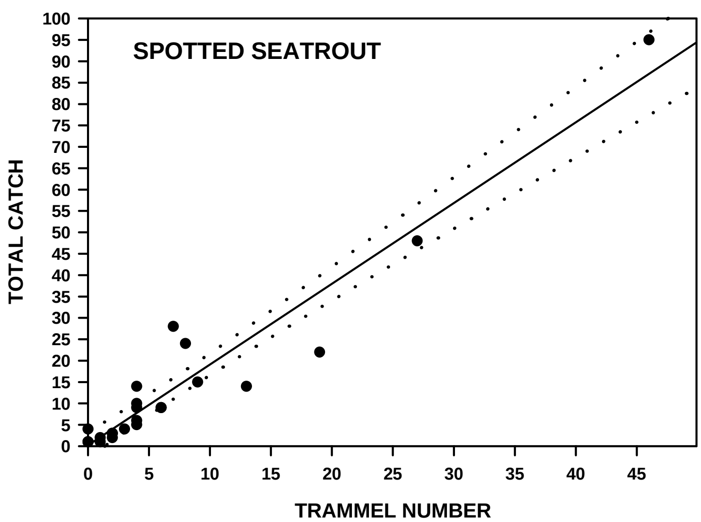


Figure 6. Relationship of the number of spotted seatrout taken in trammel net sets to the total catch in numbers; dotted lines are the 95% confidence limits about the line. Sets that caught no spotted seatrout in either the trammel net or the efficiency net are excluded from the analysis.



SOUTHERN FLOUNDER

The trammel nets used during the survey were quite inefficient in collecting southern flounder. Only 18.5% of the total catch of this species was taken in the standard sets (see Table 1). The total catches were related to the trammel net catches by the linear model:

$$\text{Total Catch} = 1.85(\text{Trammel Catch}) + 4.79$$

The relationship explained 66.5% of the variability in total catch ($r^2 = 0.665$, $n = 31$) (Figure 7). Analysis of variance found no significant difference in mean size of southern flounder caught in the two net types ($F = 1.306$, $df = 1, 387$) (Table E-4). Length frequency distributions for both nets were approximately normal with modal sizes at 31-cm TL (Figure 8).

Figure 7. Relationship of the number of southern flounder in trammel net sets to the total catch; dotted lines are the 95% confidence limits about the line. Sets with no southern flounder in either of the nets were excluded from the analysis

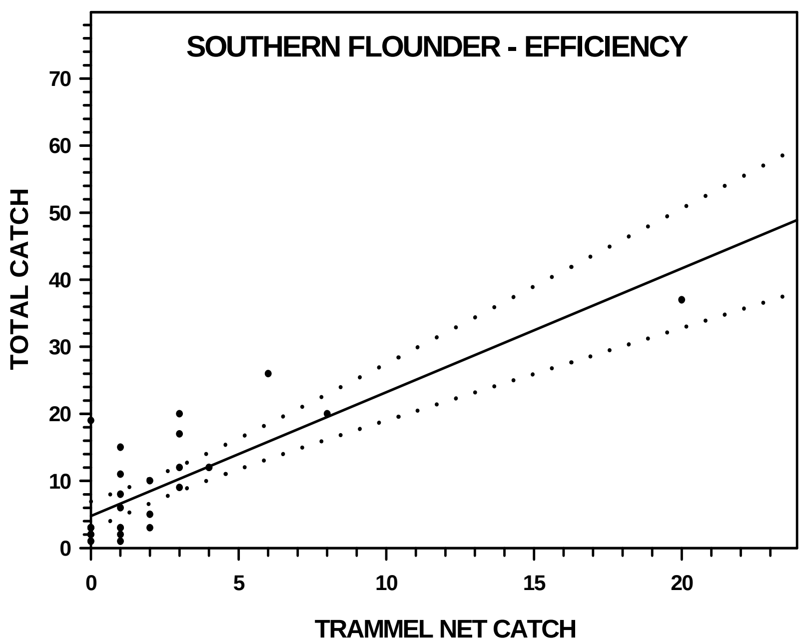
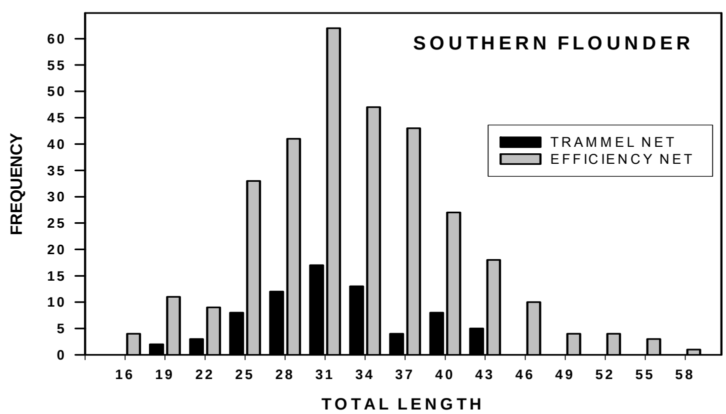


Table 5. Total length statistics for southern flounder captured during the efficiency study; units are mm. CL = confidence limits.

Net Type	***Number of Fish***	***Mean***	***95% CL***		***Range***
			Lower	*Upper*	
Trammel	72	324	310	338	199 – 448
Efficiency	317	335	326	343	154 – 590

Figure 8. Length frequency distributions of southern flounder caught by the trammel and efficiency nets in 3-cm intervals.



STRIPED MULLET

Among the most abundant species, the trammel net was also very inefficient in catching striped mullet. Survey gear collected only 23.8% of the individuals in a sampling site. The catch of this species in the trammel net was related to the total number of striped mullet in the site by the equation:

$$\log_e(\text{Total Catch} + 1) = 0.7048(\log_e(\text{trammel catch} + 1)) + 1.8287$$

The model accounted for 58.1% of the variability between the transformed number of striped mullet in the trammel net and the transformed values of the actual abundance of the species in the site (Figure 9).

The trammel net caught striped mullet from 18 to 32-cm standard length (SL), whereas the efficiency net caught fish as large as 36-cm SL (Table 4). Analysis of variance found a significant difference in mean SL of striped mullet between those captured by the trammel and efficiency net ($F = 12.082$, df = 1 , 837). The difference between the two means was 7-mm SL, which was probably not biologically significant. This was supported by the shape of the length frequency distributions for fishes taken by the different nets. The two distributions had the same shape with modes at 27-cm SL (Figure 10).

Figure 9. Relationship of the ln(number + 1) values for striped mullet taken in trammel net sets to the total catch; dotted lines are the 95% confidence limits about the line. Sets with no striped mullet in either of the nets were excluded from the analysis

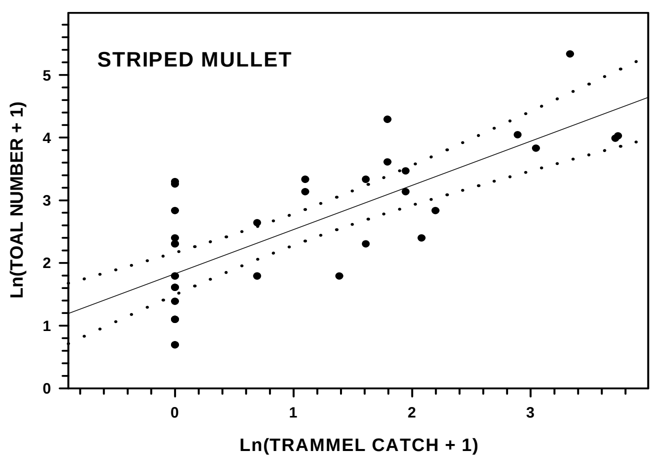
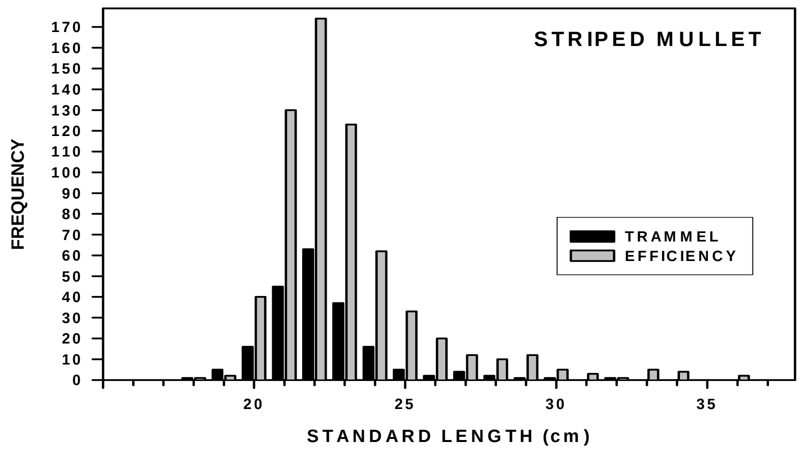


Table 5. Standard length statistics for striped mullet captured during the efficiency study; units are mm. CL = confidence limits.

Net Type	***Number of Fish***	***Mean***	***95% CL***		***Range***
			Lower	*Upper*	
Trammel	199	227	224	230	187 – 332
Efficiency	639	234	232	236	189 – 364

Figure 10 . Standard length frequency distributions of striped mullet caught by the trammel and efficiency nets in 1-cm intervals.



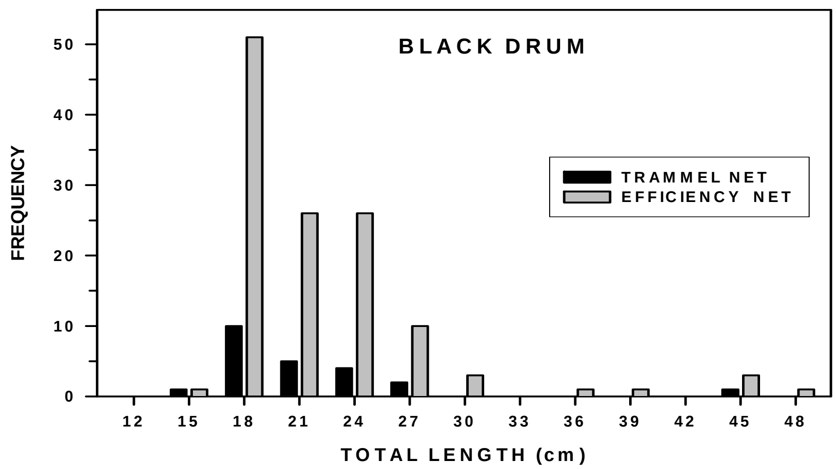
BLACK DRUM

Black drum were sampled by the trammel net at the lowest efficiency rate of any fish species caught in some reasonable numbers (15.6%). This species occurred in six of the thirty-eight test sets and in fourteen of the efficiency sets. Analysis of variance found no significant difference in the mean size of black drum caught in the two nets (F = 0.179, df = 1, 144). Length statistics for black drum are in Table 6. Most of the black drum were young-of-year fish with a modal size of ~ 18-cm TL (Figure 11).

Table 6. Total length statistics for black drum captured during the efficiency study; units are mm. CL = confidence limits.

Net Type	***Number of Fish***	***Mean***	***95% CL***		***Range***
			Lower	*Upper*	
Trammel	23	219	194	243	160 – 440
Efficiency	123	224	214	235	163 – 485

Figure 11 . Total length frequency distributions of black drum caught by the trammel and efficiency nets in 3-cm intervals.



SPOT

Spot were caught by the trammel net at a 54.25% efficiency rate. The catches in the survey gear were related to the total catch by the linear model:

$$\text{Total Catch} = 1.81(\text{Trammel Catch}) + 0.23$$

The models accounted for 92.8% of the variability in the total catch (r^2 = 0.928, n = 24) (Figure 12). Analysis of variance found no significant differences in mean size of spot in the trammel and efficiency net (Table 7) (F= 3.151; df = 1, 339). Frequency distribution of fishes in both nets had a modal size of 17-cm SL (Figure 13).

Figure 12. Relationship of the number of spot taken in trammel net sets to the total catch; dotted lines are the 95% confidence limits about the line. Sets with no spot in either of the nets were excluded from the analysis

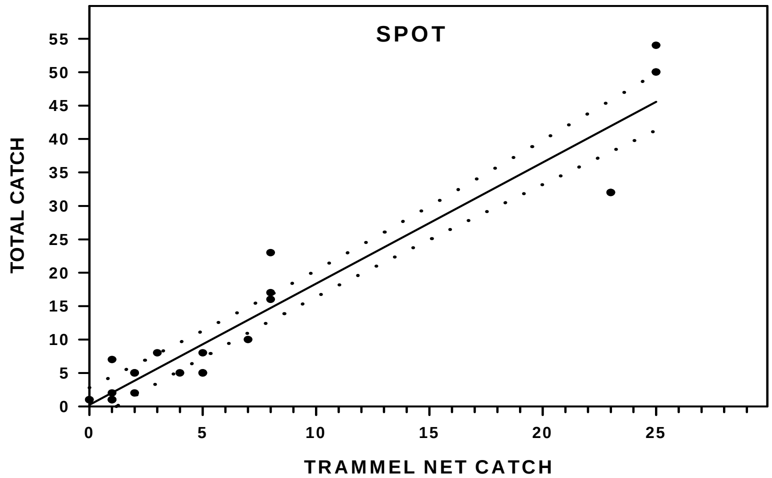


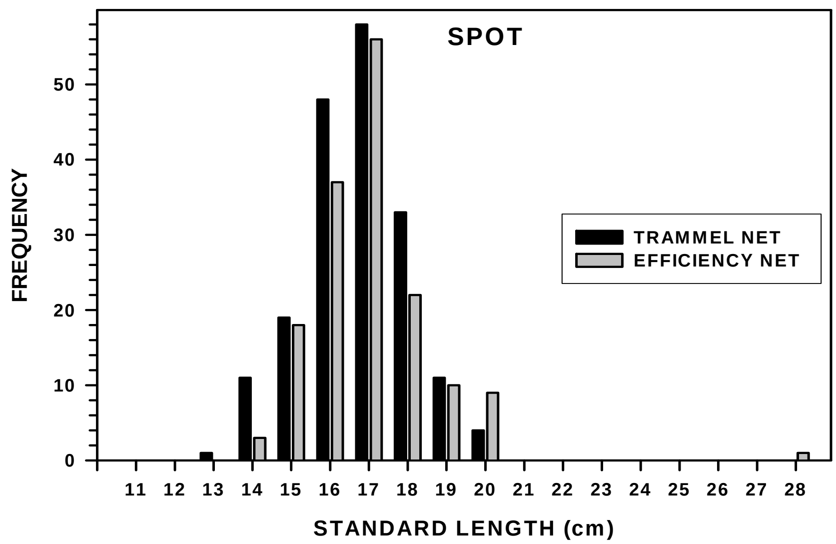
Table 7. Standard length statistics for spot captured during the efficiency study; units are mm. CL = confidence limits.

Net Type	***Number of Fish***	***Mean***	***95% CL***		***Range***
			Lower	*Upper*	
Trammel	185	171	169	173	139 – 204
Efficiency	156	174	171	176	144 – 282

DISCUSSION

The data indicated that the efficiency of the trammel net varied according to the species. Among the more widely occurring and abundant fish taxa, efficiencies of ~ 50% were seen for spotted seatrout and spot. Slightly more than 30% of the red drum were taken by the survey gear, whereas the trammel net caught only 21.7% of the three species of bothid flounders (Table 1). Trammel nets were also inefficient in collecting striped mullet (23.81%) and black drum (15.65%).

Figure 13 . Standard length frequency distributions of spot caught by the trammel and efficiency nets in 1-cm intervals.



Bothid flounders when disturbed on the bottom, dart short distances away from the source of the problem, fall to the bottom, and move their fins to throw substrate over their bodies. In addition, the chromatophores in their integument concentrate or disperse pigment so that the fish blends in with the color of the substrate. If disturbed by the sampling activities within a site, their behavior would explain the low efficiencies observed for this group. Dasyatid stingrays also tend to stay in small depressions in the substrate that they create by flapping their wings.

Size avoidance of the sampling gear was only seen in the spotted seatrout where the efficiency net caught significantly larger individuals than the standard sampling net. We are planning to conduct additional trials to obtain ages of this taxon in both gears to determine the impacts of size differences on our estimates of the age composition of this species in South Carolina's estuaries.

CHAPTER 2

MAINTENANCE OF A MARK-RECAPTURE DATA BASE FOR RED DRUM AND OTHER ESTUARINE SPECIES TAGGED IN SOUTH CAROLINA

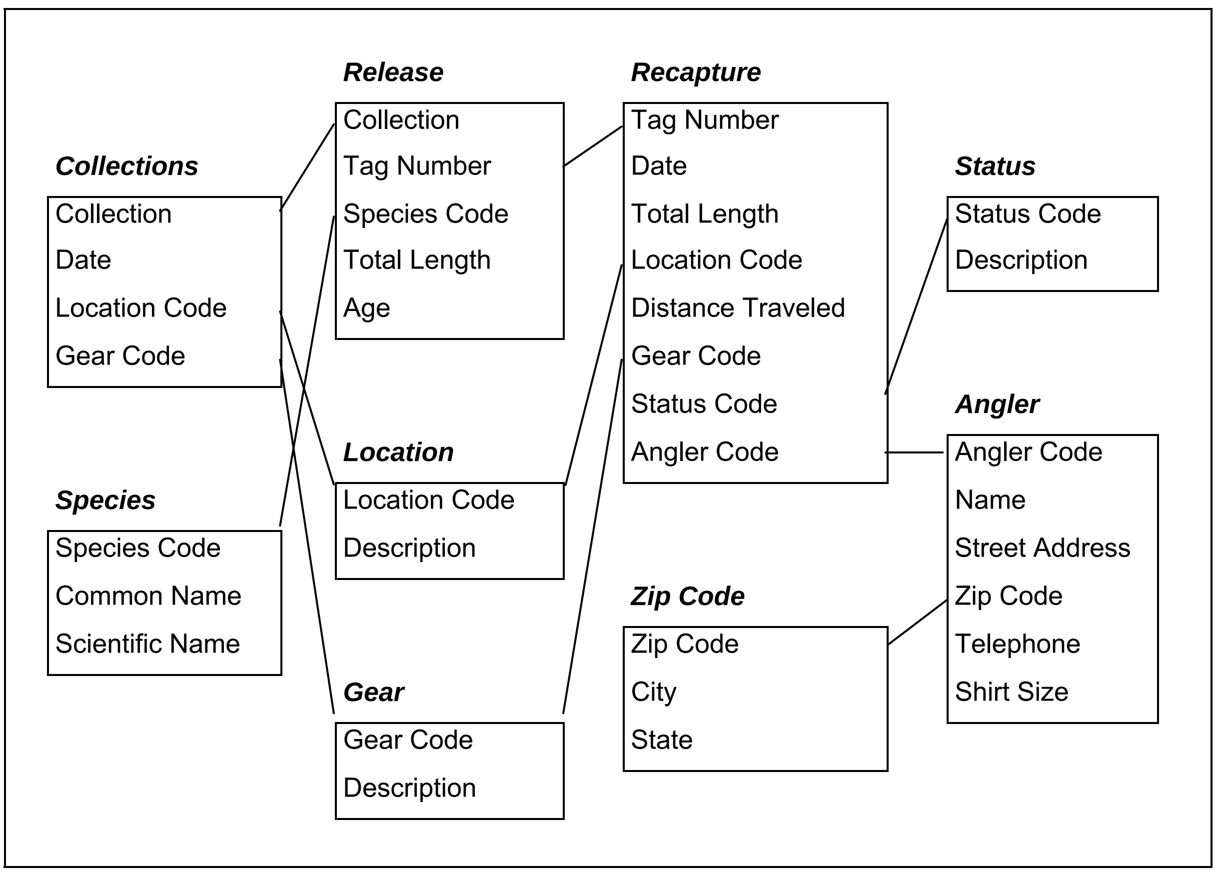
BY

JOHN ARCHAMBAULT

TAGGED FISH DATA BASE

Data on all fish tagged by the Inshore Fisheries Research Section is maintained in a devoted relational database (Figure 1). The core of the database consists of three tables: a collections table, a release table, and a recapture table.

Figure 1. A schematic diagram of the tagged fish relational database. Each box represents a table, with the table name in Italics and the included variables listed within the box. Relationships (or "links") between tables are indicated by lines connecting common variables.



The collections table contains records on gear deployments from which fish were tagged, *ie*. units of tagging effort. Associated with each unique collection entry are fields for date, location (in coded form), and the type of gear used (in coded form). The collection field relates each record in the collections table to the records, on fish tagged from that gear deployment, in the release table.

The release table contains one record for each tagged fish. In addition to the collection field, each record contains fields for tag number (which uniquely identifies that specimen), species code, total length, and age.

The third principal table contains records on recaptures of tagged fish. All recaptures made by the public as well as those made by the project in the course of sampling are recorded in this table. The recapture table includes fields for tag number (which links to the specimen's release data), total length, date of recapture, location (in coded form), minimum distance traveled from release location, gear (in coded form), status (in coded form: whether the fish was retained, released with the tag intact, or released without the tag), and angler (in coded form). Each record is uniquely identified by tag number and date entries.

The remainder of the database consists of six additional tables: an angler information table and five simple "look-up" tables, which relate to codes in other tables. The angler table includes the angler identification code, name, address, telephone number, and preferred T-shirt size fields. Other tables include species (with species code, common name and scientific name), location (with location code and location description), gear (which includes gear codes and descriptions), status (with status codes and descriptions), and zip code (with zip code, city and state).

Figure 2. An example of an angler report on a recapture of a tagged red drum. Reports are forwarded to all reporting anglers.

Fisheries Research Section **Angler Report**

23-Mar-00

Release Data

Tag Number: 41923 **LENGTH_MM:** 539

Release Date: 14-Sep-93 **LENGTH (IN):** 212

Release Location: **AGE:** 2

CHAS HARBOR @ FT. JOHNSON **SPECIES:** RED DRUM

Capture Data

DATE	LENGTH (IN)	Days At Large	DISTANCE	ANGLER
11-Nov-93	21.5	58	0	PROJECT RECAPTURE
11-Jan-94	21.9	119	0	PROJECT RECAPTURE
17-Jan-94	21.8	125	0	PROJECT RECAPTURE
08-Feb-94	21.7	147	0	PROJECT RECAPTURE
14-Apr-94	22.0	212	0	PROJECT RECAPTURE
09-May-94	22.5	237	0	PROJECT RECAPTURE
22-Jul-94	24.0	311	0	JENNIFER SCHULTZ

Anglers capturing tagged fish are requested to contact the Department of Natural Resources. Information on the recapture should include the tag number, fish species, total length, date, location, gear used, and the fate of the fish as well as contact information for the angler. Upon receipt of this information, it is entered into the database. A report on the captured specimen is then generated and sent to the angler along with a cover letter (Figure 2). Each angler also receives a T-shirt with a screen-printed design encouraging sportfish conservation. The angler is also entered into a monthly drawing for six cash bonus rewards of $50 (one reward issued), $20 (two issued), or $10 (three issued).

As of March 23, 2000 the database contains information on more than 46,000 fish tagged since 1986 (Table 1).

Table 1. Current status of tagged fish as of March 23, 2000.

Species	***Tagged & Not Recaptured***	***Angler Re-release***	***Project Re-release***	***Angler Kept Fish***	***Project Kept Fish***	***Angler Re-release without Tag***	***Project Re-release without Tag***	***Total Number Tagged***
Black drum	1,199	28	121	197	2	5	0	**1,503**
Crevalle Jack	8	0	0	0	0	0	0	**8**
Red Drum	18,493	1,993	7,446	3,773	173	327	12	**28,524**
Sheepshead	891	7	20	25	1	0	0	**941**
Southern Flounder	4,391	17	692	142	91	2	0	**5,163**
Spotted Seatrout	5,514	47	306	512	77	9	0	**6,363**
Striped Bass	6	0	0	0	0	0	0	**6**
Striped Mullet	3,941	2	25	9	0	3	0	**3,980**
Summer Flounder	21	0	0	0	0	0	0	**21**
Tripletail	60	0	7	9	0	0	0	**75**
Total	**34,524**	**2,094**	**8,617**	**4,667**	**344**	**346**	**12**	**46,314**

CHAPTER 3

SIZE AND AGE AT MATURITY FOR RED DRUM IN SOUTH CAROLINA

BY

WILLIAM ROUMILLAT AND WILLIAM HEGLER

INTRODUCTION

Size and age of first maturity for red drum in the Gulf of Mexico were established by Murphy and Taylor (1990), and Wilson and Nieland (1994). Ross et al. (1995) investigated these dynamics for this species in North Carolina waters, and there is an unpublished account of size, age and maturity for red drum in South Carolina (Wenner et al., 1990). The South Carolina study was based on histological verification of maturity stages, but relatively few mature adults were sampled. Murphy and Taylor (1990) also listed size at maturity for red drum in the Indian River Lagoon system, an area in eastern Florida which harbors a population genetically distinct from either the Gulf of Mexico or Southeastern Atlantic stocks (Gold et al., 1991). All of these studies indicated varying sizes and ages of first maturity for red drum, though each employed slightly different definitions and interpretations of maturity schedules, and each admitted the complicating factors of gear bias.

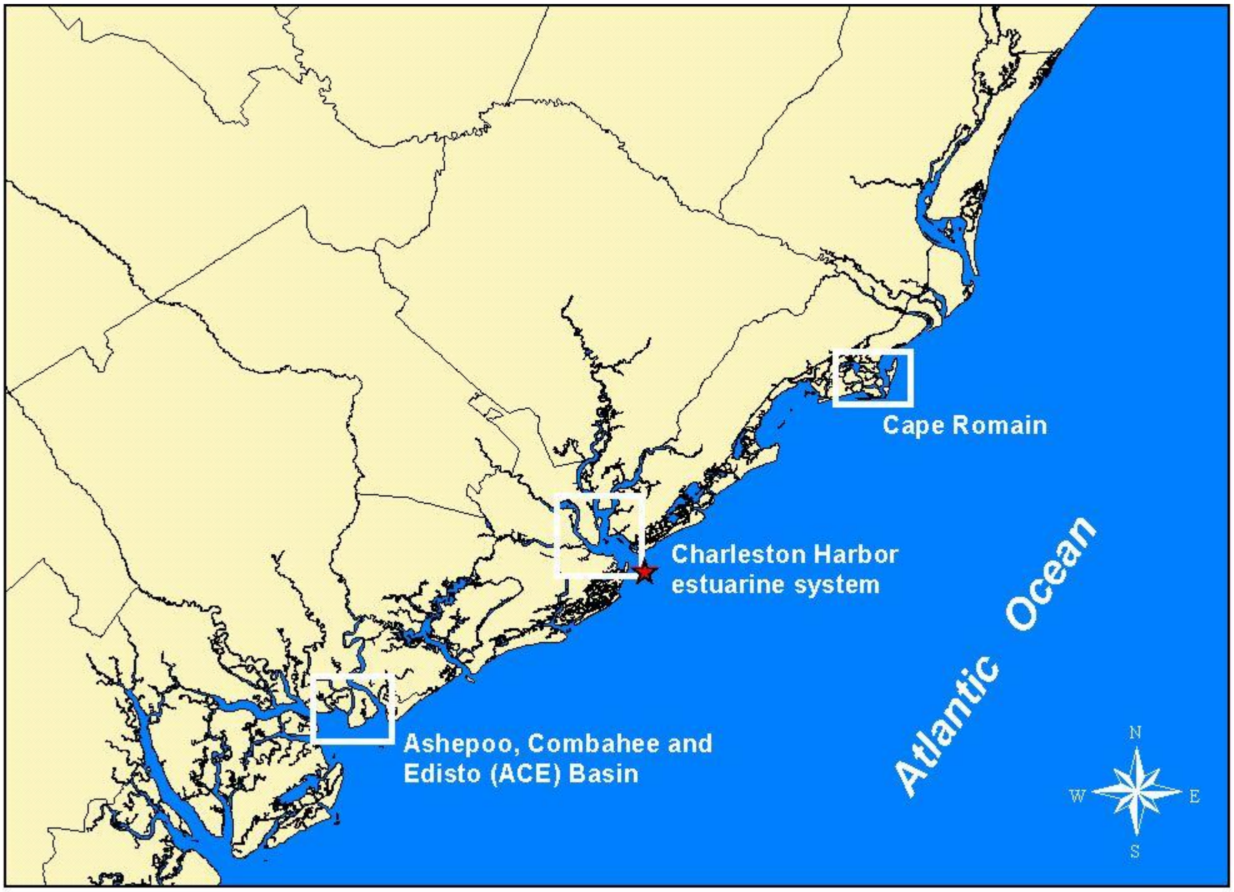
Spawning locations for this species have been documented in the Gulf of Mexico from offshore aggregations in the Eastern and Northern Gulf, and in enclosed groups of fish in the Indian River Lagoon of Florida (Murphy and Taylor, 1990; Wilson and Nieland 1994). Johnson and Funicelli (1991) also documented spawning of red drum in Indian River Lagoon, a mostly enclosed system. In the Atlantic, Ross et al. (1995) stated that spawning took place in North Carolina near the Outer Banks in inlets and passes between the barrier islands. There is presently no published information about spawning locations in South Carolina waters.

This study, using histologically defined reproductive criteria, establishes size and age of first maturities in SC waters. Areas of spawning concentrations in local estuaries are also included here as the preliminary step in establishing the age of spawning red drum in coastal SC.

METHODS AND MATERIALS

Four methods were utilized for the collection of red drum in this study: two designs of trammel nets, fish carcass donations from recreational anglers and short longline gear set during autumn months in nearshore ocean waters. The trammel nets were used as part of an ongoing inshore fish survey of South Carolina estuaries conducted by SCDNR Marine Resources biologists. The survey has been conducted monthly in eight different SC estuaries and river drainages (Figure 1). During the sampling of each estuary, trammel nets of one of two different mesh designs and

Figure 1. South Carolina coast with sampling areas indicated. Trammel nets were employed inthe Cape Romain, Charleston harbor and ACE Basin estuarine systems, outlined by boxes. The near shore sampling area is indicated by the star.



lengths, either 184m or 137m, were deployed in randomly selected sites. The nets, equipped with anchors at each end, were deployed to enclose an area of shallow water against a marsh bank. Fishes were startled into the net by splashing the water and creating noise within the enclosed site. The nets were then immediately hauled and the catch removed. Fishes were placed in an oxygenated holding tank, identified, measured, weighed or tagged, and released. The primary focus on the red drum component of the catch was tagging; therefore, life history information presented in this report was obtained from those fish which died incidentally only. Red drum carcasses were donated from recreational anglers as part of a SCDNR program that rewards anglers for providing biologists with data from fishes that would otherwise be filleted and discarded. Freezers were strategically placed at landings and marinas where carcasses could be easily donated. Cards requesting pertinent capture information were made available at each freezer. Size at age determination from otoliths was the primary objective of this program, but gross examination of sex and maturity information was also made. Histological examination of gonad tissues was not attempted for these specimens because of freezing-induced tissue degradation.

Near shore longline sets were made from September through November of each sampling year. Two sets of heavy monofilament, each with 200 (size 7-0) circle hooks, and baited with cut pieces of spot (*Leiostomus xanthurus*), were made in an area 15 km southeast of Charleston Harbor (Figure 1). Red drum captured were measured, tagged with numbered nylon barb tags (Hallprint LLC*, New South Wales, Australia). Selected specimens less than 900mm TL were sacrificed for age and reproductive determinations.

Histological interpretations of red drum gonads were made from prepared slides. Gonad tissues were removed, placed into plastic tissue cassettes and fixed in 10% seawater buffered formalin for at least 48 hours. The samples were transferred to 50% isopropanol, and processed through paraffin embedding using a Research and Manufacturing Company* Modular Vacuum Processor (MVP-I). The embedded tissues were trimmed to achieve a clean cross section, and embedded in paraffin blocks. Blocks were cut on a manual microtome into 6-micron thick cross sections. Slides were stained with hematoxylin and counter stained with eosin-Y (Humason, 1972) and examined for sex and maturity stages.

Otoliths were excised from specimens returned to the laboratory, and appropriate life history information was recorded. The otoliths were then stored dry in coin envelopes. The left sagittae were always used unless broken, deformed, or otherwise unavailable. A pencil mark was drawn on the otolith over the core to ensure an accurate section prior to being embedded in Epoxide resin. Transverse sections through the otolith core were obtained using an Isomet* low speed saw equipped with two diamond-edged circular blades to create a wafer 0.5 mm thick. These sections were washed in isopropyl alcohol to remove any residual cutting fluid, and glued onto glass microscope slides using a low-viscosity mounting medium. Ages were assigned and measurements made using Optimas* image analysis software and a Nikon SMZ-U dissecting microscope.

The characteristic of red drum to produce spawning sounds created the opportunity to establish multiple survey in discrete estuarine regions of South Carolina (Fig. 2). Stations were sampled

Figure 2. Areas along the coast of South Carolina where spawning activity for red drum was investigated. Red dots indicate locales where listening activities used real-time hydrophone equipment; blue dots show where the remote hydrophone was employed. The yellow dots are in locations where red drum were repeatedly heard, and both real-time and remote hydrophones were used in these areas.

from a 6-meter outboard with an Interocean* hydrophone (model 902). Transects were divided into one-quarter mile sections, resulting in approximately 50-60 stations per river system (Riekerk, 1997). At least fifteen stations were chosen randomly during each event. Transects (two per week) were made during known diurnal periods of red drum sound production (Roumillat and Tyree, in prep.). Additional discrete locations were also examined for red drum spawning activities as indicated in Figure 2.

Three remote ambient sound recording units were used from 1994 through 1998; one constructed by Coastal Technologies* Inc, and two made by the Harbor Branch Oceanographic Institute* (modeled after the first). These devices allowed for continuous analogue and digital recordings to be made of autochthonous red drum spawning sounds for a period of one week between their deployment and retrieval. These devices were placed in discrete locations within estuaries along the SC coast (Fig. 2).

Statistical procedures were accomplished using the Statistical Package for the Social Sciences software (SPSS version 7.5.1).

RESULTS

From 1994 through 1998, 1048 red drum, comprised of 461 females and 587 males, were examined for sex and maturity status. Fish obtained from the freezer fish donation program had gonads that were damaged from the freezing process; therefore, a total of 289 females and 401 males were assigned maturities through use of histological means. Reproductive assessments utilizing gross examinations followed criteria found in Wenner et al. (1990).

Because red drum have a lunate caudal fin morphology at lengths exceeding 450mm, some fishery biologists have indicated the size of this species utilizing a ‘fork length’ measurement. In effort to correct this problem and allow other data to be directly compared to this study, the following length conversions were determined:

$$FL = 0.921\ TL + 17.573 \quad r^2 = 0.999 \qquad N = 3374$$

$$TL = 1.084\ FL - 18.425 \quad r^2 = 0.999 \qquad N= 3374$$

All lengths reported in this study have been adjusted to TL.

Histological assessments

Determination of maturity schedules based on histological interpretations proved to be the most repeatable technique (Wilson and Nieland, 1994). The most difficult assessment of maturity was that of determining whether a young, small fish was immature or resting (Table 1). Through use of the microscopic characters defined in Table 1, an accurate determination of male and female maturities was made. Histological assessments of ovarian development relied on descriptions given by Wallace and Selman (1981), and definitions used for repeat spawning followed Hunter and Macewicz (1985)(Table 1). Male maturity staging was that of Wenner et al. (1990).

Gear

Lengths and ages showed heterogeneity of variance, so a Kruskal-Wallis non-parametric test was performed on these data. Because both types of trammel nets and the hook and line samples were fished inshore, these were segregated as ‘estuarine gears’, and analyzed distinctly from the nearshore longline gear. An assessment of the four major gears used in this work revealed that the two types of trammel nets caught statistically similar sizes of red drum (Table 2). A Scheffe homogeneity subset test for total lengths indicated that sizes of red rum collected using the estuarine gears were not significantly different from one another, but differed ($p<0.05$) from the size of fish obtained nearshore. Hook and line sampling and longline gear caught significantly different ages of red drum compared to the two trammel net gears (Table 2).

Table 1. Histological criteria used to stage maturities of red drum captured from 1994 through 1998 in this study. Definitions of terms follow those defined by Wallace and Selman (1981) and Hunter and Macewicz (1985).

Reproductive Stage	***Male***	***Female***
Immature	Small cross section when compared to resting gonad. Ductwork poorly developed with little branching; no ducts extending to gonad periphery. Little or no spermatogenesis occurring.	Small cross sectional area when compared to resting female. Small similarly sized previtellogenic oocytes throughout ovary. No atretic or other post-spawn residual tissue present. Ovarian wall thinner than in mature female.
Developing	Crypts showing primary and secondary spermatocyte development through spermatozoa-filled ducts. Ductwork more anastmosing resulting from increased branching.	Appearance of cortical alveoli in oocytes (precursor to vitellogenesis) through predominance of oocytes undergoing vitellogenesis. Not yet showing signs of yolk coalescence or maturation.
Ripe	Predominance of spermatozoa fillingbranching ductwork throughout gonad. Active spermatogenesis occurring only near gonad periphery.	Largest oocytes beginning to show yolk globule coalescence and stages of early through late maturation. No evidence of previous spawning activity (postovulatory follicles or oocytic atresia).
Spent	No spermatogenesis occurring. Residual spermatozoa in ductwork.	Atresia affecting all stages of vitellogenic oocytes through little evidence of regressing tissues.
Resting	Larger cross section when compared to immature gonad. Ductworks empty, reaching to gonad periphery. Mitotic regeneration of spermatogonia and interstitial tissues.	Larger in cross section than immature tissue. Previtellogenic oocytes of various diameters occur throughout the ovary. Post-spawning residue in ovary, and gonad wall thicker than that found in immature tissue.
Repeat spawning	Not applicable to males.	Ovary exhibits characteristics of developing stage with postovulatory follicles evident.

Table 2. Relationship of mean lengths and ages for the four gear types comprising specimens used in this study. Trammel net collections were significantly similar in both these values, but significantly distinct from the hook and line and the nearshore longline samples (underscores of values; α = 0.05).

Gear	Standard Trammel	MARFIN Trammel	Hook & Line	Nearshore Longline
Mean TL(mm)	467	474	506	900
Mean Age	1.34	1.40	1.62	6.22

Sex Ratios

The overall sex ratio, using specimens caught with all four gears was 0.80:1 females:males. Our estuarine samples contained 95.0% juveniles, and showed a sex ratio of 0.76:1 (Table 3). The sex ratio in the nearshore sampling effort (96.8% mature) was 1.62:1 in favor of females.

Table 3. Sex ratios resulting from four distinct gear-types used to sample red drum in coastal South Carolina from 1994 through 1998. F = female; M = male; N = sample size. ** = $p < 0.05$ * = $p < 0.1$

Gear Type	F: M	N
All Gears combined	0.80:1**	1010
Standard Trammel Net	0.76:1**	379
Marfin Trammel Net	0.55:1**	90
Hook and Line	0.80:1**	478
Nearshore Longline	1.62:1*	63

Males were not only statistically more abundant in the estuaries than females (Table 3), but were also found to dominate each of the age classes found there. Females dominated the nearshore samples, but the number of individuals was too small and seasonally restricted to make more than cursory sex ratio assessments.

Size and Age at Maturity

Male red drum began maturing at two years, but only 8.1% showed signs of gonad development prior to age 3. Mature males in their third year represented 25.0% of that age class. All males age 4 and greater were mature (Table 4). Males as small as 573 mm TL showed signs of maturity, and immature specimens were found as large as 785 mm TL. Female maturity began at a later age than males (Table 4). Only 3.6% of females three years old showed signs of maturity, 11.1% of 4 year olds were mature, and all females older than 5 were mature adults. The smallest mature female was 691 mm TL, and the largest immature specimen was 840 mm TL.

Because of the wide range of both sizes and ages of initial maturity in red drum, a probit analysis was done for each of these parameters. The size of 50% maturity for females in SC was 792mm, and for males was 713 mm TL (Table 5). The age of 50% maturity for females was 4.3 yr (52 months), while for males was 3.5 yr (43 months; Table 5). Comparisons of size and age data from this study were compared to those of other pertinent works (Table 5). This study contained samples that were primarily juveniles (95%). Murphy and Taylor (1990) and Ross et al. (1995) each reported samples consisting of 32% juveniles, and Wilson and Nieland (1994) showed that 10% of their specimens were immature.

Table 5. Sizes and ages for first maturities and 50% maturities for red from the Southeastern US and the Gulf of Mexico. Lengths are reported in mm TL (converted from other studies using the formula TL = 1.092 FL – 22.568).

Source	***First Maturity***				***P_{50}Maturity***			
	%%		&&		%%		&&	
	TL	Age	TL	Age	TL	Age	TL	Age
Present Study	573	2	691	3	713	3.5	792	4.3
Wilson and Nieland (1994)	578	2	630	3	698	4	731	4
Ross et al (1995)	523	1	742	3	656	2	847	3
Murphy and Taylor (1990)	414	1	633	3	555	2	878	5

Seasonality of Maturities

No developing or spawning females were found in our samples. Mature females (Table 6) were represented by spent or resting animals found during immediately post-spawning months from our near shore sampling. A small percentage of males were found to be mature (Table 6). These were represented by a few red drum with developing and spawning gonads from our estuarine gears, and post-spawning adults from near shore.

Spawning Locations

The spawning noise producing capability of red drum allowed us to determine, through hydrophone surveys, the locations not only of areas where spawning activities occurred, but also the diurnal periods of maximal noise production. Through surveys for sound production for other species of sciaenids, a spawning location for red drum was identified in the Charleston Harbor entrance (Fig. 1). A remote hydrophone was placed near this active spawning site thus allowing the establishment of daily periods of intense sound production (Roumillat and Tyree, in prep). A cursory attempt was made to ensure that a concentration of sounds indicated spawning activity. This effort resulted in the capture of a few recently spawned red drum eggs immediately down-current from this spawning site.

Areas along the entire estuarine coast of South Carolina were surveyed for red drum spawning sounds (Fig. 2). Caution was taken to conduct our listening activities during the already established dates and diurnal periods of red drum sound production (Fig. 3). Evidence of spawning was found in only one area other than the Charleston Harbor entrance. Roumillat and Tyree (in prep.) placed remote hydrophone equipment in St. Helena Sound, and found that spawning noise production there followed the same diurnal sequence as that in the Charleston Harbor entrance.

DISCUSSION

Red rum specimens used in this study were captured using four gear types, three of which were used only in estuaries, the other only in nearshore ocean waters. A Kruskal-Wallis test for total lengths showed them to be statistically similar in fish caught estuarine gears, but significantly different from the adults sampled from nearshore. A similar test for ages showed three statistically distinct groupings, with the two trammel net catches forming one of these. Hook and line samples and nearshore longline samples showed different age compositions; the former because many larger specimens were caught from which we were able to obtain lengths but not age, and the latter captured only adult specimens from nearshore.

Table 6. Specimens of red drum examined for sex and maturity from 1994 – 1998. Total number = 1048 (587 males; 641 females). Total lengths designated as follows: 250mm= 226 - 275mm, 300mm = 276-325mm, etc.
*= only one fish aged **= none of the fish aged.

Total Lengths	***Percentage Mature/ N***		***Avg. Age in Months***		***Avg. Age in Years***		***Range of Ages in Years Represented***	
	Male	***Female***	***Male***	***Female***	***Male***	***Female***	***Male***	***Female***
250mm	0/2	0/1	11.5	11.0	0.96	0.92	0.92- 1.00	0.92
300mm	0/9	0/5	12.5	12.0	1.05	1.0	0.92- 1.08	0.92- 1.08
350mm	0/47	0/31	14.7	14.4	1.23	1.20	1.00- 1.67	1.00- 1.50
400mm	0/130	0/90	16.7	16.7	1.39	1.39	1.08- 1.92	1.08- 2.00
450mm	0/60	0/43	20.8	19.6	1.73	1.63	1.25- 2.00	1.08- 2.00
500mm	0/49	0/43	23.5	24.3	1.96	2.03	1.33- 2.66	1.33- 2.75
550mm	2/60	0/45	26.3	27.6	2.19	2.30	1.42- 3.17	1.83- 2.92
600mm	7/60	0/54	30.4	30.7	2.53	2.56	2.00- 3.33	2.00- 3.67
650mm	17/60	2/52	34.7	35.3	2.89	2.94	2.00- 3.67	2.17- 5.00
700mm	30/43	5/39	38.8	42.6	3.23	3.55	2.00- 3.92	2.42- 7.83
750mm	66/12	0/13	45.5	49.5	3.79	4.12	2.42- 4.92	3.00- 5.92
800mm	88/17	57/7	48.0	54.3	4.00	4.53	2.42- 5.00	3.83- 6.17
850mm	92/12	78/9	76.3	59.8	6.36	4.98	4.00- 9.17	3.16- 6.33
900mm	100/13	94/16	83.0	85.5	6.92	7.12	4.83- 10.17	4.17- 11.17
950mm	100/6	100/9	107.5	108.7	8.95	9.06	8.17- 10.25	6.17- 11.17
1000mm	100/4	100/1	374.0*	266.0	31.20*	22.16	31.17*	22.17
1050mm	100/3	100/3	**	237.3	**	19.8	**	18.70- 21.00

The paucity of mature red drum from our estuarine samples, and the abundance of adults in the nearshore samples corroborate the fact that immature fish inhabit marsh areas inside of inlets, moving out of this habitat as they become mature. More mature males than females were found in the estuaries, but the trend is for all individuals to eventually move into nearshore adult habitats as they age and mature.

The use of histological methods has been demonstrated as the most reliable technique for interpreting fish sex and maturity information (Wilson and Nieland, 1994). The use of histology for staging spawning activities, especially the determination of female spawning frequencies is crucial. This study was primarily restricted to estuarine sampling of red drum and no actively spawning adults were captured. Histological verification of maturities used in this study was used to examine the sex ratio of immature red drum found in S.C. estuaries, and to establish when these animals first become mature. Maturity determinations of small, young specimens caught during the period of spawning inactivity can only by accomplished through use of histological means.

Red drum spawn for six-eight weeks during late summer (August/September), and those individuals that take part show signs of development for a month or two preceding this event. The strategy of Murphy and Taylor (1990) to determine both size and age of first maturity based on the degree of development immediately preceding a spawning event seemed well reasoned. Establishing size and age for first maturity at this time eliminates the possibility of misinterpreting immature specimens from mature ones. Red drum in coastal South Carolina waters appeared to mature over a similar size and age range to those reported in the northern Gulf of Mexico (Wilson and Nieland, 1994). These dynamics showed a wider range of values than those reported in North Carolina (Ross et al., 1995). Although the maturity schedules used by Murphy and Taylor (1990) differed from those used here, and elsewhere (Wilson and Nieland, 1994; Ross et al., 1995) the variations in first maturities found in these works might also be explained by the different abundance of sizes and ages of fish used in each. The red drum used here were selectively smaller and younger because focus was on animals found inside the estuarine environment, and all of the other studies used primarily large adults taken from offshore or beachfront locations.

Sex ratios from our estuarine samples showed a male dominance, even when segregated by ages. Wilson and Nieland (1994) indicated an abundance of males in their immature fish from the Louisiana, but Ross et al. (1995) claimed to have essentially a 1:1 sex ratio from their samples in

North Carolina. Specimens from the nearshore samples in SC had ratios strongly in favor of females, just as was found by Wilson and Nieland (1994) in Louisiana. The samples from nearshore in this study were taken over a very limited time period during each year, and should not be considered representative of adult male-female relationships throughout the year. Data indicated that as females age to maturity, they emigrated from estuarine areas, never returning to their juvenile haunts. Some males, though, apparently revisited the estuarine juvenile habitats for up to two years after attaining adulthood (achieving adult gonad development).

We did not intend to answer questions involving adult reproductive biology, but more the relative abundances of juvenile year-classes as they moved through their estuarine phase over time. Similar differences might be noted for other studies that established maturity dynamics for red drum in neighboring states (Johnson and Funicelli, 1991; Wilson and Nieland, 1994; Ross et al., 1995). All of these works contained specimens of sizes and ages that were demonstrably greater than those found in this study.

Spawning locales for red drum in South Carolina estuarine waters were documented as occurring in the Charleston Harbor entrance and in St. Helena Sound (Fig. 2). Spawning in these two areas would explain recruitment of red drum to central and southern estuaries of SC, but does not explain the abundance of small fish found in regions north of Charleston Harbor.

Gulf Stream induced water movements along nearshore coastal South Carolina have a southerly movement (Matthews and Pashuk, 1977), especially during the late summer spawning season of red drum. This pattern of water movement eliminates passive drift as a mechanism to explain the large numbers of red drum recruited to SC estuaries north of Charleston. A plausible source for this recruitment of larvae to estuarine habitats would be red drum spawning in nearshore waters between Charleston and Georgetown, SC. Nearshore shoal areas around Cape Romain seem to be a likely spot for this activity to occur, but this phenomenon has not been investigated because of time and funding limitations.

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CHAPTER 4

SONIC TAGGING AND TRACKING OF SUBADULT AND ADULT RED DRUM IN SOUTH CAROLINA

BY

WILLIAM ROUMILLAT

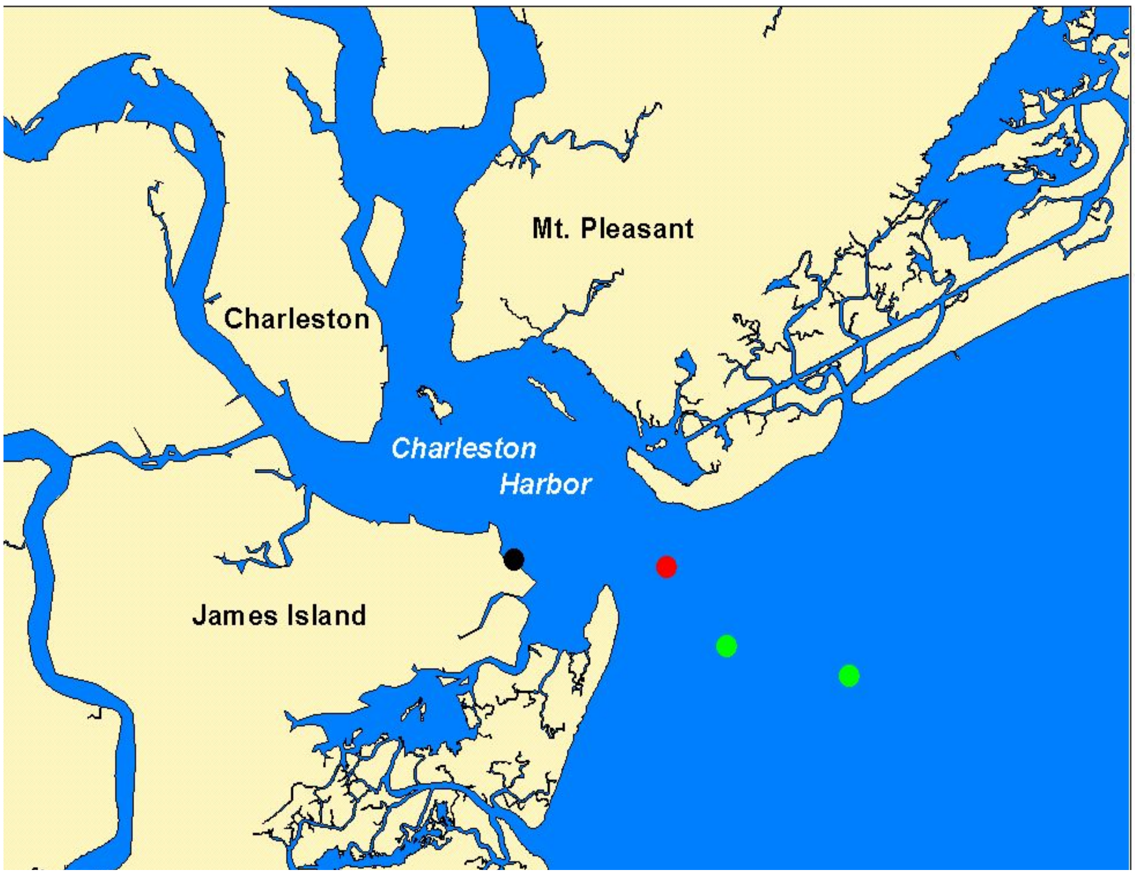
INTRODUCTION

Escapement of North Carolina red drum from their juvenile estuarine habitat into the spawning stock was estimated to have occurred less in the late 1980s than in the early 1970s (Ross et al., 1995). Murphy and Crabtree (1998) indicated that fishery regulations enacted during the late 1980s was responsible for an increase in the number of young adults in offshore waters of western Florida. In South Carolina, Wenner et al.(1990) demonstrated that juvenile red drum left estuaries as they became mature, with the presumption that they were leaving to enter near shore spawning stocks. Escapement, though, of red drum from estuarine habitats, and their immediate inclusion into spawning stocks has never been documented (Nicholson et al., 1996). Actively transmitting tags (radio and sound wave emitting) have been used successfully to study movements and behaviors of finfishes in freshwater (Nielsen, 1992). Since saltwater severely attenuates radio waves, sonic tags are the only option for use in estuarine and oceanic environments. Nicholson and Jordan (1994) used sonic tags to monitor movements of red drum in coastal and near shore waters of Georgia. His efforts to follow a few members of this species from the juvenile dominated estuaries into adult spawning stocks was inconclusive because locations for active spawning could not be demonstrated (Nicholson et al., 1996). Because locations of spawning red drum were found in the Charleston Harbor Estuary by Roumillat and Tyree (in prep.), we followed methods of Nicholson and Jordan (1994) to implant sonic tags into early maturing red drum captured inside the Charleston Harbor Estuary, and follow them into the local spawning aggregation.

METHODS AND MATERIALS

Three red drum were captured for the sonic tagging experiment. The initial fish was 797 mm TL (fish #1), and was taken by trammel net (184 m, 355 mm outside mesh, 63.5 mm inside mesh) from the Charleston Harbor on July 26, 1994. This specimen was brought to the Marine Resources Research Institute lab where a sonic tag (Sonotronics CHP-87-m, 18 x 100 mm) was surgically implanted into the body cavity. The fish was kept alive in the laboratory until 1 August 1994 to ensure that the tag was retained and the incision was healing. Release was in an area of the Charleston Harbor where movements could be readily monitored (Figure 1). The remaining two specimens were caught in the Charleston Harbor entrance channel on 27 September 1994 using standard hook and line gear from a 10.2 m depth. These fish were captured in a rocky area proximal to the 24 m spawning hole in the Charleston Harbor entrance (Roumillat and Tyree, in prep.). The red drum (873 and 945 mm TL; fish #2 and #3) had tags implanted through a slit made into the body cavity, were held at the surface until appropriately recovered, and then

Figure 1. Locations of sonically tagged red drum within the Charleston Harbor estuary. Fish # 1 was released inside the harbor (black dot); fish #2 and #3 were released near the established red drum spawning site (red dot). Searches for signals were conducted in the spawning site and at known proximal fishing spots for red drum (green dots).



released on site. All specimens were monitored using a Sonotronics DH-2 directional hydrophone.

RESULTS

Specimen #1 remained within 100 m of the initial release location throughout the first two weeks of monitoring. Migrations into and out of *Spartina alternaflora* marsh occurred when tidal inundation permitted. Monitoring was constant for the first 24 hr, then episodic through 13 August

1994. On 14 August 1994, the fish could no longer be found in the release location. Subsequent attempts to locate the specimen in the near-by red drum spawning aggregation were unsuccessful.

When the second and third fish were released, the sonic signal from fish #2 disappeared within minutes. The initial thought was that signals from fish #2 were obscured by rock outcrops near the spawning site. The signal from fish #3 was monitored for 2 hr after release, then found in the same location for 4 successive days.

Signals from fish #1 or #2 were not subsequently found. Fish #3 was relocated in its release location until 1 October 1994. Unsuccessful surveys were conducted until 1 November 1994 in the release location and other nearby red drum fishing holes (Figure 1).

DISCUSSION

Escapement of red drum from estuarine habitats into spawning stocks has never been directly documented (Nicholson et al., 1996). Ross et al. (1995) indicated the number of young spawners in coastal North Carolina appeared to have been greater in the early 1970s than in the mid-1980s based on age composition of older adults taken between 1987 – 1990. Increased fishing pressure on red drum during the 1980s was blamed for this decrease. Murphy and Crabtree (1998) surmised that fishery regulations enacted during the late 1980s resulted in greater numbers of younger adults in offshore populations of western Florida during the early 1990s.

The concept of using sonic tags to follow first maturing red drum into reproductively active aggregations was not intended as a tool to assess the age composition of the spawning stock. Using the argument posed by Nicholson et al. (1996), this sonic tagging effort hoped to establish that young adults were active in the spawning group during their initial year of maturity.

[The amount of effort expended by laboratory personnel to appropriately follow sonically tagged red drum was far greater than initially anticipated. Logistics quickly became overwhelming, and the amount of effort necessary to successfully complete the task outweighed the usefulness of the expected knowledge gained. The sonic tagging part of this research was abandoned.]

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CHAPTER 5

AN INVESTIGATION OF THE FEASIBILITY OF AERIAL SURVEYS FOR RED DRUM, *Sciaenops ocellatus*, IN INSHORE WATERS OF SOUTH CAROLINA

BY

JOHN ARCHAMBAULT

INTRODUCTION

Aerial surveys have been employed to evaluate populations of marine mammals, sea turtles, and several fish species. Pilots, including menhaden spotters, frequently report sighting schools of red drum (Overstreet1983). Near-surface schools of large red drum have been surveyed and enumerated from the air in the northern Gulf of Mexico (Lohoefner et al. 1987, Lohoefner et al. 1988, Mullin et al. 1996).

The South Carolina Department of Natural Resources' Marine Resources Division occasionally receives reports of sightings of red drum from pilots of small aircraft. This fact, together with the success of aerial surveys of red drum in other areas, led the Inshore Sportfish Research Section of the Marine Resources Research Institute to investigate the feasibility of using aerial surveys to evaluate red drum stocks and habitat utilization in South Carolina.

Two distinct habitats and seasons were identified for aerial surveys. In light of the success of aerial surveys of large offshore schools (some suspected to be spawning aggregations) of red drum in the Gulf of Mexico, attempts were made to locate spawning or pre-spawning schools along the beaches, inlets, and banks (sandbar islands often associated with inlets) in South Carolina. Also, sub-adult red drum are known to form schools in sheltered, shallow inshore areas during winter. These mud flats, bays, and sounds were examined to attempt to survey these schools.

MATERIALS AND METHODS

All flights originated from Charleston Executive Airport on John's Island, South Carolina. Flights on 26 and 27 January 1995 were made with a private carrier (Carolina Aviation). All other flights were conducted in aircraft owned by the South Carolina Department of Natural Resources and operated by departmental pilots. All flights were made in either a Cesna model 206 or model 180.

Overflights were made at an altitude of 300 to 400 feet, with occasional descents to 200 feet to verify sightings. Surveys were conducted at airspeeds of approximately 75 to 80 knots.

Every effort was made to schedule surveys at times that we hoped would maximize fish visibility. Flights occurred during late morning or midday, when the sun was high, and around the time of low tide to early flood tide, when water was lowest and clearest. However, because flights had to be scheduled a month or more in advance, it was not possible to control the weather conditions on flight days.

Identification of sighted fish as red drum was based on several factors. Possibly the single most useful factor in identification of sighted fish is the short list of possible species. The list of species that could be expected to be present in shallow inshore waters during winter is limited to red drum, spotted seatrout, and striped mullet. Red drum tend to be the largest of these three species and appear a copper or reddish or brown color. Seatrout do not tend to form cohesive schools in shallow water as do red drum, and appear more green or gray from above. Striped mullet tend to be significantly smaller than red drum and are a dark gray to black in color when viewed from above. Summertime surveys of inlets, banks, and the area just outside the surfzone could present a longer list of species. Mullet are also common in this habitat as are sharks. Most sharks tend to be significantly larger, more tapered posteriorly, and move in a distinctively sinuous manner. Jack crevalle are similar in appearance to red drum when viewed from above, but can generally be distinguished by their deeply forked tails and yellow pectoral and dorsal fins.

Numbers of red drum sighted in a school or group were estimated visually. No attempt was made to verify visual estimates of numbers.

Surveyed habitats differed seasonally. The warm season surveys targeted the area immediately outside of the surfzone on the outer coast, as well as inlets and “banks” (sandbar islands associated with many major inlets in South Carolina). Cold-season surveys targeted gently-sloping subtidal flats in more sheltered inside waterways. These flats make up nearly the entirety of some small bowl-shaped “sounds” and “bays” (terms used in South Carolina to identify shallow, sheltered, largely-landlocked bodies of water) and the margins of larger sounds, harbors, and rivers. The region surveyed extended from North Inlet in the north to Calibogue Sound, near the Georgia border, in the south.

The area surveyed during a flight was determined by available time at an appropriate tide stage. Generally flights were limited to roughly two to three hours duration. The summertime surveys of the outer coastal areas could cover the entire target area in one flight. Because of the greater area of flats surveyed during the winter flights, each flight could cover only a portion of the selected total sample area. The area to be surveyed on a particular flight was chosen based upon weather conditions throughout the region as well as areas surveyed on recent flights (and thus, areas not yet surveyed).

During analysis, weather conditions on flight days were estimated a posteriori from historic data. Wind speed and direction were taken from archives maintained by the National Weather Service's National Data Buoy Center for the Folly Island (fixed shore station) and EDISTO (buoy: 41 nautical miles southeast of Charleston) stations. The South Carolina State Climatology Office supplied data on percent cloud cover and ceiling height as well as confirming data for wind speed and direction.

RESULTS

29 August, 1994

Departure Time: 07:00

Conditions: Charleston Harbor low tide at 08:06
(0.1 feet above mean low water)
Wind: West – light to moderate.
Cloud: 10 percent, ceiling unlimited.

Survey:

Surveyed area includes the outer coast and inlets: the oceanfront side of South Island, Santee River delta, Murphy Island, Cape Island, Bulls Bay, Bull Island, Prices Inlet, Capers Island and Inlet, Dewees Island and Inlet, Isle of Palms, Breach Inlet, Sulivans Island, Morris Island, Lighthouse Inlet, Folly Beach, Stono Inlet including Bird Key, Kiawah Island, Seabrook Island, North Edisto Inlet including Deveaux Bank, Edisto Island, Pine and Otter Islands (several large sharks were sighted swimming at the surface in an estimated 5 to 10 feet of water on the south side of Otter Islands), Hunting Island, Fripp Island, Pritchards Island, Trenchards Inlet, and Hilton Head Island including Joiner Bank (Figure 1). The Surf zone was almost uniformly muddy. No red drum were sighted.

1 September, 1994

Departure Time: 10:00 hours.

Conditions: Charleston Harbor low tide at 10:59
(0.8 feet above mean low water)
Wind: Southwest – light to moderate.
Cloud: 50 percent, ceiling unlimited.

Survey:

Surveyed area was the ocean-front of islands and inlets from St. Helena sound north to the Santee Delta: Hutchinson and Otter Islands, Edisto Island, North Edisto Inlet (including Deveaux Bank), Seabrook and Kiawah Islands, Stono Inlet, Folly Beach, Lighthouse Inlet, Morris Island, Sulivans Island, Breach Inlet, Isle of Palms, Dewees Inlet and Island, Capers Inlet and Island, Prices Inlet, Bull Island, Bulls Bay, Cape Island, Murphy Island, and the Santee River delta. On the return flight the inside sounds from Bulls Bay south to Charleston were also surveyed: Seewee Bay, Copahee Sound, Hamlin Sound, and Gray Bay (Figure 2). No red drum were sighted.

12 September, 1994

Departure Time: 07:30 hours.

Conditions: Charleston Harbor low tide at 07:49 hours (0.4 feet).
Wind: North to northeast – light to moderate.
Cloud Cover: Clear sky, ceiling unlimited.

Survey:

Researchers surveyed the Stono River (from the airport south to the inlet), Folly River (Bottlenose Dolphins were sighted. They were clearly visible at the surface, but disappeared completely from view after diving just a few feet.), Lighthouse Creek, Clarks Sound, north side of Morris Island, Charleston Harbor (south rim), Ashley River (from Charleston Harbor north to Orange Grove Creek), Wando River (eastern shore from Horlbeck Creek south), Hamlin Sound, Grey Bay, Copahee Sound, Sewee Bay, and Bulls Bay (south rim along Bulls Island). No red drum were seen in the above listed areas.

The survey then followed the Intracoastal Waterway, from Bulls Bay south to the mouth of the Charleston Harbor, to Folly River, Stono Inlet (approximately 20 red drum sighted on the flat at the confluence of Stono and Folly Rivers) (Figure 3).

14 September, 1994

Departure Time: 09:30 hours.

Conditions: Charleston Harbor low tide at 10:02 hours (0.6 feet).

Wind: Variable – light.

Cloud Cover: Clear sky, ceiling unlimited.

Survey:

Surveyed areas encompassed Hunting Island and the St. Helena Sound area including the front of Hutchinson, Pine and Otter Islands. The flight then proceeded along the ocean front of Edisto Island, by North Edisto Inlet (including Deveaux Bank, where a possible sighting of red drum was made just outside the surf, but poor visibility precluded a definite identification), along Seabrook and Kiawah Islands, and around Stono Inlet and up the Stono River back to the airport (Figure 4).

26 January, 1995

Departure Time:	09:15 hours.
Conditions:	Charleston Harbor low tide at 09:51 hours (0.1 feet).
	Wind: Northwest to west – moderate.
	Cloud Cover: Clear sky, ceiling unlimited.

Survey:

Flew with Donald Britton from Carolina Aviation. We surveyed the upper Stono River to Wadmalaw Sound, Wadmalaw River, North Edisto River, Dawho River, and Edisto River to the seaward sides of Pine, Otter, Hutchinson, and Ashe Islands. The flight then proceeded up the mouth of the Combahee River before circling Morgan Island, and flew west up the Coosaw River as far as the Beaufort River. We then turned and flew south down Lucy Point creek past its confluence with Morgan River. A large school of perhaps 100 to 150 red drum was sighted in the small sound immediately Northeast of the Beaufort County Airport. The flight then proceeded north up Jenkins Creek to the Morgan River before returning to Charleston. On the return trip Wadmalaw Sound, Stono Inlet, Kiawah River, and the confluence of the Stono and Kiawah Rivers were examined. One school of red drum (approximately 50) plus a few scattered individuals were sighted in Stono Inlet west of Bass Creek (Figure 5).

The lack of fish sightings in areas that are known to hold red drum (ie. Flats at the mouth of the Combahee River) may have been due to the extremely low tides on this date, caused partially by brisk northwest winds. Most mud and sand flats were completely exposed, which would force fish into channels where they would be difficult to spot in the tannic and murky water.

27 January, 1995

Departure Time:	10:15 hours.

Conditions: Charleston Harbor low tide at 10:54 hours (-0.1 feet).
Wind: Northeast – light.
Cloud Cover: 100 percent, ceiling 25,000 feet.

Survey:

On departure we proceeded to Clark Sound and Charleston Harbor. Areas of muddy water, possibly indicating the presence of fish, were sighted near an angler near Plum Island and also near Kushiwah Creek mouth, but fish were not apparent. From this point the flight proceeded directly to North Inlet. Visibility in North Inlet was very poor due to discolored water (tannic) as it was in Winyah Bay. Winyah Bay was also very turbid (including Mud Bay) except for Mother Norton Shoal, where a few scattered red drum were seen away from the bank. No fish were sighted in North Santee Bay or South Santee River, except for two groups on the southeast side of Cane Island (N. Santee) totaling about 25 red drum.

The flight proceeded south along the Atlantic coast to Cape Romain Harbor, Romain River, Northern Bulls Bay, and Muddy Bay in that order. Many schools of red drum were sighted [Cape Romain Harbor: indeterminate small group on the bank north of the Cowpen, approximately 75 on the bank north of Deepwater Point, approximately100 in a dispersed school off the northeast side of Mill Island; Romain River: 75 west of S Creek (north side of Lighthouse Island - we did not get a good look at the north bank of Romain River); Northern Bulls Bay: 50 on the north bank of Five Fathom Creek mouth, two groups of 150 and 50 respectively proceeding northwest between Five Fathom Creek and Bull River, 20 (plus a scattered few) somewhere to seaward in White Banks] (Figure 6a).

The flight continued to follow the shore of Bulls Bay southward and sighted no groups of red drum (central Bulls Bay was very shallow, fish may have been present to seaward) until a group of 60 was located between Venning and Blind Creeks and another of 75 south of Anderson Creek mouth.

Each of the sounds proceeding southward toward Charleston was inspected. Red drum were seen in virtually all: 100 in a shallow channel in the eastern end of Sewee Bay (the west end of the bay was nearly dry), 200 total in scattered pods in eastern Copahee Sound , 75 in western Copahee sound, 100 in Bullyard Sound (roughly opposite marker '103'), 70 in two schools in eastern Hamlin Sound, 80 in two schools in northern and southeastern Gray Bay, and 30 near the mouth of Jeanette Creek.

We looked around the Clark Sound area once more, on the way back to the airport, without seeing red drum with the exception of 15 individuals southeast of Parrot Point Creek mouth (Figure 6b).

13 February, 1995

Departure Time: 11:30 hours.

Conditions: Charleston Harbor low tide at 12:36 hours (0.1 feet).
Wind: Northeast – light to moderate.
Cloud Cover: Overcast, ceiling 14,000 feet.

Survey:

Briefly, the areas of Whale Branch to Broad River, including the Chechessee and Colleton Rivers east to the Beaufort River were inspected. One group of possibly 40 red drum was sighted in the Broad River just south of Archers Creek (Figure 7).

14 February, 1995

Departure Time: 12:15 hours.

Conditions: Charleston Harbor low tide at 13:17 hours (-0.1 feet).
Wind: Northeast – light to moderate.
Cloud Cover: 80 percent, ceiling 11,000 feet.

Survey:

Inspected the Bear's Bluff flat in the Wadmalaw River and the eastern Dawho River: no red drum sighted. Proceeded to the eastern end of Morgan Island, around the northeast and east sides of St. Helena Island (these areas look like good habitat, possibly promising for trammel netting), and up the Harbor River. The large Harbor River sound area was inspected, but it is likely that some sections were missed. (It consists mainly of intertidal flats and channels, with some smallish flats and bowls.) Hunting Island Lagoon (possible "mud" within the lagoon proper) and the canal in Fripp Island were also examined, before heading out Station Creek and southwest to the mouth of Trenchards Inlet. Within Skull Creek one group of 40 to 50 red drum was sighted on a shallow flat west of marker '14.' Mackay Creek was inspected as were Calibogue Sound and it's lower tributaries. Most open areas were quite wavy and as a result muddy in the shallows. Visibility in the more sheltered areas appeared fair to good (Figure 8).

27 February, 1995

Departure Time: 11:15 hours.

Conditions: Charleston Harbor low tide at 12:24 hours (-0.5 feet).
Wind: Southeast – light to moderate.
Cloud Cover: Overcast, ceiling 4,000 feet.

Survey:

Researchers flew over Harbor River and Sisters Creek on the way to the Chechessee River. Chechessee River, Hazard Creek, and Broad River (west bank only, from highway to the railroad bridge) were surveyed. Also inspected were the waters around Daws Island and the Colleton River. On the way home, they surveyed the uppermost reaches of the Morgan River and followed Lucy Point Creek out to the Coosaw River. No red drum schools were sighted (Figure 9).

17 January, 1996 Flight canceled due to weather (fog).

18 January, 1996

Departure Time:	10:15 hours.
Conditions:	Charleston Harbor low tide at 12:06 hours (-0.5 feet).
	Wind: East – light to moderate.
	Cloud Cover: 60 percent, ceiling 4,800 feet.

Survey:

Researchers inspected the Stono River from Abbapoola Creek south to its confluence with the Kiawah River and then the length of the Kiawah River. Visibility was poor throughout this section of the flight (water very muddy). No fish were sighted. From here they flew at a higher elevation rather quickly to the southern end of Edisto Island (note that flying over Edisto a bald eagle was spotted). The survey was to continue on to Hilton Head, however, due to weather conditions, was forced to turn around. The party began looking for fish again at Wappoo Cut and proceeded along the south rim Charleston Harbor to Ft. Johnson: again visibility was poor and no fish were seen, although bottlenose dolphins were seen swirling around what were believed to be fish (red drum?) near the dock of the JIYC. The surveyors then flew north across Charleston Harbor to the Intracoastal Waterway and the sounds behind Sullivan's Island, Isle of Palms, Dewees and Capers Islands. No fish spotted in Gray Bay, Hamlin Sound, Copahee Sound, or Mark Bay. The flight continued along the front of Capers Island south to Capers Inlet where there was too much surf to see any fish. The flight was terminated at this point due to foul weather conditions (Figure 10).

January 30, 1996 Flight canceled due to weather (fog and rain moving in).

February 1, 1996

Departure Time:	11:15 hours.
Conditions:	Charleston Harbor low tide at 11:52 hours (0.4 feet).

Wind: Northeast – moderate.

Cloud Cover: Overcast, ceiling 1,700 feet.

Survey:

Surveyors proceeded directly to Hilton Head after takeoff, but as they passed over the North Edisto one observer saw a small group of red drum on the southwest bank near Point of Pines. On reaching Hilton Head Island they flew over Broad Creek (middle of HHI), across Calibogue Sound to mouth of Cooper River (north side of Daufuskie Island) and up the west bank of Calibogue Sound, to mouth of Bass Creek, over Skull Creek, and looped back over Mackay Creek. From there they flew to the Colleton River where a school of red drum was spotted behind the marsh island across from Callawassie Creek. The flight continued up the Chechessee to Hazard Creek and into the Broad River, down the southeast bank of the Broad River (where another small group of red drum was spotted on the flats in front of the island at Euhaw Creek). The flight down the rest of Broad River and up Whale Branch to Coosaw River produced no red drum sightings. A quick inspection of Deveaux Bank was made as a last ditch effort before terminating the survey (Figure 11).

Visibility was poor due to thick cloud cover as well as turbid water. Researchers did, however, see many dolphins in the shallows.

February 14, 1996

Departure Time: 09:30 hours.

Conditions: Charleston Harbor low tide at 09:49 hours (0.2 feet).

Wind: Northeast – moderate to heavy.

Cloud Cover: Clear sky, ceiling unlimited.

Survey:

The survey included the shallows of Kiawah River before heading to Pine and Otter Islands and the north side of St. Helena Sound, to the mouth of the Coosaw River. Because of wave action and turbidity (in the shallows), the majority of the Coosaw River was omitted. The flight then proceeded to the mouth of Lucy Point Creek. Researchers sighted a school (maybe 100 red drum) traveling west in the shallows just east of the mouth of the creek. They then headed south along the creek to Morgan River and saw another group of roughly 75 red drum on the northwest corner of the more northerly small sound (just east of the city of Beaufort). Two or three dolphins were harassing these fish. The survey then inspected Trenchard's Inlet. At this point, the flight was terminated because one of the researchers was taken ill. On the trip back to the airport, flying high (>1000 ft) and fast, one surveyor believed he saw a group of red drum (50-75 fish?) in the Harbor River sound directly north of Fripp Inlet and another group (indeterminate number) on flat southeast of Pine Island (Figure 12).

February 15, 1996

Departure Time: 10:45 hours.

Conditions: Charleston Harbor low tide at 10:48 hours (-0.1 feet).
Wind: West to southwest – moderate to heavy.
Cloud Cover: 60 percent, ceiling unknown.

Survey:

The survey began by looking around Stono Inlet and Kiawah River, to Steamboat Creek to St. Pierre Creek, down to the mouth of Big Bay Creek in the mouth of the South Edisto River. A great number of birds were seen stirring up mud in the flats area above Big Bay Creek. The flight proceeded across the front of Pine and Otter Islands across the seaward face of Hutchinson Island and up to the mouth of the Combahee River. From here it headed to Lucy Point Creek and Morgan Island to upper Morgan Flats. Throughout the period the water was very low, apparently too low for red drum to inhabit the flats. The flight then proceeded to the south point of Parris Island and up the east bank of Broad River to near the bridge, then to the mouth of Hazard Creek, Chechessee Creek (almost dry!), to Colleton River, back out to the west bank of Broad River, down to and past the mouth of Mackay and Skull Creeks. The water was still very low even to this point. The survey then proceeded to Trenchards Inlet, past Otter and Pine Islands, and over the flat above the mouth of Big Bay Creek (where the tide had come in a bit: again many birds), up the North Edisto past Bears Bluff, Younges Island, and the Wadmalaw Sound flats (Figure 13). The water had come up to a level that appeared promising. At no time during the flight did they see any red drum.

February 16, 1996 Flight canceled due to weather (heavy, gusty winds; storm impending).

February 28, 1996 Flight canceled due to weather (rain in Columbia, which headed to Charleston).

February 29, 1996

Departure Time: 10:50 hours.

Conditions: Charleston Harbor low tide at 10:29 hours (0.7 feet).
Wind: Northwest – moderate.
Cloud Cover: Data unavailable.

Survey:

The survey was begun with the back sides of Morris and Sulivan's Islands and proceeded north along the Intracoastal Waterway. At Skull, Inlet, Swinton and Hamlin Creeks no fish were sighted (water too low?). In Hamlin Sound, Copahee Sound, and Seewee Bay, no fish were sighted (water very low).

The crew then flew directly to North Inlet and began to work their way south again. They inspected North Inlet (no sightings in the northern section of the inlet, a few red drum on flats due east of Baruch dock: water still too low), Winyah Bay (water was uniformly dark, visibility estimated to be one foot), Mud Bay, Mother Norton Shoals (saw six or eight vapor-trails, possibly indicative of red drum). South Island, North Santee Bay, South Santee Bay, and the ocean-front past Santee Delta. They then flew inside of northern Cape Island to Lighthouse Island, around Mill Island, and north through Cape Romain Harbor. They sighted scattered red drum in The Cowpen, a few fish near the lighthouse, a small pod of fish 50 meters from the marsh edge northeast of Mill Island, and a few near the mouth of Deepwater Point Creek. They flew over Muddy Bay (few fish along northern rim), Oyster Bay, Five Fathom Creek, Bulls Bay (few fish south of Bull River, few midway south, and a few more near Venning Creek mouth), Seewee and Mark Bays (few red drum sighted in each), and Bullyard Sound.

On the return flight Charleston Harbor, the back of Morris Island, Clark Sound and Stono Inlet were examined once more. No red drum were sighted (Figure 14).

DISCUSSION

Attempts to locate red drum in inlets or along beachfront areas proved unsuccessful. The surfzone and a band outside the breaking waves proved to be uniformly turbid, making sighting of fish in the area impossible. Further, breaking waves result in a broken water surface and often foam. Off of the beach, clearer water occurs only at depths of at least three to five feet. Even under optimum conditions, in South Carolina inshore waters visibility is limited to about three feet. Therefore visibility is insufficient to reliably sight fish swimming along the bottom.

One full flight (September 12, 1994) and a part of another (September 13, 1994) were devoted to inspection of inside waterways during late summer. While the first flight did produce sightings of several red drum, results indicate that this habitat could better be surveyed during winter. South Carolina's waters tend to be significantly clearer during winter than during other seasons, as a result of reduced phytoplankton densities. Though red drum were sighted in inside waterways during warm weather, they appeared to be scattered. During winter red drum in South Carolina are known to gather into large schools, which might more easily be sighted from the air than are scattered individual fish.

Numbers of red drum sighted during survey flights over inside waters during winter proved to be highly variable. Further, the number of fish sighted varied not only with area, but also with repeated flights over the same area. The very large areas that were repeatedly surveyed without any red rum sightings are troubling. It is highly unlikely that such areas were devoid of fish. On many occasions survey flights passed over areas that are known to hold red drum, because of catches of red drum in trammel-net surveys in these areas (Inshore Fisheries Research Section Data). These facts indicate that the ability of researchers to sight red drum from the air in South Carolina is inconsistent.

The visibility of red drum from the air appears to be dependent on the interplay of a number of factors, including temporal, climatic, topographic and possibly even behavioral variables. Some factors such as sun angle/height and tide stage are highly predictable and easily controlled. Other factors such as cloud cover, wind speed, and wind direction are predictable on a short time scale, but are difficult to control given that flights usually need to be scheduled weeks or at least days in advance. Finally, the topography of any given area, while it is constant and known, affects the visibility and possibly the behavior of the red drum in the area, and thereby affects the potential utility of aerial surveys as an assessment tool.

The most predictable and most easily controlled factor influencing visibility is the sun’s height in the sky. The angle of incoming sunlight determines penetration into the water. A high sun angle leads to high penetration and low glare. The importance of the angle of incident sunlight increases with water depth. Light penetration is highly dependent on incident angle. Since we inspected areas that were largely very shallow (less than three feet deep), sun angle was probably not as important as other factors in determining visibility of red drum.

The second variable strongly affecting glare on the water’s surface is cloud cover. Low clouds tend to reflect on the surface of the water, producing a great deal of glare and cutting down on visibility into the water. High, thin clouds produce less glare than low heavy clouds. Optimum visibility is possible with a clear sky. It is interesting to note that the flight that produced the greatest number of red drum sighted was made on a day with full cloud cover, 27 January 1995. The clouds that day were quite high, however, as the ceiling was reported to be 25,000 feet.

Wind velocity and direction have an immediate effect on the visibility of red drum from the air. Wind affects visibility in two ways: by agitating the waters surface and by stirring the shallows and suspending sediments and thereby muddying the water column. A broken or agitated water surface interferes directly with vision and also refracts incoming sunlight, creating a pattern of shadows in constant motion. Further, significant winds increase turbidity thereby additionally restricting visibility. The degree of interference with visibility is directly related to wind speed as higher winds produce larger waves and more turbid water. The detrimental effects of wind on visibility vary locally. Waters along lee shorelines can be calm and clear while those in windward areas are wavy and turbid. Strong winds can also affect the likelihood of sighting red drum by influencing tide height.

Researchers surveying red drum in the northern Gulf of Mexico were similarly affected by weather. Loheofner et al. (1987) reported a formula for computing a condition index to determine whether or not to survey. The criterion involved assessment of weather, sea state, water clarity, sunlight, and time of day. They also reported that results, the number of schools of red drum sighted on any particular survey, were affected by conditions. Mullin et al (1996) reported their results were affected by conditions as was the earlier survey, but they also lost many sample days as a result of unfavorable conditions.

During the surveys of red drum schools in the northern Gulf of Mexico, tide stage did not play a role (Lohoefner et al. 1987, Lohoefner et al 1988, Mullin et al. 1996). The depth of offshore waters was great enough to minimize any effect of tide stage. Also, inside waters surveys were apparently not affected, presumably because of the small tidal amplitude in the northern Gulf of Mexico.

Tide stage controls the visibility of red drum from the air in South Carolina by determining the location of the fish and the depth of water overlying them. Red drum in inshore waters are typically benthically oriented. Also, when possible they tend to enter flooded marsh grass or orient to other structural features, such as oyster bars. Therefore, they are visible only when the tide stage is low enough to force them out of the grass and away from other obstructions. Shallow enough conditions exist from mid to late ebb tide through early to mid flood tide, depending on the location and amplitude of the tide in question. The optimum tide stage would likely be the early flood as the incoming water tends, all other factors being equal, to be clearer and the increasing water depths seems to encourage the fish to move into the shallows.

It is possible for a tide to be too low for red drum sightings. On extremely low tides, as occur on some spring tides or when a strong wind blows from the west or northwest in South Carolina, larger areas of normally shallow subtidal flats are left devoid of water. This forces fish out of their normal habitat, often into adjacent channels. Because these channels are, by definition, deeper

than the surrounding waters and tend to be rather steep sided, visibility within them is poor. This consideration is affected by local topography. If steep sided channels are not present or are a long distance from typically-subtidal shallow flats, then the effect of a lower-than-average tide is reduced.
The topography of estuarine systems, including inshore red drum habitat, appears to be shaped, at least in part, by tidal amplitude. Average tidal amplitude increases from north to south along the Carolina coast. The mean tidal range for Winyah Bay at the Georgetown lighthouse is 3.89 feet, for Charleston Harbor at the Customhouse is 5.27 feet, for the Edisto River at Big Bay Creek entrance is 6.00 feet and for Calibogue Sound at Haig Point is 7.05 feet (Tide Tables, 1994). The variation in tidal amplitude appears to affect topography as well as red drum behavior.

The topography of red drum intertidal and shallow-subtidal inshore is varied. One typical habitat consists of a broad (up to 200 meters or more in width), gently-sloping flat that leads eventually into a major channel, such as a river or sound basin. Another habitat type consists of narrower (50 meters or less), fairly level flats that are dissected by small (often 5 to 10 meter wide by less than two meters deep at low tide), steep-sided channels. In the northern part of the coast, the first habitat, consisting of broad flats tends to be more common. Whereas in the southern part of the state, the second type, consisting of more narrow flats dissected by numerous small channels is the norm. While this is a generalization, and many different configurations exist throughout the coast, topography appears to influence red drum behavior and visibility. It appears that in areas with large tidal amplitudes and numerous channels bordering narrow flats, the red drum are much more likely to leave the flats and move into the channels where they are less visible from the air.

The visibility of red drum from the air is dependent on multiple factors. Some of the factors such as time of day/height of the sun and tide stage are easily controlled, but can limit the number of potentially effective survey days available. Other variables are predictable on a short-term basis; these include wind speed and direction and cloud cover. When survey flights must be scheduled weeks or days in advance, however, it becomes difficult to select for optimum weather conditions. Additionally, the visibility of red drum from the air appears to be linked to topography and the fish’s behavior. For these reasons, aerial surveys cannot be relied upon to provide comparable and unbiased estimates of red drum stocks in different areas. Survey of red drum schools through overflights could prove useful in monitoring trends in abundance over time. Multiple flights over chosen areas would be desirable, however, in order to lessen the effects of variable weather conditions on fish visibility.

Though red drum often are visible from the air, overflights probably should not be relied upon to assess the suitability of habitats for red drum. Sightings of red drum in a given area can be interpreted to mean that the habitat in question is favorable. The significance of a lack of sightings is not clear, however. Not seeing red drum in a location could mean that it is not good habitat for red drum. It could also mean, though, that it is simply not good habitat for sighting red drum.

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Figure 1. Area surveyed on 29 August 1994 (hatched area). No red drum were sighted on this date.

Figure 2. Area surveyed on 1 September 1994 (hatched area). No red drum were sighted on this date.

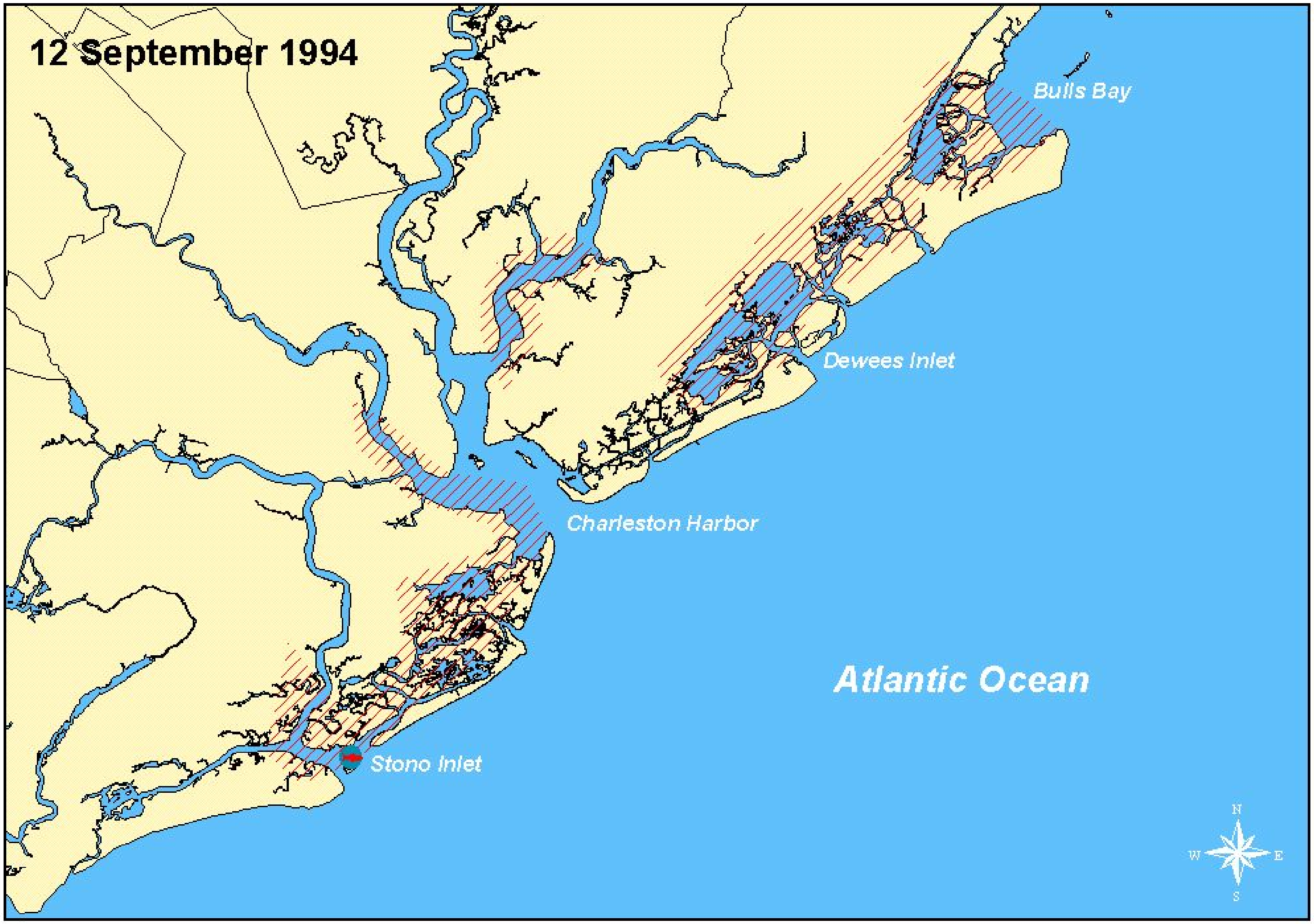


Figure 3. Area surveyed on 12 September 1994 (hatched area) and approximate location of red drum sighting (fish symbol).

Figure 4. Area surveyed on 14 September 1994 (hatched area) and approximate location of possible red drum sighting (question mark

Figure 5. Area surveyed on 26 January 1995 (hatched area) and approximate locations of red drum sightings (fish symbols).

Figure 6a. Area surveyed on 27 January 1995 (hatched area) and approximate locations of red drum sightings (fish symbols).

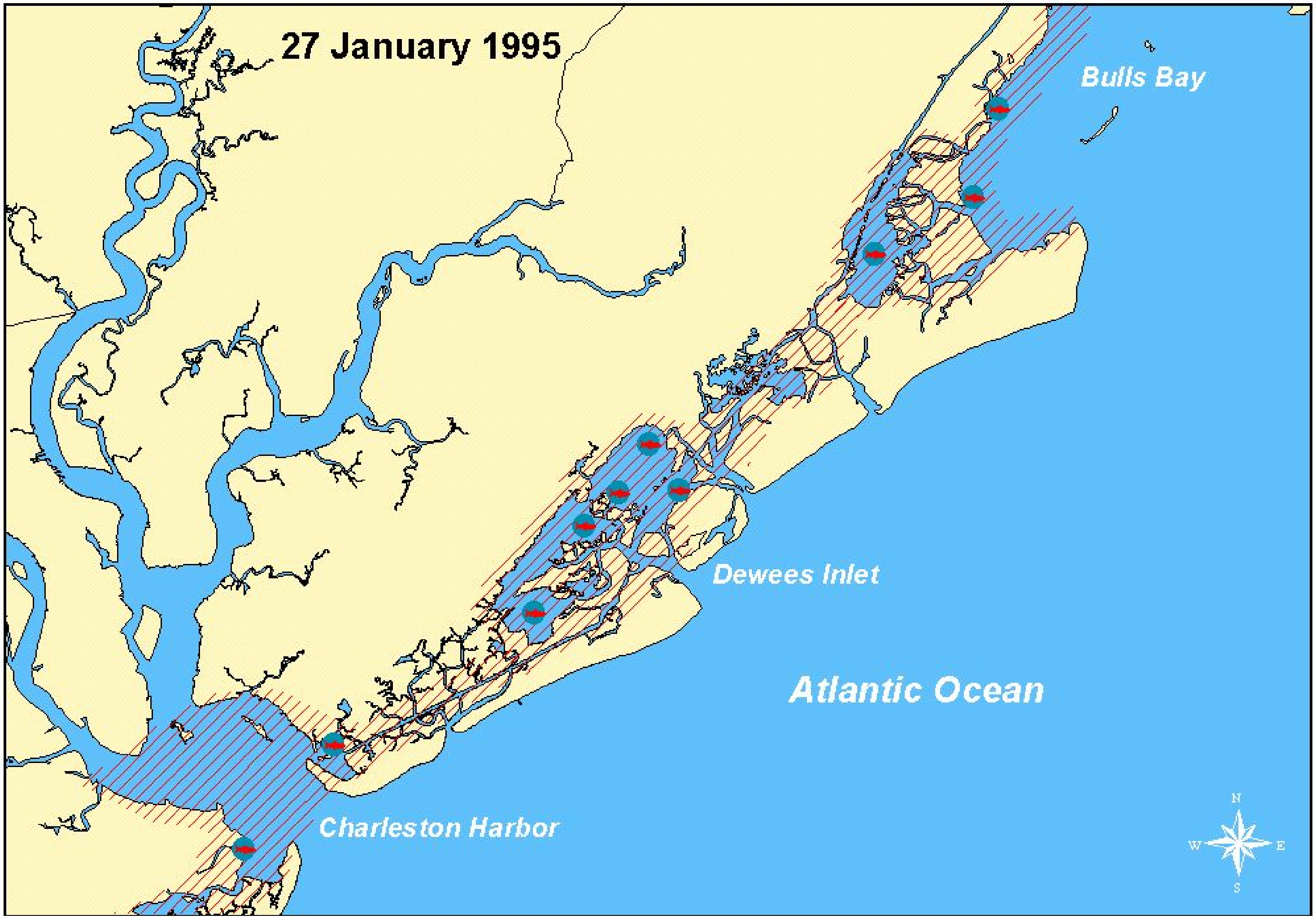


Figure 6b. Area surveyed on 27 January 1995 (hatched area) and approximate locations of red drum sightings (fish symbols).

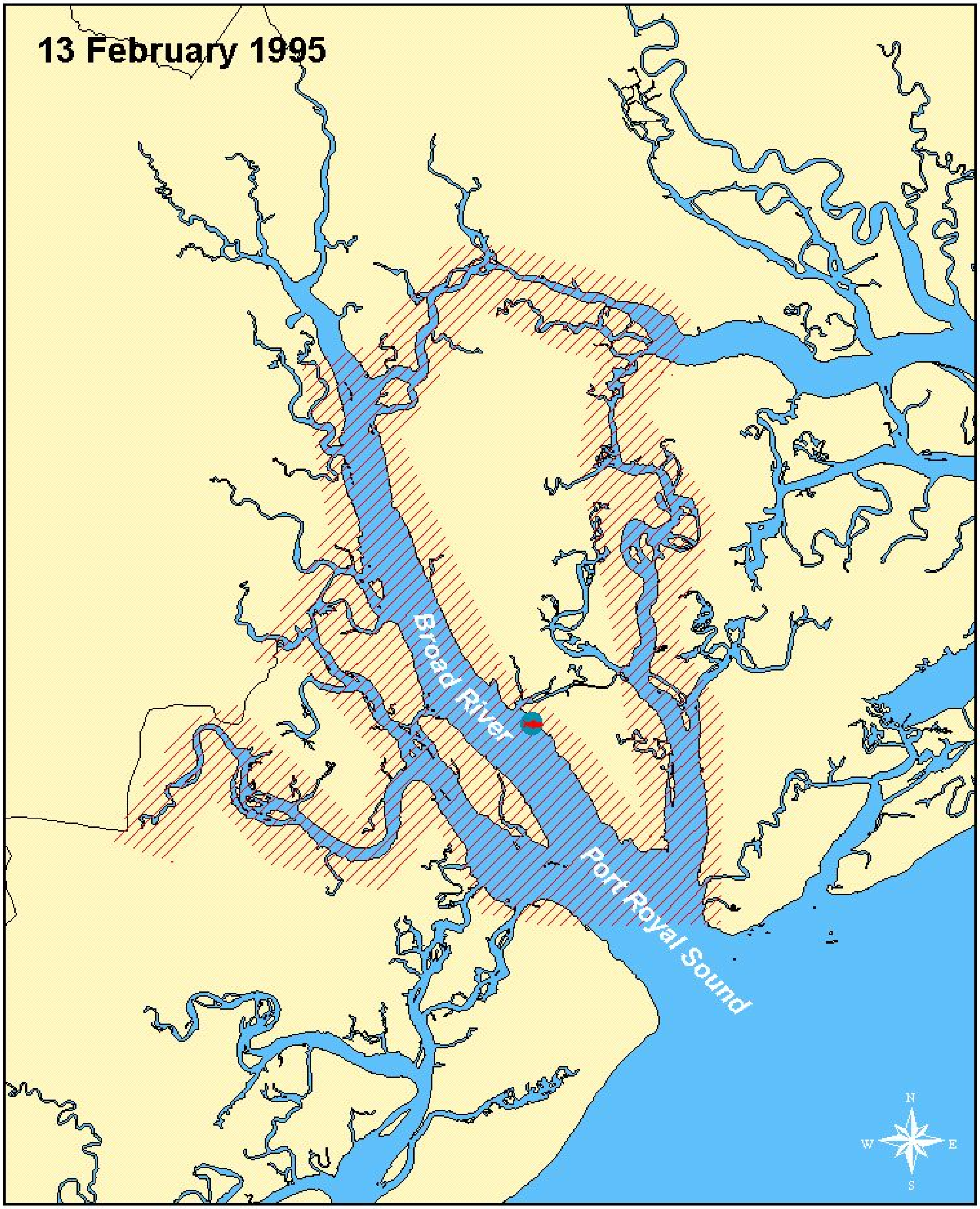


Figure 7. Area surveyed on 13 February 1995 (hatched area) and approximate location of red drum sighting (fish symbol).

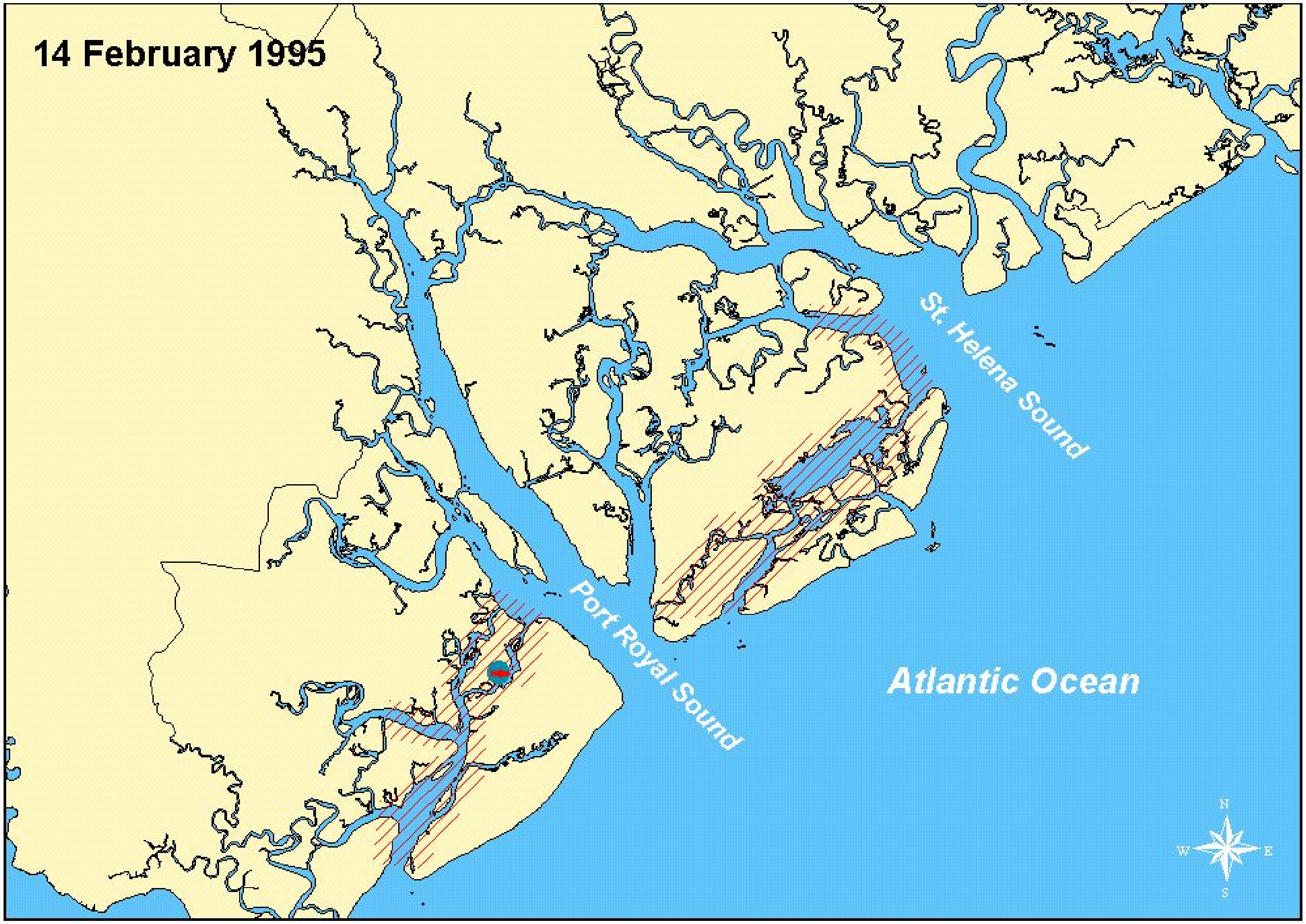


Figure 8. Area surveyed on 14 February 1995 (hatched area) and approximate location of red drum sighting (fish symbol).

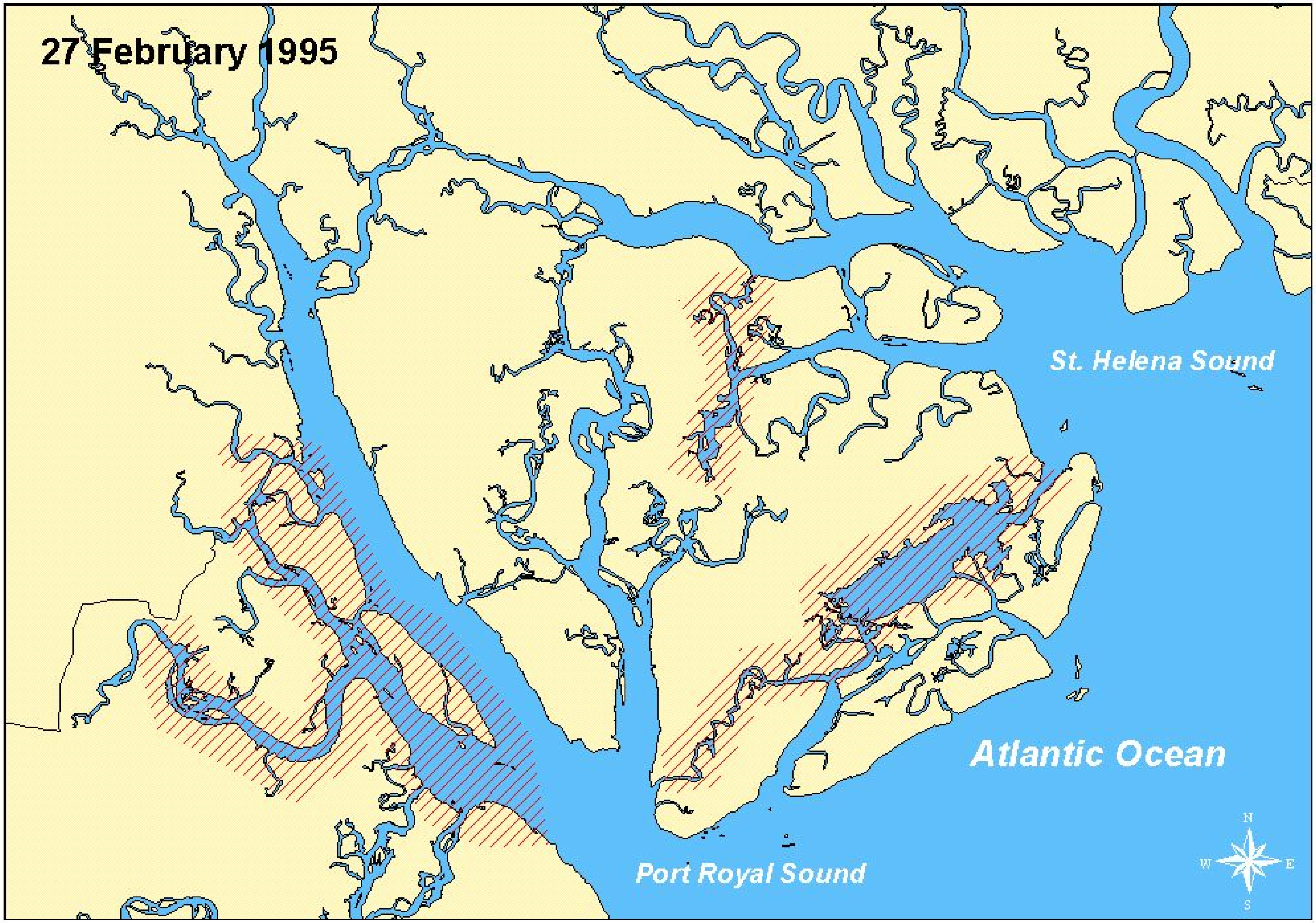


Figure 9. Area surveyed on 27 February 1995 (hatched area). No red drum were sighted on this date.

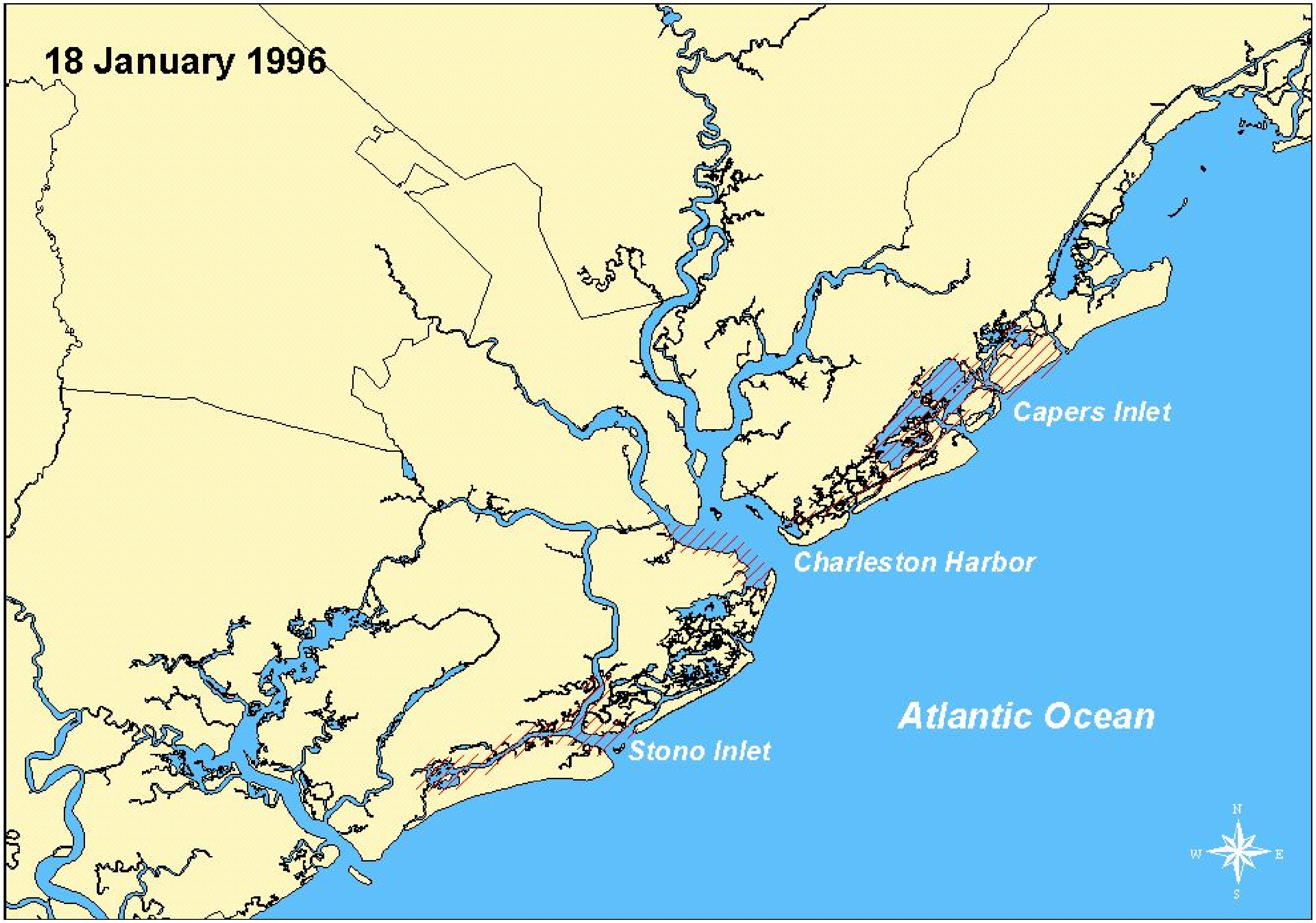


Figure 10. Area surveyed on 18 January 1996 (hatched area). No red drum were sighted on this date.

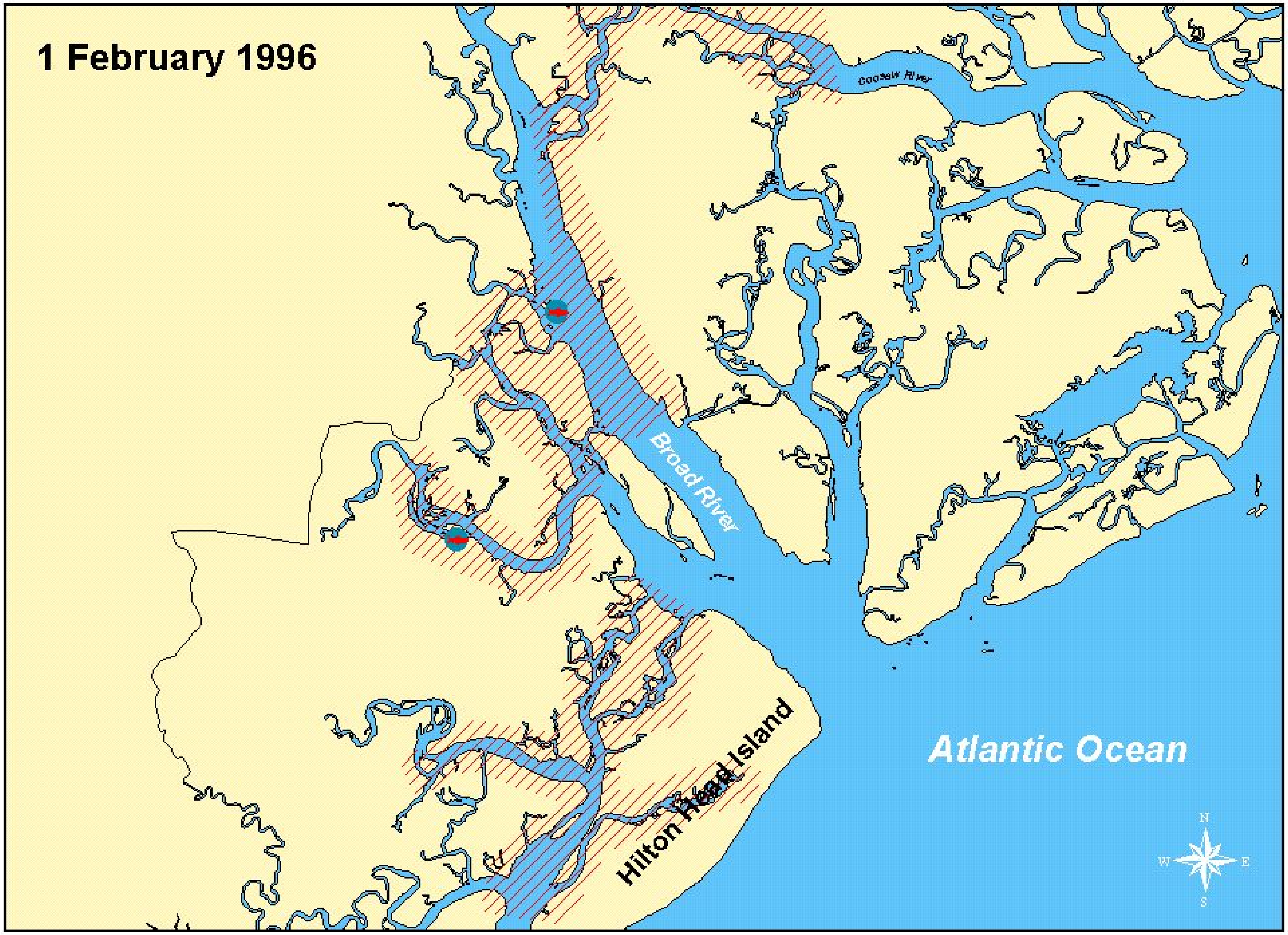


Figure 11. Area surveyed on 1 February 1996 (hatched area) and approximate locations of red drum sightings (fish symbols).

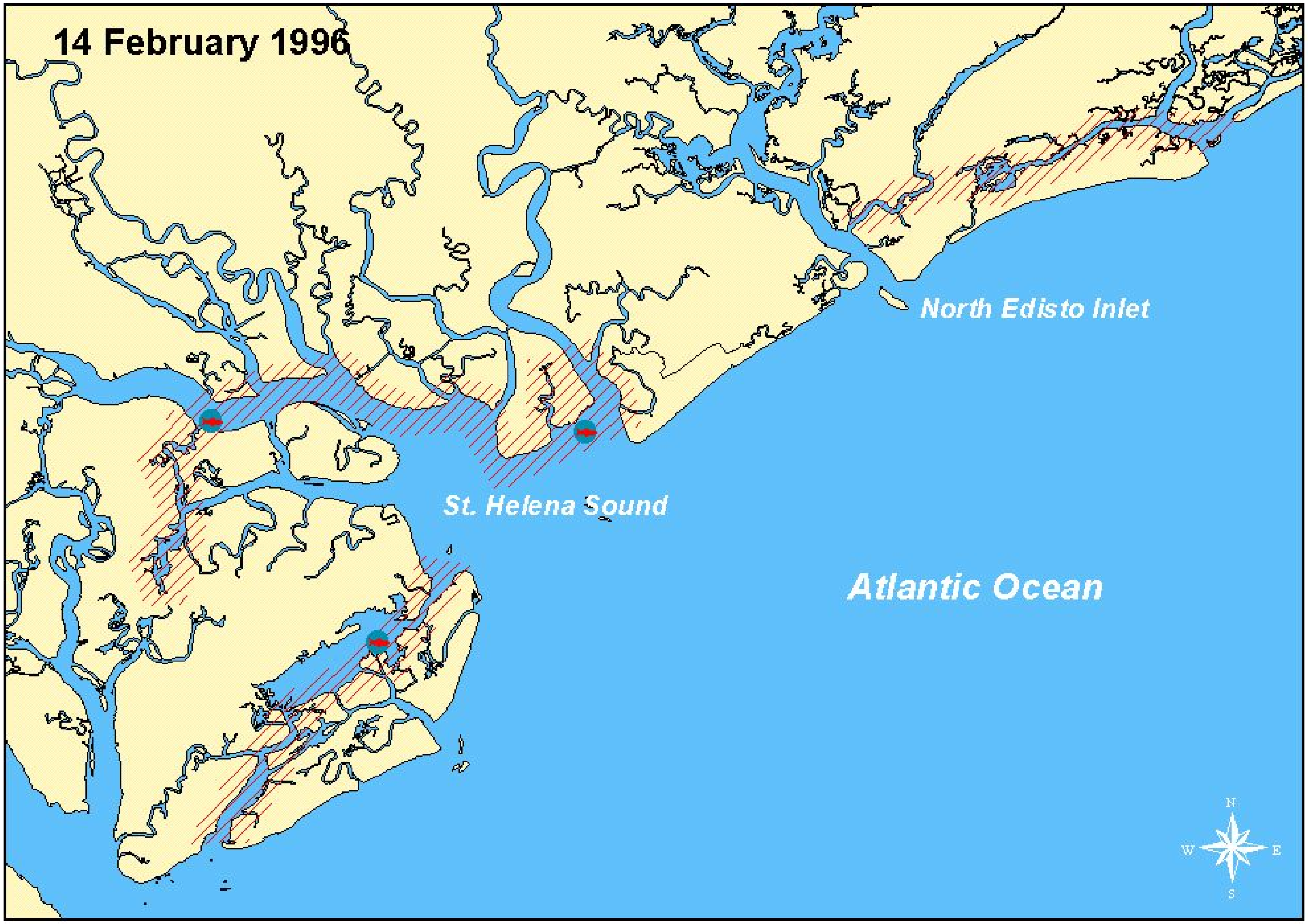


Figure 12. Area surveyed on 14 February 1996 (hatched area) and approximate locations of red drum sightings (fish symbols).

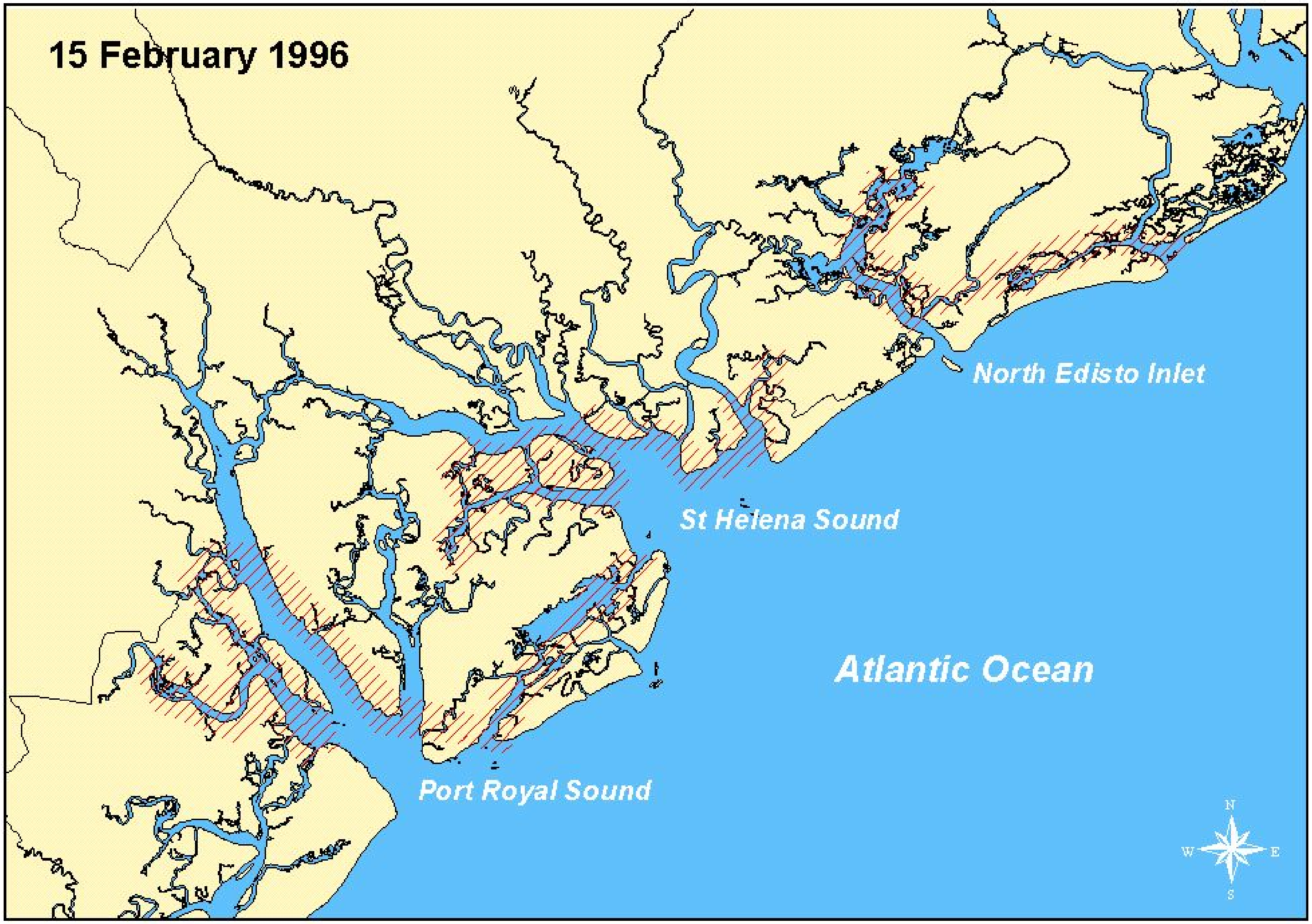


Figure 13. Area surveyed on 15 February 1996 (hatched area). No red drum were sighted on this date.

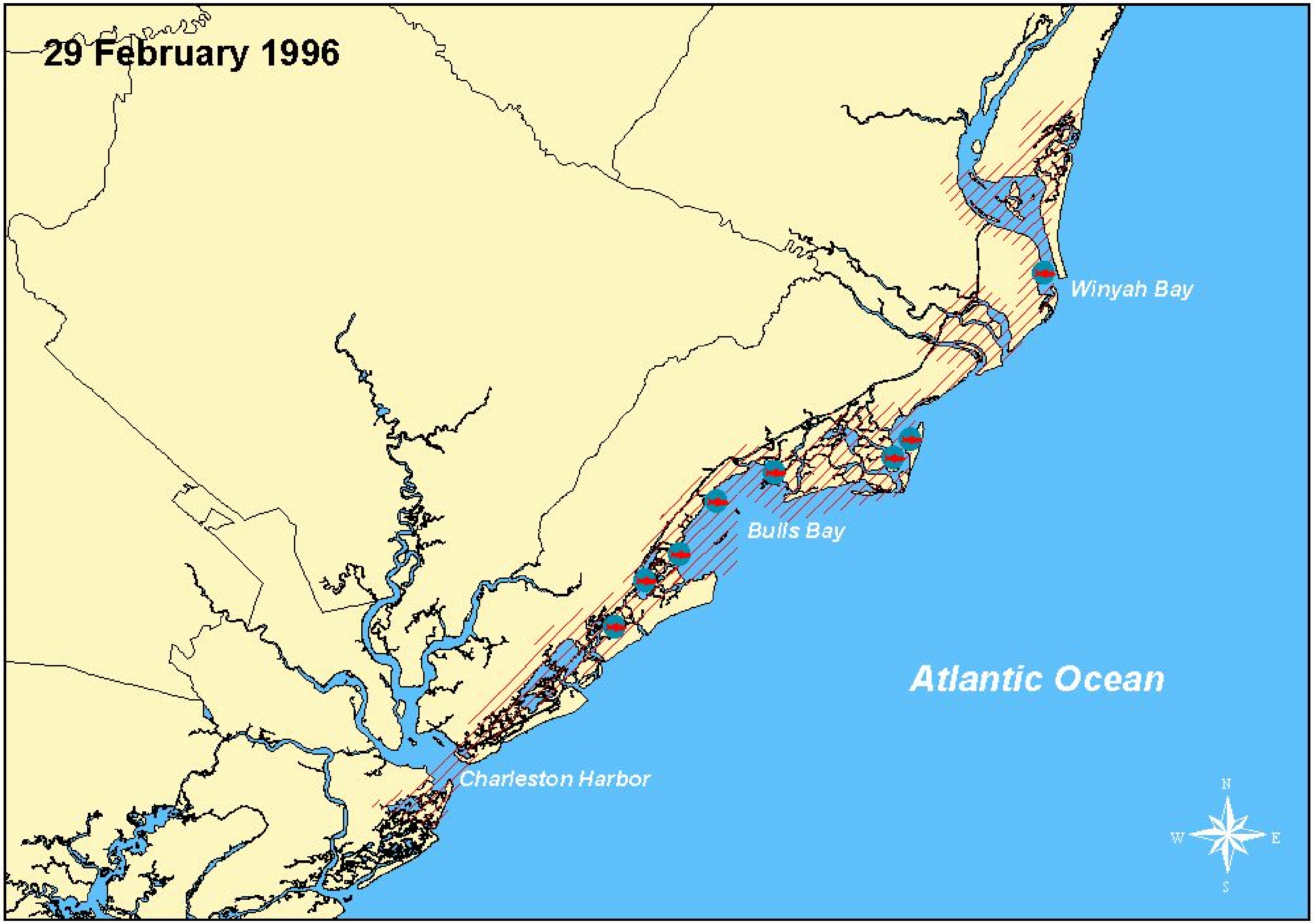


Figure 14. Area surveyed on 29 February 1996 (hatched area) and approximate locations of red drum sightings (fish symbols).

CHAPTER 6.

THE LOCATION OF INSHORE SPAWNING AREAS OF RED DRUM IN SOUTH CAROLINA FROM HYDROPHONE SURVEYS

BY

WILLIAM ROUMILLAT

INTRODUCTION

Sound production by fishes has interested researchers for many years (Fish and Mowbray, 1970; Tavolga, 1980; Fine, 1997). Fishes can produce sound in a variety of ways, by grinding teeth in the pharyngeal jaws, moving pectoral spines and by vibrating their swimbladder with the use of specialized musculature to produce croaking or drumming sounds (Fish and Mowbray, 1970). The most abundant of the sonorous fishes in South Carolina estuaries belong to the drum or croaker family (Sciaenidae). As the common name implies, these fishes have the ability to produce noise, and do so using swimbladder vibration. Red drum (*Sciaenops ocellatus*), black drum (*Pogonias cromis*), spotted seatrout (*Cynoscion nebulosus*), weakfish (*C. regalis*) and other members of this family have been shown to make autochthonous species-specific noises only during known times of spawning activity (Guest and Lasswell, 1978; Mok and Gilmore, 1983; Saucier, 1991; Saucier et al., 1992; Connaughton and Taylor, 1996).

This report is intended to document seasonal and diurnal patterns of sound production in estuarine areas of South Carolina believed to be spawning sites for red drum. Establishing spawning locations and timing of reproductive activities will provide critical information to assist in management decisions for this species. In addition, attempts can be made to minimize human activities which could negatively impact red drum reproductive success, such channel deepening and dredge spoil deposition.

METHODS AND MATERIALS

Transects established to identify the extent of spotted seatrout sound production within the Charleston Harbor estuarine system were also used to investigate red drum spawning activities. Transects were divided into one-quarter mile sections, resulting in approximately 50-60 stations per river system (Riekerk et al., 1997). At least fifteen stations were chosen randomly during each event. Transects (two per week) were made during previously established times of sound production (Riekerk et al., 1997). Stations were sampled from a 6-meter outboard boat with an Interocean hydrophone (model 902). Comparisons among sites were based on underwater sound intensities, calibrated in decibels (dB; referenced to 1 u-pascal).

Efforts to locate spawning sounds in inlets and estuarine waters were made during the known spawning season for this species (mid-August through mid-September) from 1993 through 1998. Data were compiled and analyzed to estimate presence/absence, periodicity and duration of sounds made. Global Positioning Systems (GPS) instrumentation was used to precisely determine coordinates for locations of red drum spawning sounds. Surface hydrophones were used to investigate red drum spawning activities in Winyah Bay and Winyah Bay entrance, the mouth of the Santee River, the north end of Cape Island, Key Inlet, the mouth of Five Fathom Creek, the north end of Bulls Island, Prices Inlet, Capers Inlet, Dewees Inlet, Charleston Harbor and the Charleston Harbor entrance, Stono Inlet, South Edisto Inlet, St Helena Sound, Port Royal Sound and Inlet and Calibogue Sound and Inlet (Figure 1).

Three remote units were used from 1994 through 1998; one constructed by Coastal Technologies Inc, and two made by the Harbor Branch Oceanographic Institute (modeled after the first). Recordings made in Five-Fathom Creek at Cape Romain, the Charleston Harbor entrance, North Edisto Inlet, St Helena Sound and Port Royal Inlet were accomplished using remote hydrophones. These units allowed for continuous analogue and digital recordings to be made for period of up to one week between each deployment and retrieval. Two remote recordings were chosen to compare spawning sound production with tidal flow data. These observations were taken during August of 1996 and 1997.

Statistical and procedures and data summarization were accomplished using the Statistical Package for the Social Sciences software (SPSS version 7.5.1). A student's t-test was used to compare spawning activities with tidal flow data.

Figure 1. Areas along the coast of South Carolina where spawning activity for red drum was investigated. Red dots indicate locales where listening activities used real-time hydrophone equipment; blue dots show where the remote hydrophone was employed. The yellow dots are in locations where red drum were repeatedly heard, and both real-time and remote hydrophones were used in these areas.

RESULTS

Hydrophone use in a deep area near the Charleston Harbor entrance revealed aggregations of spawning sciaenids (spotted seatrout, red drum, black drum and silver perch). Red drum spawning sounds were heard only there within the Charleston Harbor Estuarine System (Table 1, Figure 1). Aggregations of spawning black drum were found in the Charleston Harbor entrance as well as under the Cooper River Bridge farther up the estuary (Table 1). Spotted seatrout spawning aggregations were found in several locations within the Charleston Harbor Estuary (Table 1; Riekerk et al., 1997).

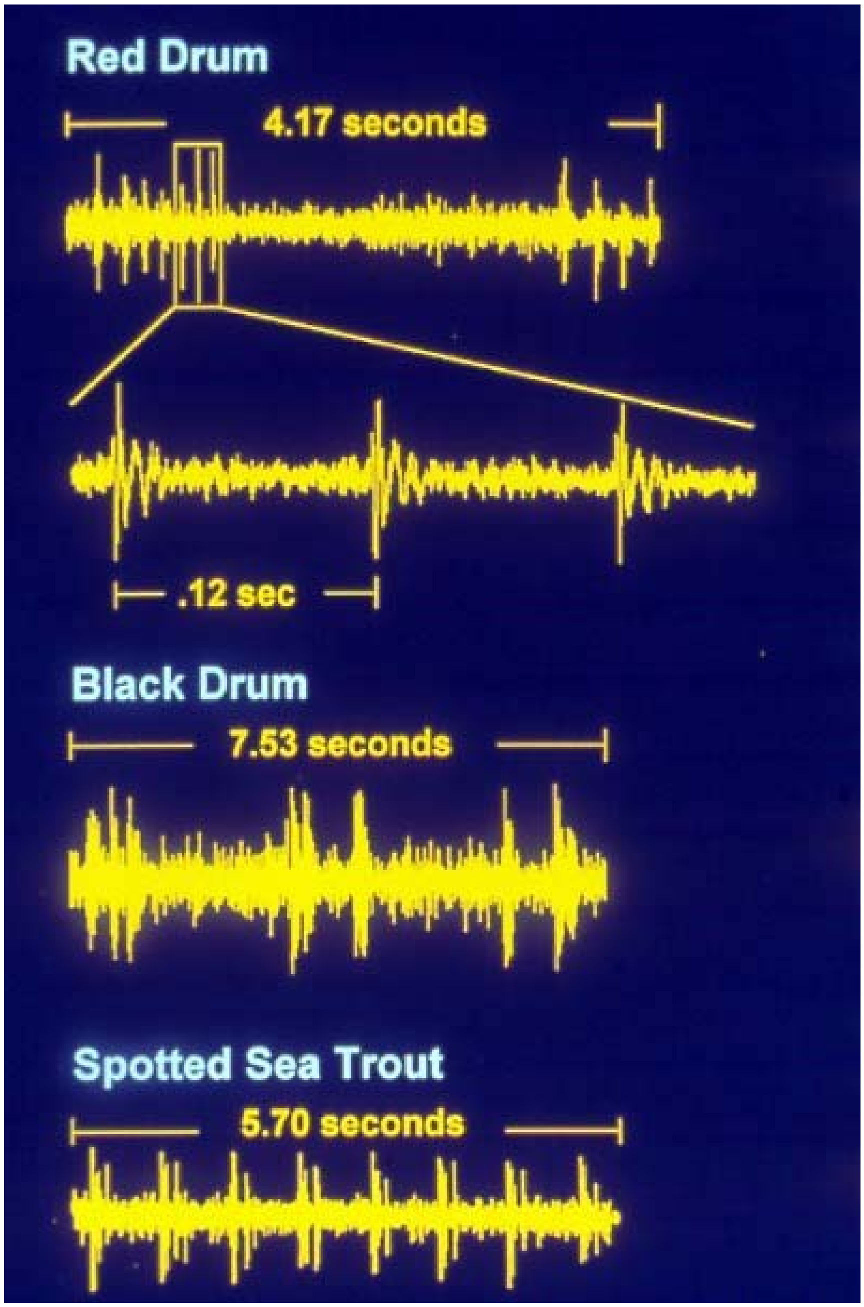
Table 1. Global Positioning System (GPS) latitude and longitude coordinates for spawning activities in the Charleston Harbor as indicated by species-specific fish generated noise levels. SST = spotted seatrout, RD = red drum, BD = black drum. (+) = spawning activity, (-) = no spawning activity.

Location	*Latitude (N)*	*Longitude (W)*	*SST*	*RD*	*BD*
Charleston Harbor Entrance	32^o 44.97’	79^o51.33’	+	+	+
Cooper River Bridge	32^o 48.21’	79^o54.97’	+	-	+
Fort Johnson	32^o 45.22’	79^o53.98’	+	-	-

Dissections of adult male and female red drum revealed that only males possessed the specialized muscle used to create the characteristic knocking noise. Graphic representations of sounds from three common sciaenids are shown in Figure 2.

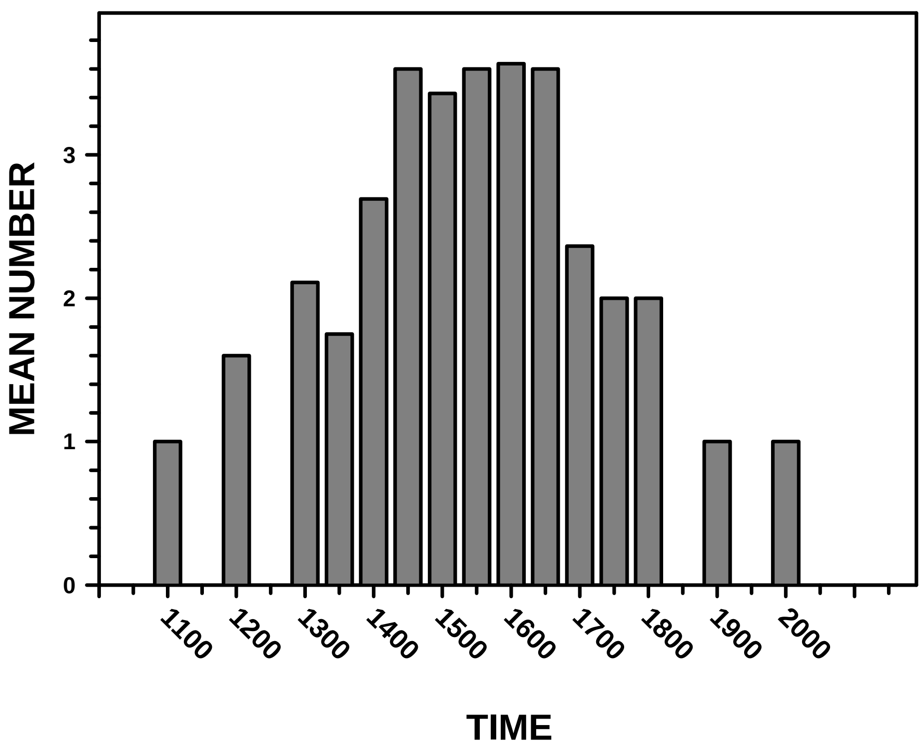
Red drum actively made sounds from 1400 - 2000 hr, with increased noise intensity occurring between

Figure 2. Sonograms of three estuarine species of sciaenids.


Red Drum
4.17 seconds
.12 sec
Black Drum
7.53 seconds
Spotted Sea Trout
5.70 seconds

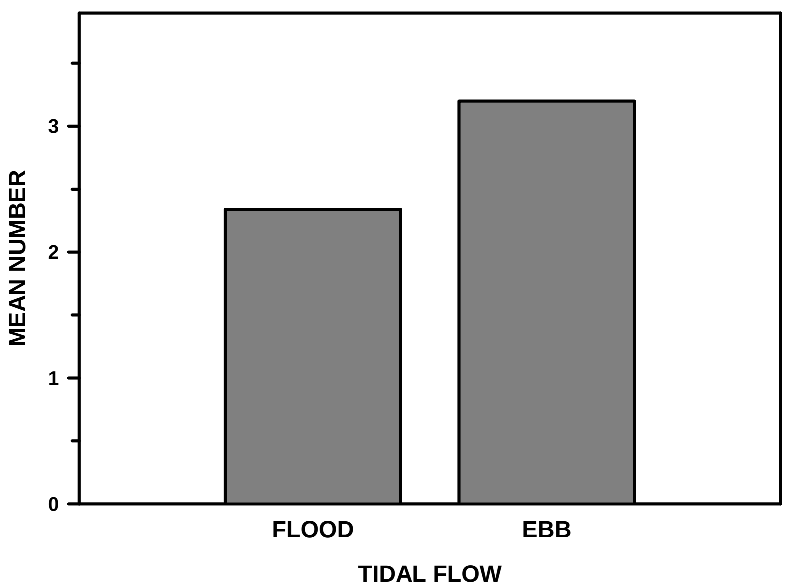
1400 - 1700. Figure 3 shows diurnal activity for red drum from continuous hourly observations from 7 – 15 August 1996. Peak estimated mean number of individuals responsible for the sounds occurred at 1600 hr, and rapidly decreased from that point.

Figure 3. Estimates of the number of red drum participating in sound production by time of day during the spawing season. Data from hydrophone recordings.



Charleston Harbor tidal information from August 1996 and 1997 was plotted against mean number of fish making noise (Figure 4). A students t – test ($p<0.05$) indicated an increase in activity during outgoing tidal stages. There was not enough temporally taken data to test for spawning activity with moon phase.

Figure 4. Estimates of the number of red drum producing sounds by tidal stage during the spawning season. Data from hydrophone recordings.



The area in the Charleston Harbor where spawning noises were detected consists of a hydraulic hole (20-25m) with 6 - 8m of vertical relief on its northeastern edge. Using the physical characteristics of this particular location, other inlets along the South Carolina coast were targeted (Figure 1). No red drum noises were heard in any of these areas.

St.. Helena Sound was the only other location besides Charleston Harbor where red drum spawning activity was detected. The St. Helena region differed from our previously targeted areas in that it was comprised of three 10 - 12m holes surrounded by shoaler regions, and located 10 - 15 km inshore of the ocean beaches (Figure 1). Once there was an indication of red drum spawning inside an estuary, activities were directed to other inshore areas in South Carolina. Transects were established in Winyah Bay, St Helena Sound, Port Royal Sound and Calibogue Sound (see Figure 1). Spawning noise was detected only in St. Helena Sound and the Charleston Harbor entrance.

DISCUSSION

Red drum and spotted seatrout have been granted gamefish status in South Carolina; this in recognition of their economic and aesthetic importance to the recreational angling community. Little has been published on fishery dynamics of either species, in SC or elsewhere, even though evidence of declining stocks and human population growth along the coast seem to be related. In an effort to ensure healthy numbers of red drum in coastal SC, escapement from the estuarine dependent juveniles to the adult spawning stock must be established. Approaching this problem pragmatically, the first piece of critical information was to discover locations of red drum spawning aggregations. After these areas were appropriately defined, attempts could be made to establish the age composition of spawning adults. This study establishes the first part of this problem by defining areas of red drum spawning activity in coastal South Carolina.

It has been demonstrated that spawning activity by members of the drum family can be identified though the use of passive underwater listening devices (Takemura et al., 1978; Saucier et al., 1992; Riekerk et al., 1997). Hydrophone sampling for spotted seatrout, red drum, and black drum has been done intermittently for the last 6-8 years (Riekerk et al., 1997). A regimented transect design monitored spotted seatrout aggregations throughout the 1993 spawning period, and was found to overlap the season of red drum reproductive activity. Other less regimented surveys of red drum and black drum spawning activities have also been compiled. Concentrations of spotted seatrout spawning activities were found under many of the bridges on transects made while sampling the entire Charleston Harbor Estuarine System (Riekerk et al., 1997). Red drum spawning, however, was much more localized and restricted to the entrance channel. We expected to find additional aggregations of spawning red drum in habitats along the SC coast with characteristics similar to those locations where spawning aggregations were found in the Charleston Harbor. Deep water near the ocean was surveyed for red drum spawning activity since 1994, but no other areas with similar physical characteristics to the Charleston Harbor entrance appeared to be utilized by spawning red drum. The area in St. Helena Sound where spawning red drum were heard was different from the Charleston Harbor entrance site in that it was shallower and further away from the ocean. Investigations into a broader array of habitats and locations (including deeper areas of estuaries well inland of the coast) showed no additional signs of red drum spawning.

Takemura et al. (1978) mentioned that spawning activities of Japanese drum could not be correlated with tidal flows. This study found that spawning occurred every afternoon from mid-August through mid-September, regardless of tidal current direction. There was, however, more activity noted when the diurnal times for spawning co-occurred with ebbing tides. If this relationship held true throughout the spawning period for red drum, a maximal dispersion of eggs and larvae might be posed as an explanation. Wenner et al. (1990) demonstrated tidal transport as an estuarine ingress mechanism for red drum larvae. If more eggs and larvae were released during ebb-tide flows through the Charleston Harbor entrance channel, larvae from a single spawning event would disperse over a wider area. The young red drum would spread into the near shore oceanic waters before their ultimate estuarine ingress. This strategy might explain the discrete, well-separated locations of red drum spawning activity found along the middle and southern parts of the South Carolina coast. Based, though on near-shore water current movements in South Carolina, passive drift during August and September would move eggs and larvae toward the south (Matthews and Pashuk, 1977). Discovering no active spawning sites for red drum in the northern coastal area of South Carolina remains problematic.

Location coordinates (GPS) and times of spawning activities of spotted seatrout, red drum and black drum are critical for two important reasons. First, the locations of these discrete areas in coastal South Carolina will allow resource managers to make rational decisions on issues concerning dredging activities and dredge-spoil deposition. Second, this information is important to biologists interested in establishing the size and age composition of spawning populations. Once the specific spawning locations are known, efforts to estimate size of aggregations and their spawning potential can be attempted. Parameters such as egg production and spawning-stock biomass can be assessed to provide critical data for managing the red drum fishery and ensuring its continued survival.

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CHAPTER 7 {A}

ESTIAMTES OF CAPTURE, HANDLING AND TAGGING MORTALITY OF RED DRUM

BY

MYRA BROUWER

INTRODUCTION

Mark-recapture analyses for multi-year tagging studies employ methods (Brownie models) that allow for the estimation of tag recovery rates and survival rates that are age- and year-specific (Hoenig *et al*., 1998a). Models developed by Brownie *et al.* (1985) were recently modified in order to estimate instantaneous rates of fishing and natural mortality by utilizing information on the seasonal distribution of fishing effort (Hoenig *et al*, 1998a). One approach depends strongly on effort data; in this case tag recovery rates and tag retention-survival rates must be known. Tag-induced mortality is a component of the retention-survival rate and can be estimated by conducting experiments whereby animals are tagged and held in captivity for an amount of time. Seasonal experiments are necessary in certain environments to account for added stress independent of the tagging procedure. Thus a series of experiments at different water temperatures was designed to estimate handling and tag-induced mortality to incorporate in the models.

MATERIALS AND METHODS

A series of seasonal handling mortality experiments were carried out beginning in the winter of 1997 until the winter of 1998. During each of the four seasons, red drum were sampled using trammel nets deployed from shallow water boats in Charleston Harbor. Sets were made during the ebbing tide in areas where red drum activity was observed. When a school was located in shallow water, the trammel net was deployed in an arc against the shore from a fast moving boat. The boat then moved inside the enclosed area and the water was disturbed in an attempt to frighten the fish into hitting the net and becoming entangled. Captured fish were placed in a large oxygenated tank brought on an accompanying boat. As the fish were placed in the tank, their size was recorded to ensure that enough individuals of each size category (above and below 55 cm TL) were obtained. If previously tagged individuals were captured and not enough untagged fish were available, tagged fish were used as controls since it was assumed that any stress resulting from a previous tag would not bias the experiment (J. Archambault, SCDNR, pers. comm., 1999). Red drum were then transported by boat to the Marine Resources Research Institute where the mortality experiments were carried out. Fish were once again measured and tagged appropriately based on size. Fish larger than 55 cm TL received a steel-tipped shoulder dart tag whereas individuals below this size were tagged using an internal anchor abdominal tag. Tagged and untagged (or previously tagged) fish were randomly paired by size and placed in 3.7m diameter x 0.9m deep outdoor holding tanks with flow-through Charleston Harbor water. This ensured that the animals were kept at approximately the same environmental conditions as when they were captured. Attempts were made to limit the number of fish per tank to about 20. This number was considered to be below or within the carrying capacity for each tank (T. Smith, SCDNR, pers. comm., 1997). Fish were kept in the holding tanks for 4 days. Water quality parameters for each tank were monitored daily and the condition of the animals noted. At the end of the experiment, the tanks were drained and mortality data recorded. Untagged control fish were tagged as appropriate and all animals were then released.

RESULTS

A total of 10 handling and tag mortality experiments were carried out between January 13, 1997 and November 13, 1998. Experiments were conducted for three ambient temperature regimes (1) cold (< 15^{O}C), (2) mild (16-25^{O}C), and (3) hot (> 26^{O}C). Hence, based on mean water temperature at the time of specimen capture, 2 of the experiments were done in cold temperature (winter), 5 in mild temperature (spring – fall), and 3 in hot temperature (summer).

Cold temperature (winter) experiments

The first cold water temperature experiment was carried out on January 13, 1997. Mean water temperature at the time of specimen capture on this day was 13.3^{O}C. Thirty red drum > 55 cm TL were tagged with shoulder dart tags and 10 fish < 55 cm TL were tagged using internal abdominal anchor tags. An equal number of untagged controls were included in the experiment. Fish were held for 96 hours at water temperatures ranging from 8.0^{O}C to 11.5^{O}C. Salinity ranged from 26 ppt to 29 ppt, and dissolved oxygen ranged from 9.13 mg/L to 10.36 mg/L. No mortality was observed for either size category among either tagged fish or controls.

The second cold water handling and tag mortality experiment was conducted on February 3, 1997. The mean ambient water temperature on this day was 12.6^{O}C. Twenty red drum received shoulder dart tags and 33 received abdominal anchor tags. An equal number of untagged controls were included in the experiment. Fish remained in holding tanks for 96 hours. Water temperature inside the tanks ranged from 11.2^{O}C to 12.0^{O}C, salinity ranged from 32 ppt to 34 ppt, and dissolved oxygen ranged from 9.16 mg/L to 9.70 mg/L. No mortality was observed for either tagged fish or controls.

Mild temperature (spring – fall) experiments

On February 27, 1997, 54 red drum were captured in waters averaging 16.8^{O}C. Twelve fish received shoulder dart tags, 13 received internal anchor tags and an equal number of controls for each category remained untagged. Water temperatures in the holding tanks, where the animals remained for 96 hours, ranged from 14.8^{O}C to 16.9^{O}C. Salinity and dissolved oxygen ranged from 25 ppt to 29 ppt and 8.50 mg/L to 9.15 mg/L, respectively. No mortality was observed during this experiment for either tagged fish or controls.

The following month, on October 27, 1997, only 19 red drum were obtained for the experiment. Ambient water temperature on this day averaged 20.0^{O}C whereas temperature in the holding tanks ranged from 17.2^{O}C to 20.7^{O}C. Salinity and dissolved oxygen ranged from 23 ppt to 30 ppt and 6.92 mg/L to 7.50 mg/L, respectively. Eight red drum were newly tagged with shoulder dart tags and 2 fish received abdominal tags. Only 7 fish > 55 cm TL were obtained as controls and, of these, 4 had been previously tagged. Two untagged fish < 55 cm TL also served as controls. No mortality was observed during this experiment among tagged fish or controls.

Sampling for red drum was conducted again on October 30, 1998, in waters averaging 20.3^{O}C. Ten red drum > 55 cm TL received shoulder dart tags and twenty fish received internal anchor tags. An equal number of controls were obtained for each of the size categories. However, all 10 controls for the large category had been previously tagged whereas 7 out of 20 of the smaller animals had also been tagged in the past. Water temperature in the holding tanks for the 96 hours that the animals were kept ranged from 20.6^{O}C to 22.7^{O}C. Salinity ranged from 25.5 ppt to 33.5 ppt and dissolved oxygen ranged from 6.48 mg/L to 7.9 mg/L. No mortality was observed in this experiment among either tagged or control animals.

Another mild temperature mortality experiment was conducted on November 9, 1998 when ambient water temperature averaged 18.7^{O}C. Four red drum > 55 cm TL were newly tagged with shoulder dart tags. Four control fish were obtained two of which had been previously tagged. Six fish were newly tagged with internal abdominal anchor tags and five controls were available for this size category. Of these, two had been previously tagged. Water temperature in the holding tanks, where the fish remained for 96 hours, ranged from 18.2^{O}C to 19.7^{O}C. Salinity and dissolved oxygen ranged from 23.8 ppt to 31.9 ppt and 7.14 mg/L to 7.38 mg/L, respectively. No mortality was observed in this experiment among tagged or control fish.

The last mild temperature experiment was carried out on November 13, 1998. Mean water temperature on this day was 16.6^{O}C. Thirteen red drum received shoulder dart tags and 12 served as controls. Eleven of the control animals had been previously tagged. Six fish were tagged using internal anchor tags and 5 served as controls. Among the control animals, one had been previously tagged. Water temperature in the holding tanks during this experiment ranged from 18.4^{O}C to 18.9^{O}C. Salinity ranged from 22.9 ppt to 31.5 ppt and dissolved oxygen ranged from 7.43 mg/L to 8.04 mg/L. Again, no mortality was observed among tagged or control red drum.

Hot temperature (summer) experiments

Three tag mortality and handling experiments were conducted at high water temperatures during the summer of 1997. The first took place on July 14, 1997 when water temperature in Charleston Harbor averaged 28^{O}C. Twenty-one red rum in the large size category (> 55 cm TL) were tagged using shoulder dart tags and 21 animals in the same size class remained untagged. Only 6 fish were obtained that measured < 55 cm TL. Three of the fish were tagged using internal anchor tags and three untagged animals served as controls. Water temperature in the holding tanks ranged from 27.9^{O}C to 29.1^{O}C. Salinity and dissolved oxygen ranged from 16 ppt to 26 ppt and 5.0 mg/L to 6.7 mg/L, respectively. Mortality was observed within 24 hours among fish > 55 cm TL. Three of the experimental animals (14.3% mortality) and 5 of the control fish died (23.8% mortality). No mortality was observed among tagged or control animals in the smaller size category (< 55 cm TL).

The second experiment took place on July 28, 1997. Water temperature in Charleston Harbor averaged 30^{O}C that day. Nine red drum received shoulder dart tags and 13 fish received abdominal anchor tags. The same number of animals in each of the size categories served as controls and remained untagged. Water temperature in the holding tanks during this experiment ranged from 26.0^{O}C to 31.5^{O}C whereas salinity and dissolved oxygen ranged from 18 ppt to 27 ppt and 5.2 mg/L to 10.1 mg/L, respectively. Three of the experimental animals who received shoulder tags died (33.3% mortality) whereas one of the control fish died (11.1% mortality). Similar to the previous experiment, no mortality was observed among the smaller fish.

The last of the tag mortality and handling experiments at high water temperature was conducted on August 15, 1997. On this day, water temperature in the Harbor averaged 29.3^{O}C. Twenty red drum received shoulder dart tags whereas 10 fish were fitted with internal anchor tags. The same number of animals served as controls for each category. Sixteen of the 20 large fish (> 55 cm TL) had been previously tagged. Water temperature in the holding tanks ranged from 25.0^{O}C to 29.0^{O}C. Salinity ranged from 25 ppt to 28 ppt and dissolved oxygen ranged from 5.75 mg/L to 7.4 mg/L. Two out of the 20 experimental animals who received shoulder tags died (10% mortality) and 7 of the control fish in this same size category died (35% mortality). Again, no mortality was observed among either tagged or control fish in the smaller (< 55 cm TL) size category.

Thus, mortality was only observed among red drum > 55 cm TL during summer months. Overall mortality was 26% for fish in this size category.

Results for each water temperature treatment are summarized in Table 1.

Table 1. Results of ten tag mortality and handling experiments conducted at three water temperatures from January 1997 through November 1998. Numbers in parentheses indicate sample size.

Water Temperature	***Tag Type***	***Mortality***	
		Tagged	***Control***
Cold	Shoulder dart	0 (30)	0 (30)
	Internal anchor	0 (10)	0 (10)
Cold	Shoulder dart	0 (20)	0 (20)
	Internal anchor	0 (33)	0 (33)
Mild	Shoulder dart	0 (12)	0 (12)
	Internal anchor	0 (13)	0 (13)
Mild	Shoulder dart	0 (8)	0 (7)
	Internal anchor	0 (2)	0 (2)
Mild	Shoulder dart	0 (10)	0 (10)
	Internal anchor	0 (20)	0 (20)
Mild	Shoulder dart	0 (4)	0 (4)
	Internal anchor	0 (6)	0 (5)
Mild	Shoulder dart	0 (13)	0 (12)
	Internal anchor	0 (6)	0 (5)
Hot	Shoulder dart	3 (21)	5 (21)
	Internal anchor	0 (3)	0 (3)
Hot	Shoulder dart	3 (9)	1 (9)
	Internal anchor	0 (13)	0 (13)
Hot	Shoulder dart	2 (20)	7 (20)
	Internal anchor	0 (10)	0 (10)

DISCUSSION

Previous tag mortality studies have revealed that red drum are particularly well suited to handle stress related to capture, handling and tagging. In a study conducted by the Texas Parks and Wildlife Department to assess the efficacy of different types of tags and measure tag related mortality, red drum showed the lowest mortality rate (24%) during the nine-month experiment (Elam, 1971). Gutherz *et al*. (1990) found that tagging adult red drum with internal anchor tags did not increase mortality over untagged fish. Among juvenile red drum (102-173 mm TL), tagged with internal anchor tags and nylon dart tags, Winner *et al*. (1999) found 21% mortality, 32% mortality and 21% mortality among control animals, those fitted with anchor tags and those tagged using dart tags, respectively, 66 days after tagging took place. These studies suggest that red drum generally respond well to handling and tagging stress. However, water temperature was not addressed as a factor that could potentially alter the response of the fish to tagging stress.

In studies undertaken at the Marine Resources Research Institute involving the capture and tagging of red drum in coastal South Carolina, it has been consistently observed that animals respond better to handling stress at low temperatures (W. Roumillat, SCDNR, pers. comm., 1998). Overall, red drum in this study responded well to handling and tagging stress at water temperatures below 25^{O}C. No mortality was observed during any of the cold temperature or mild temperature experiments in either size category. At high temperatures, however, results of these experiments suggest that fish > 55 cm TL experience low mortality levels. It is unclear whether fish die as a result of the tagging procedure or due to handling stress. Because a relatively high number of untagged control fish in this size category also experienced mortality, handling stress seems to be the most likely cause. Weathers *et al*. (1990) found up to 32% mortality among largemouth bass tagged with internal anchor tags. However, they cited handling stress and water temperature as contributing factors and reported that internal anchor tags did not cause significant mortality over a 30-day period. Similarly, this study showed that red drum fitted with internal anchor tags experienced zero mortality over 96 hours at all temperatures.

There was an obvious difference in mortality between the two size categories. Overall, 292 red drum > 55 cm TL and 230 fish < 55 cm TL were used in this series of experiments. Red drum < 55 cm TL experienced no mortality at all temperatures whereas larger animals experienced low levels of mortality (26%) at high water temperatures. Because sample sizes are not the same, relative comparisons between the two groups are biased. However, we may speculate as to other contributing factors. For instance, young red drum inhabit estuarine environments that are typically low in dissolved oxygen, especially during summer months. It may be that there is a physiological adaptation to such low levels of oxygen that allows younger animals to withstand temperature-related stresses. Another factor that may have contributed to the observed mortality among large fish is the relative amount of handling stress they experienced. It takes longer to remove a large red drum that has become entangled in a trammel net than it does to remove a smaller fish. Also, large red drum appear to struggle more once they become entangled in the net and therefore become fatigued more quickly than smaller animals. Because of their sheer size and volume, large fish were probably handled more than small fish.

Short-term handling mortality rates obtained through this study were incorporated into analyses using modified Brownie models (Hoenig *et al*., 1998a) to estimate fishing and natural mortality of subadult red drum in the Charleston Harbor estuarine system (Latour *et al*., in prep.). It was determined that tag-induced mortality at the levels observed among red drum in this study does not bias parameter estimates obtained through the models for either age 1 or age 2 red drum.

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CHAPTER 7{B}

ESTIMATES OF TAG SHEDDING RATES IN MARKED RED DRUM BY DOUBLE TAGGING EXPERIMENTS

BY MYRA BROUWER

INTRODUCTION

Models used in the analysis of mark-recapture data require estimates of tag-shedding rates in order to adjust survival rate estimates. Survival rates may be underestimated when tag loss is present because the number of recaptured animals will be greater than the number of animals observed with a tag during any particular sampling event (Fabrizio *et al*., 1996). Treble *et al*. (1993) point out that estimates of fishing mortality may be biased by tag loss occurring soon after the animal is released (type I tag loss after Beverton and Holt, 1957) whereas chronic tag loss (type II tag loss) may affect estimates of total mortality (Ricker 1958). Therefore, estimates of instantaneous tag loss and chronic tag loss must be established and incorporated into the models. Double tagging experiments are a valid method of obtaining such estimates (Seber, 1982).

Tag-recapture data has been collected for red drum in South Carolina since 1986. Some of these data will be analyzed using models first proposed by Brownie *et al.* (1985) and reparameterized by Hoenig *et al*. (1998a and b). Double tagging was begun in September 1996 and continued until July 1999 in all estuarine areas where stratified random trammel net sampling was conducted by project biologists. Data obtained in the Charleston Harbor estuarine system (including the Lower Wando and Ashley Rivers) was provided to Robert J. Latour and Kenneth H. Pollock of North Carolina State University and John M. Hoenig of the Virginia Institute of Marine Science, College of William and Mary, for analysis using the above mentioned models.

MATERIALS AND METHODS

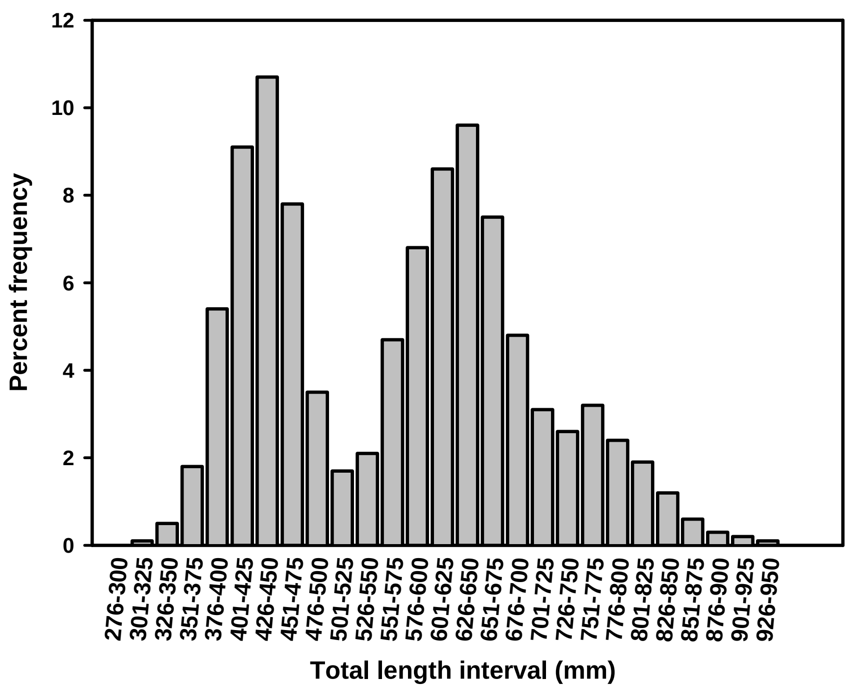
Red drum were sampled in estuarine areas throughout coastal South Carolina using trammel nets deployed from shallow water boats (see previous sections for complete description). Subadult red drum were tagged using two different types of tags according to the animal's total length (TL). Fish < 55 cm TL were fitted with Floy ¼'' x 1" orange color laminated internal anchor tags with a 3" orange colored streamer with wire through the entire length of the streamer (tag type A). Tags were inserted through an incision made in the abdominal cavity just posterior and slightly below the tip of the left pectoral fin as the latter was depressed against the side of the fish. Fish > 55 cm TL were tagged using Hallprint's type SSD steel-tipped dart tags with orange streamers with wire through the entire streamer (tag type B). Dart tags were inserted in the body musculature to the left of the first dorsal fin using a tag applicator. Hallprints's small nylon dart tags, type PTD, were used as double tags. They were also inserted in the body musculature to the left of the first dorsal fin using a tag applicator.

Some of the data obtained through this study for red drum inhabiting the Charleston Harbor estuarine system were analyzed by Latour *et al.* (in prep.) in order to obtain estimates of tag loss for each type of tag. The authors used tag shedding models of the form $Q_x(t) = \rho_x e^{-\phi xt}$, x= A or B, where Q_X is the probability of a tag of type x being retained at time t after release, ρ_x is the probability of retention immediately after tagging and ϕ_x is the instantaneous rate of tag shedding (Barrowman and Myers, 1996).

RESULTS

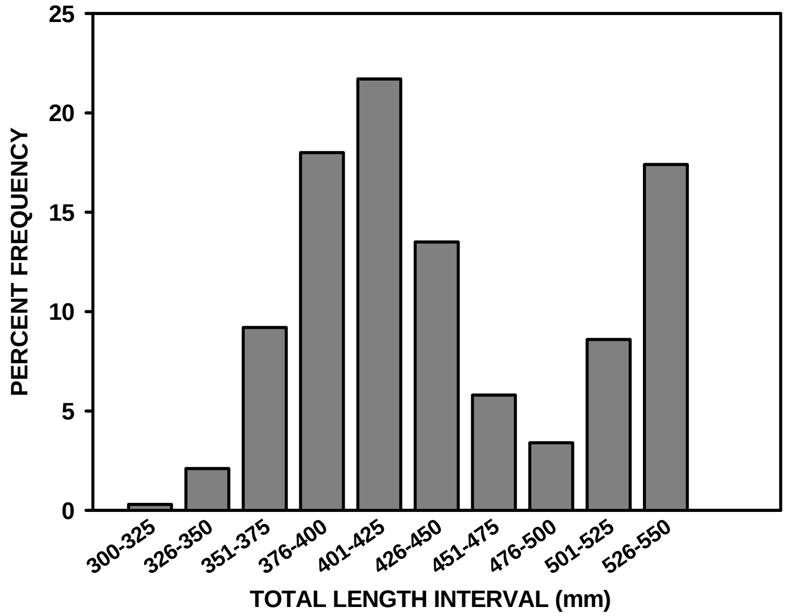
During the period from September 1996 through July 1999, in all estuarine areas sampled, 4,161 red drum were double tagged (Figure 1). Of these, 770 animals were recovered with one or both tags intact.

Figure 1. Percent frequency of tagged red drum in SC waters from Sept. 1996 through July 1999. Total length is length at release in 25 mm intervals



A total of 1,954 red drum < 55 cm TL were double tagged and released. Of these, 323 animals were recaptured. Figure 2 shows the length frequency distribution of the double tag recaptures in this size category.

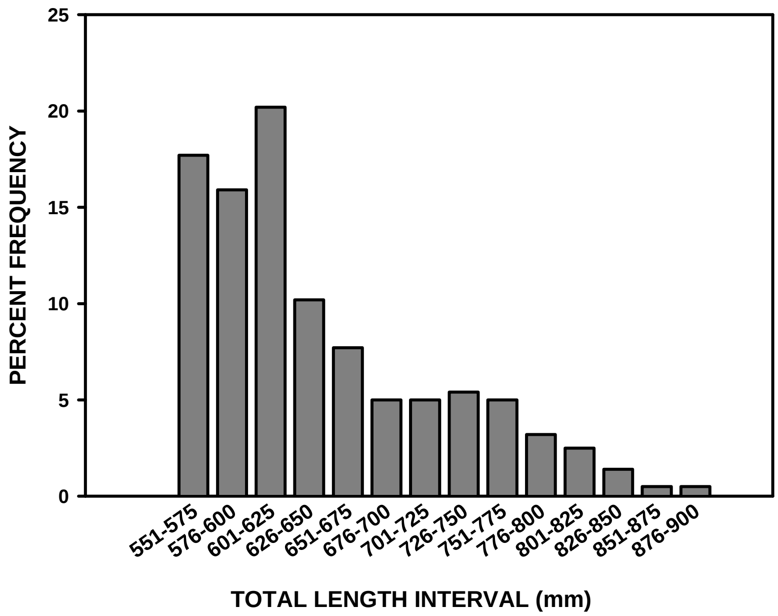
Figure 2. Percent frequency of recaptures for red drum < 55 cm TL tagged with internal anchor tags (Type A). Total length is length at release in 25 mm intervals



Out of 2,207 red drum > 55 cm TL that were double tagged and released, 447 were recaptured. The length frequency distribution for this size category is shown in Figure 3. Among recaptured fish tagged with internal anchor tags, a total of 30 lost the nylon double tag and 10 lost the anchor tag (Figure 4). Of the 447 fish > 55 cm TL that received the steel-tipped dart tags, 24 lost the nylon double tag and only 6 lost the shoulder dart tag (Figure 4). Two of the internal anchor tags were lost within the first 100 days at liberty (one at 57 days and one at 83 days) whereas the first incidence of tag loss among fish with steel-tipped dart tags did not occur until 274 days at large (Tables 1 and 2).

Figure 3. Percent frequency of recaptures for red drum > 55 cm TL tagged

Table 1. Observed tag loss for subadult red drum < 55 mm TL based on days at large expressed in 100-day intervals.



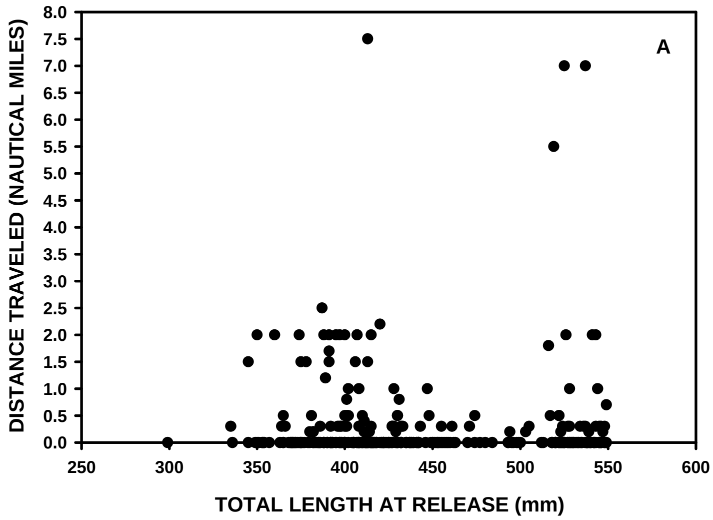
Days at large (100-day intervals)	Both tags present	Nylon (double) tag missing	Anchor tag missing	Total
100	74	1	2	77
200	61	2	1	64
300	40	3		43
400	38	6	2	46
500	33	8	1	42
600	15	3	2	20
700	12	3		15
800	8	2	1	11
900	1	2		3
1000+	1		1	2

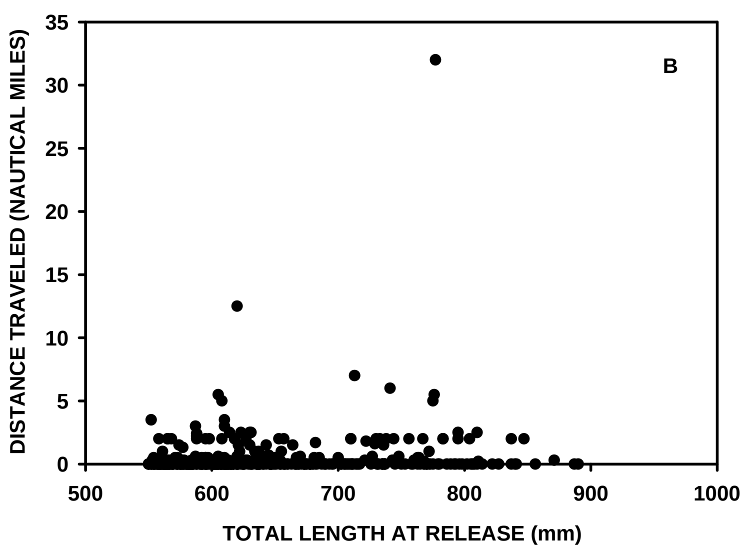
Table 2. Observed tag loss for subadult red drum > 55 mm TL based on days at large expressed in 100-day intervals.

Days at large (100-day intervals)	Both tags present	Nylon (double) tag missing	Shoulder dart tag missing	Total
100	188	1		190
200	101	4		105
300	37	5	1	43
400	35	3	2	40
500	27	5	3	35
600	10	1		11
700	5	3		8
800	9	2		11
900	1			1
1000+	1			1

The maximum distance traveled by an individual among those measuring < 55 cm TL, was 7.5 nautical miles. In general subadult red drum in this size category did not travel further than 2.5 nautical miles from where they were captured, tagged and released (Figure 5a). The majority of larger red drum, those > 55 cm TL, remained within 5 nautical miles of the site of capture and release. However, a few individuals ventured up to 12 nautical miles away and one fish was recaptured 35 nautical miles from the site of initial capture and release (Figure 5b).

Figure 5. Distance traveled (nautical miles) for red drum < 55 cm TL tagged with internal abdominal anchor tags (A) or shoulder dart tags (B).


A
DISTANCE TRAVELED (NAUTICAL MILES)
TOTAL LENGTH AT RELEASE (mm)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
250
300
350
400
450
500
550
600


B
DISTANCE TRAVELED (NAUTICAL MILES)
TOTAL LENGTH AT RELEASE (mm)
0
5
10
15
20
25
30
35
500
600
700
800
900
1000

Latour *et al*. (in prep.) estimated maximum likelihood parameters based on double tagging data from Charleston Harbor and adjacent estuaries obtained from September 1996 through April 1998. The tag shedding models used in the analysis suggested that instantaneous and long-term, or chronic, tag loss were small for both the anchor and steel-tipped dart tags (Table 3). Since tag loss among fish with shoulder dart tags was not observed until approximately 9 months at large, the instantaneous shedding rate was not calculated for the first 8 months. Therefore, the ϕ_B value shown on Table 3 corresponds to the instantaneous shedding rate after the fish had been at large for 9 or more months.

Table 3. Tag shedding parameter estimates and standard errors for both internal anchor tag (type A) and steel-tipped dart tag (type B).

Parameter	***Estimate (SE)***
Immediate shedding of anchor tag, ρ_A	0.9898 (0.0120)
Instantaneous rate of anchor tag loss, ϕ_A	0.0031 (0.0015)
Immediate shedding of shoulder tag, ρ_B	1.0000 (fixed)
Instantaneous rate of shoulder tag loss >= 9 months at large, ϕ_B	0.0043 (0.0013)

DISCUSSION

Results of this study suggest that chronic or long-term tag loss is negligible among subadult red drum tagged in South Carolina waters. Therefore, the bias introduced in the mortality estimates derived from the models is very low. Latour *et al*. (in prep.) reported that estimates of total mortality for both age 1 and age 2 red drum in the Charleston Harbor system were not significantly affected when tag loss was incorporated into the data matrices. Similarly, immediate tag shedding was very low for both tag types. In a similar study conducted in Georgia, Woodward (1994) reported high short-term retention of anchor tags among subadult red drum. Dart tags, on the other hand, showed low retention rates among individuals < 400 mm FL. However, their relative retention rate in double-tagged red drum increased with size indicating that they were more appropriate for tagging larger animals.

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CHAPTER 9.

SUMMARY OF WORKSHOPS DEALING WITH RED DRUM AND HELD IN CHARLESTON, SOUTH CAROLINA

BY MYRA BROUWER

October 4 -- 5, 1994

A workshop was conducted to discuss the status of red drum, *Sciaenops ocellatus*, in South Carolina waters as well as the condition of the red drum stocks in the South Atlantic and Gulf of Mexico. Participants from federal and stage agencies throughout the region were in attendance. Topics of discussion were as follows:

(1) overview of agencies conducting research on red drum and issues being addressed
(2) discussion on ways to measure escapement and attain the targeted 30%
(3) overview of state's compliance with ASMFC management plan
(4) data needed from individual states to conduct stock assessment and fishery trends for the South Atlantic region
(5) monitoring needs and measures needed to ensure stability in the spawning stock biomass
(6) overview of recreational fishing effort and how it affects compliance with measures in the red drum management plan
(7) overview of tag-recapture programs in South Carolina and other South Atlantic states and discussion on how data is utilized
(8) discussion in the tri-state initiative funded by MARFIN to use fishery-independent sampling to follow the disappearance of subadult red drum
(9) overview of problems with MRFSS data
(10) discussion on sonic tracking of red drum, overflights and hydroacoustic estimates

November 23 – 24, 1998

A workshop on red drum mark-recapture studies was hosted at the Marine Resources Research Institute in Charleston. Participants from federal and state agencies were in attendance. Topics of discussion were as follows:

(1) overview of tag-return models including Brownie formulation, extension to instantaneous rates, effect of non-mixing, estimation of selectivity, use of effort as auxiliary variable, estimation of tag reporting and tag shedding, and multiple age class models
(2) demonstration of software developed by Drs. Hoenig and Pollock of the Virginia Institute of Marine Science and North Carolina State University
(3) discussion on the South Carolina red drum tagging program including study design, mortality estimation and estimation of model parameters from reward tagging studies, double-tagging studies, and holding tank studies.

CHAPTER 9.
STORE AND PROVIDE ALL DATA TO THE NATIONAL MARINE FISHERIES SERVICE STOCK ASSESSMENT SCIENTISTS AND PROVIDE ASSISTANCE AS NEEDED

BY

CHARLES A. WENNER

All data collected during the study were provided to Dr. Douglas Vaughan of the Beaufort Laboratory of the National Marine Fisheries Service. He is in charge of performing the stock assessment for east coast red drum and the data from this project have all been incorporated into his analysis.

A copy of the catch data (numbers and weight of fishes taken at each set) as well as the individual length frequency and biological observations are enclosed as SPSS portable files on the enclosed CD. The report is also in an electronic file on the CD.