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REPRODUCTIVE ECOLOGY, POPULATION DYNAMICS AND SEASONAL MOVEMENTS OF THE HOGCHOKER (TRINECTES MACULATUS), IN THE ELIZABETH RIVER, VIRGINIA

A Thesis

Presented to

The Faculty of the School of Marine Science

The College of William and Mary in Virginia

In Partial Fulfillment

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Master of Arts

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by

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This thesis is submitted in partial fulfillment of

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ABSTRACT

Twelve stations, from the mouth to the upper reaches, of the Southern Branch of the Elizabeth River System, Virginia, were sampled by trawl to determine seasonal movements and reproductive ecology of *Trinectes maculatus* within a severely polluted environment. Sex ratio was 1 : 1.4 (male:female) overall, with males predominating at the most downstream stations during the spawning season. Maximal spawn as determined by female Gonado-somatic and maturity indices occurred at the lower station group during July and August with precocious individuals commencing in June. Spawning ceased abruptly in September followed by the commencement of an upstream overwintering migration. Histological examination of ovaries and testes showed mean ripe egg diameter to be 0.354 mm. and all phases of spermatogenesis to be present in unison. Asynchronous single spawning was observed for females however males appear to spawn repeatedly throughout the season. All migratory movement ceased as bottom temperatures dropped below 9.8^{o}C. and fish remained resident until at least April 22 when bottom temperatures rose above 16.5^{o}C. A spring return migration to downriver spawning sites was observed from April to June. Maximum rate of movement was 461.8 meters day^{-1} with some evidence of reduced residence at the most severely polluted bottom sites.

Of 6,418 fish tagged, a total of 90 were recaptured from two to 350 days at liberty. Single and multiple census techniques were utilized to estimate population size and survival rate from mark recapture data. All estimates were within 10 % of 241,402 multiple census estimate with s = 0.2171 (T.L. >90 mm.).

Rate of sinistrality for *T. maculatus* was observed to be 0.069 percent within the Elizabeth River system.

Bottom temperature was considered to be the controlling factor for migratory activity while salinity and channel depth appear important in spawning and overwintering site selection.

REPRODUCTIVE ECOLOGY, POPULATION DYNAMICS AND SEASONAL MOVEMENTS OF THE HOGCHOKER (*TRINECTES MACULATUS*), IN THE ELIZABETH RIVER, VIRGINIA

INTRODUCTION

The Hogchoker, Trinectes maculatus is a widely distributed benthic sole occurring in the Chesapeake Bay estuary, and ranging from Massachusetts Bay to Panama (Bigelow and Schroeder 1953). The maximum recorded size for this species is 212 mm. total length (TL), with typical estuarine size range from 20 - 160 mm TL. Hogchokers have been observed in the full spectrum of the estuarine salinity gradient, from freshwater to marine conditions. Hildebrand and Cable (1938), Gunter (1945) and Maurer and Tinsman (1980) reported large mature hogchokers from the nearshore coastal waters of Delaware, whereas juveniles have been captured in freshwater 95 miles upstream from the Gulf of Mexico (Boschung and Hemple 1960), and 40 miles upriver from the brackish-freshwater interface in Virginia rivers (Massman 1954). Spawning occurs in the evening (1800-2000 hours) (Ferraro 1980), from late spring though late summer (Hildebrand and Cable 1938, Wang and Kernahan 1979). Koski (1980) validated using annular circuli on the ctenoid scales to age hogchokers, and calculated mean size at age. Back-calculated lengths at annulus formation for age I fish showed the first annulus was formed at a mean length of 59 mm (TL). Late spawned individuals grew most rapidly and by age II had attained the same size as others of their generation. Mansuetti and Pauly (1956) found sexual separation of hogchokers in the Patuxent River during the summer months and believed that females moved into the grassbeds and shoal regions prior to spawning, whereas males frequented deeper areas.

Diet analysis of *T. maculatus* showed that gammarid amphipods predominated in the diet of smaller individuals (< 61 mm SL) but became less important in larger fish, being replaced by nereid polycheates and clam siphons (Smith *et al*. 1984). The ontogenetic feeding shift is indicative of an opportunistic feeding strategy. Carr and Adams (1973) conducted quantitative gravimetric analysis of stomach contents on juvenile hogchokers, finding polycheates to comprise the major food (60 - 88 %) with amphipods, foraminifera, detritus and sand grains completing the remaining food items. Detritus consumption was most predominant in the smallest individuals, decreasing in importance in the larger size catagories. Other investigators (Reid 1954; Castagna 1955; Darnell 1958) have found dipteran (chironomid) larvae, ostracods, annelids, incidental bits of algae and quantities of sand and bottom material in hogchoker stomachs and intestinal tracts. These food habits studies suggest that the hogchoker is strictly a bottom feeder. Effects of temperature, salinity and food availability on feeding were experimentally determined for *T. maculatus* (Peters and Boyd 1972). Maximum feeding was primarily temperature dependent with the ingestion rate highest at 25 - 35^{o}C, while food conversion efficiency was influenced by a temperature-salinity interaction where maximum efficiency was at 15^{o}C and 15 ppt.

The life cycle and ontogenetic movements of the hogchoker are correlated with the estuarine salinity gradient. Dovel *et al*. (1969) noted cyclical seasonal movements from freshwater nursery grounds to more stable and saline spawning grounds by mature hogchokers in the Patuxent River, Maryland. In addition they observed that the range of migration into progressively more saline waters increased with age and size. Distinct polymodal length-frequency distributions of hogchokers in the York River

(VIMS trawl survey data) indicated increased migration with maturity, however, return migration to freshwater by large mature individuals has not been documented.

The eggs and larval stages have been described by Hildebrand and Cable (1938), Pearson (1941) and Wang and Kernahan (1979). Eggs are semi-buoyant and occupy coastal habitats and the more saline regions of the estuary. Larvae are restricted to low salinity nurseries and require approximately 34 days to develop the characteristic asymmetry of heterosomates. An incubation time of 26-36 hours (Pearson 1941, Wang and Kernahan 1979) suggests rapid passive transport of the eggs by subsurface currents to the nursery grounds prior to hatching (D. Haven pers. comm.). Castagna (1955) suggested the larvae and juveniles are physiologically restricted to low salinities, while adults are euryhaline and may occur across the estuarine salinity spectrum.

Little is known about the life history of _T. maculatus_, particularly with respect to seasonal movements. Tagging studies have been used to monitor the local movements and migrations of other resident estuarine fishes. Pollock (1982) used a tagging program to monitor differential migrations of juvenile and adult yellow bream (_Acanthopagrus australis_), in Moreton Bay, Australia. Monitoring of tagged winter flounder (_Pseudopleuronectes americanus_), (Saila 1961) revealed multidirectional movement away from identified spawning grounds. Saila's study involved computation of directional components and dispersion rates as opposed to the less complex two dimensional pattern of hogchoker migration.

The hogchoker has become an important target species for estuarine investigation into the effects and uptake of substrate adherred toxins. As such, it is essential to understand the local movements and residence time of this fish if quantified statements of toxic effect are to be made.

The present study was designed to describe seasonal movements of Trinectes maculatus, with regard to the magnitude, rate, duration and mitigating physical factors, and provide pertinant population dynamics information. Tagging results were also be used to identify major regions of overwintering and residence time. Reproductive ecology of T. maculatus was examined to determine time of spawning and major spawning areas in the Elizabeth River system, as well as to describe the relative contribution of sex and maturity stage to spawning aggregations. Aspects of population dynamics were examined using mark and recapture data to estimate total population size and survival rates.

MATERIALS AND METHODS

Samples for reproductive and sex ratio analysis were collected on monthly Elizabeth River VIMS Trawl Survey cruises from March through September 1984. All collections were made using a 30' semiballoon otter trawl equipped with 1/2 " mesh and 1/8" cod end liner and tickler chain towed from a 43' Bruno Stillman vessel at a speed of 2 - 3 knots. Each of eleven permanently situated stations ranging from the mouth of the Elizabeth River at Craney Island to the uppermost station below the Intercoastal Waterway locks (Table 1) were visited monthly and hogchokers preserved on ice for return to the laboratory. All *T. maculatus* were retained from each station sample unless the number captured exceeded eighty fish. Then a subsample of at least 50 to 60 individuals was randomly selected for analysis. Total number of specimens captured was noted for each station. Measurement of bottom temperature, salinity and disolved oxygen were made at each station with a YSI model 51B dissolved oxygen meter and temperature probe and American Optics temperature compensated refractometer.

Upon return to the laboratory specimens were frozen or preserved in 10 percent normal buffered formalin until they could be examined. Each fish was measured to the nearest mm TL, and assigned to one of three sexual catagories; male, female or juvenile, where the juvenile catagory was comprised of individuals generally < 70 mm with undifferentiated or indistinct gonadal tissue. Fish captured from May through September were wet-weighed to the nearest 0.01 g and their gonads excised and similarly wet-weighed for computation of Gonado-somatic Indices (GSI). Gonadal

TABLE 1

ELIZABETH RIVER STATIONS

Station #	Landmarks	Depth (meters)	Distance from last station (meters)	Cumulative distance (km)
1	Craney Island	13.7 - 14.6	0	0
2	Lambert's Bend	13.4 - 14.0	2,103	2.103
3	U.S. Army Corp.	13.7	2,021	4.124
4	Town Point	13.4 - 13.7	1.692	5.816
5	U.S. Navy Yard	11.9 - 12.5	2,606	8.422
6	North Jones Crk	13.1	1,875	10.297
7	'217' Hess Plant	11.3 - 11.6	2,126	12.423
9	N. Gilmerton Br.	11.0	2,515	14.938
10	N. I-64 Bridge	10.7 - 11.0	2,103	17.041
10-A	N. Swing Bridge	5.2 - 10.7	1,303	18.340
11	Landing Craft	4.3	1,106	19.450
12	N. Steele Bridge	4.3	2,057	21.507

Total distance	21.5 km 13.36 mile
Average station length	400 meter
Mean distance between stations	2,150 meter

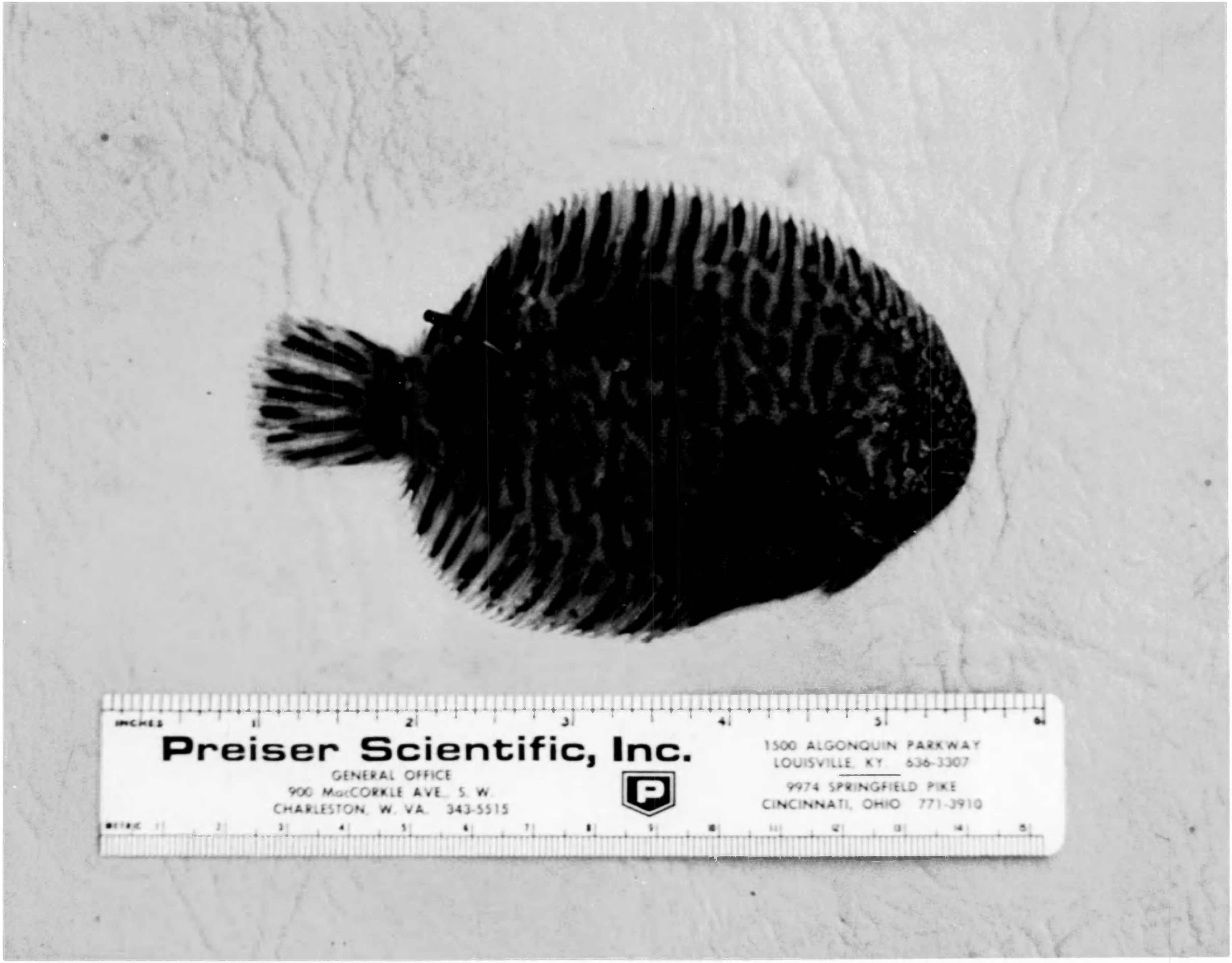
staging followed Mercer (1978) where male and female gonads were assigned to one of five developmental stages on the basis of macroscopic observation. Juvenile fish were assigned no sexual maturity catagory. During all laboratory analysis of field samples, the station and date information was concealed to avoid introduction of bias.

Typical examples of each maturity stage were prepared to histologically validate the macroscopic staging technique. Histological preparation followed Preece (1959), where gonadal tissue was embedded in paraffin, sectioned to six um slices, and stained and counterstained with Harris's hemotoxylin and eosin (H&E) consecutively.

Tagging Study

Fish were tagged commencing in October 1984 using custom Floy 1 3/16" red anchor tags. Each tag was individually numbered with a five digit code on one side and bore a "VIMS" identification marking on the other. The tags were inserted through the posterior dorsal region, approximately 1 - 1.5 cm forward of the hypurals and equidistant between the dorsal fin insertion and the lateral line spinal ridge (Figure 1). Previous tagging experiments conducted by this researcher have shown this insertion site to be superior to more medial and/or anterior sites in terms of tag retention, locomotion, trauma and reduced incidence of infection. Holding experiments at VIMS have determined no significant effect (t-test, $P < .01$) between 76 control and tagged fish held under identical conditions for a 20 day period (5 May - 25 May 1984) at temperatures of 16.9^{o}C - 19.1^{o}C. Tagging experiments were also conducted holding tagged and control fish over 20 percent Elizabeth River sediment mixture designed to simulate field conditions and detect possible

Figure 1. Location and position of tag insertion site on 118 mm TL *I*. *maculatus*.


INCHES
Preiser Scientific, Inc.
GENERAL OFFICE
900 MacCORKLE AVE., S. W.
CHARLESTON, W. VA. 343-5515
1500 ALGONQUIN PARKWAY
LOUISVILLE, KY. 636-3307
9974 SPRINGFIELD PIKE
CINCINNATI, OHIO 771-3910
METRIC

increased tagging mortality due to environmental stress. No mortality was observed for either treatment from November 1984 to January 1985 until the experiment was concluded as a result of temperature induced mortality.

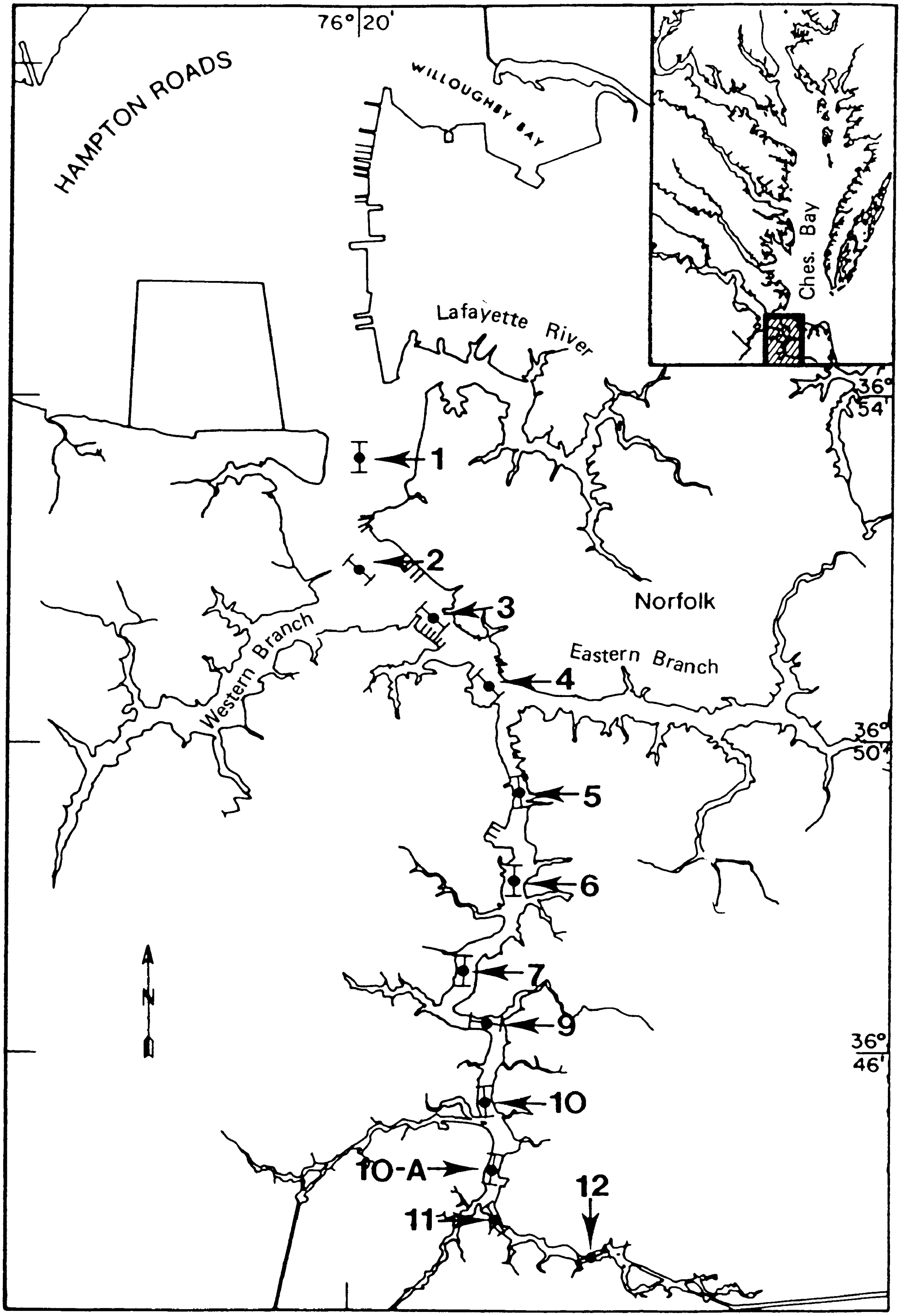
A preliminary tagging study was conducted in Queen's Creek, a small tidal creek system draining into the York River, to determine the feasiblity of the proposed large scale effort. One hundred and fifty-four experimental fish were tagged and released at three locations. A total of six fish were recaptured, one on the same day and five three days later. The resulting 3.1 percent overall return rate for this short term study indicated that tagged _T. maculatus_ are susceptible to recapture by trawl and population estimates are possible.

The major tagging effort occurred from October through December 1984 to coincide with the postulated fall upstream migration, and because thedeclining water temperatures would reduce the incidental chance of secondary bacterial infection at the insertion site.

Initially, fish for tagging were captured just below or above the intended release site in order not to further disturb experimental fish or introduce movement due to transporting fish from capture sites. Tagged fish were held in on board holding tanks for up to one hour prior to release to insure recovery of all individuals.

Three major areas were designated for release of tagged fish representing lower, middle and upper portions of the river system, with additional releases at intermediate sites. Major release sites corresponded to station 04 for the lower river, station 07 (identified as the most environmentally impacted site) served as the middle river release site, and upper river fish were released at station 10 (Figure 2). A total of 4,575 fish were tagged from the start of the program on October 23 to December 13,

Figure 2. The Elizabeth River system, including station locations and position within the Chesapeake Bay.



76°|20'
HAMPTON ROADS
WILLOUGHBY BAY
Lafayette River
Ches. Bay
36°
54'
1
2
3
Norfolk
Western Branch
Eastern Branch
4
36°
50'
5
6
7
9
36°
46'
10
10-A
11
12
N

1984. Subsequent tagging emphasis during the winter and spring months was shifted to a previously unsampled station, 10-A, situated approximately equidistant between stations 10 and 11. Fish were found to overwinter in greatest abundance in this region of dramatic channel shoaling (34' - 16'). From February 26 through June 28, 1985, an additional 1,843 fish were tagged and released.

A 16' semi-balloon otter trawl towed from a 27' Garvey (R.V. Marsh Hawk) equipped with 235 hp. outboard engine was used throughout the tagging program. During the initial tagging phase no effort was made to standardize tow duration, however regular sampling for tagged fish and ancillary tagging tows were set at seven minutes from set on bottom to time of retrieval. This tow duration represents the maximum bottom time achievable within the constraints of a channel bottom highly littered with anthropogenic material. An attempt was made to complete at least one upstream and one downstream tow at each station on a monthly basis (November 1984 to August 1985). Time contraints and the absence of fish at certain times of the year often dictated that some stations be omitted or sampled less intensively in favor of concentrating effort on stations deemed more productive. Fishing effort remained the same for comparative purposes. Bottom hydrographic data was taken at each site visitation and a complete hydrographic profile was taken on a monthly basis.

Only fish 90 mm TL or above were tagged as this was the minimun size considered capable of bearing the tag without altering or impairing normal activity. During sampling the number of tagged and untagged fish were enumerated, tagged individuals were noted for tag identification, and physical condition of the fish and any evidence of infection of insertion site were noted before rerelease at station. Secondary capture sites were recorded to document any movement that may have occured during the time between captures. The number of fish below tagging size were also enumerated for percentage comparisons with VIMS survey data and total population estimates.

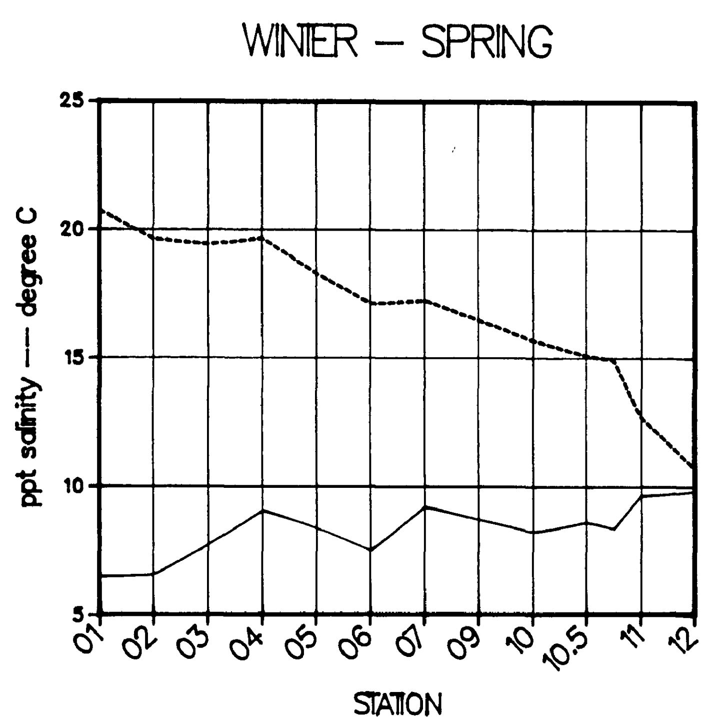
Elizabeth River Physical Conditions

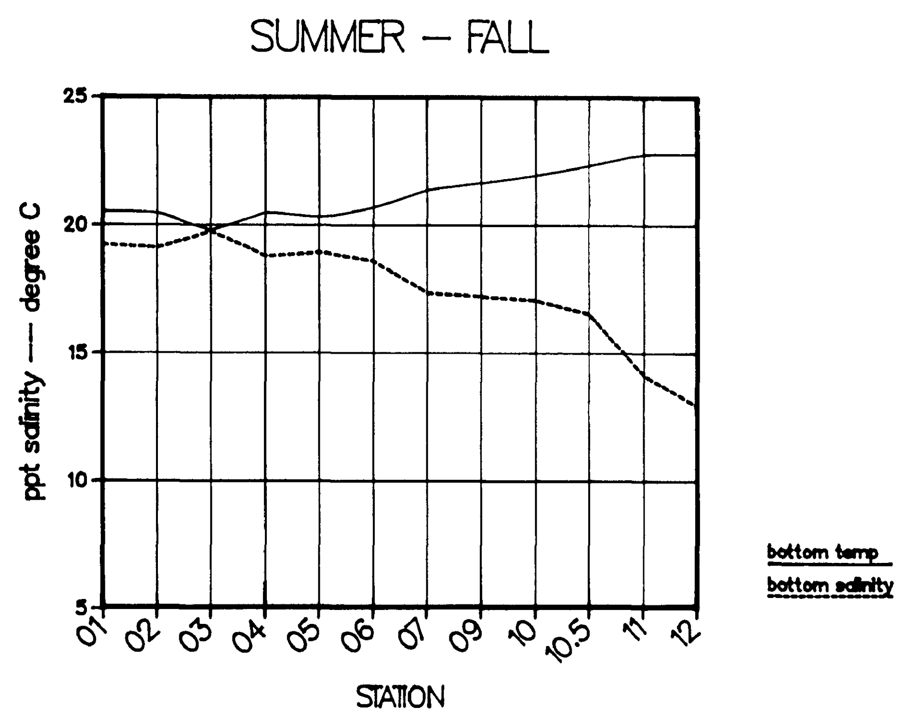
The Elizabeth River and the Nansamond River to the north comprise the two tidal tributaries draining directly into the James-Hampton Roads area. The Southern Branch along a north-south axis dominates the Elizabeth system with contributions from the Western Branch, Eastern Branch and Lafayette River (Figure 2). The drainage area of the Elizabeth River System is approximately 300 square miles (777 km^2). However since the drainage basin itself is not large and is characterized by little topographic relief, fresh water input is small (Cerco and Kuo 1981). The primary source of freshwater input is from stormwater runoff and drainage into the Southern Branch from the Dismal Swamp Canal.

The tidal range was described by Calder and Bremer (1967) as averaging 0.8 m with current velocities rarely exceeding 0.9 m sec^{-1}. The salinity stucture of the Southern Branch is characterized by a typical estuarine gradient with occasional freshwater plumes resulting from discharge from the Dismal Swamp canal and other sources. Mean summer and winter bottom temperatures corresponded with depth such that summer temperatures at the deepest site exhibited the lowest seasonal readings while the opposite was true for the winter (Figure 3). The mouth of the Elizabeth River appeared to experience slightly lower overall salinities as a result of the superior and somewhat fresher James River discharge averaging 2 m sec^{-1} (Boesch

Figure 3. Mean seasonal bottom temperatures and salinities for Elizabeth River stations.

MEAN BOTTOM TEMPERATURES AND SALINITIES





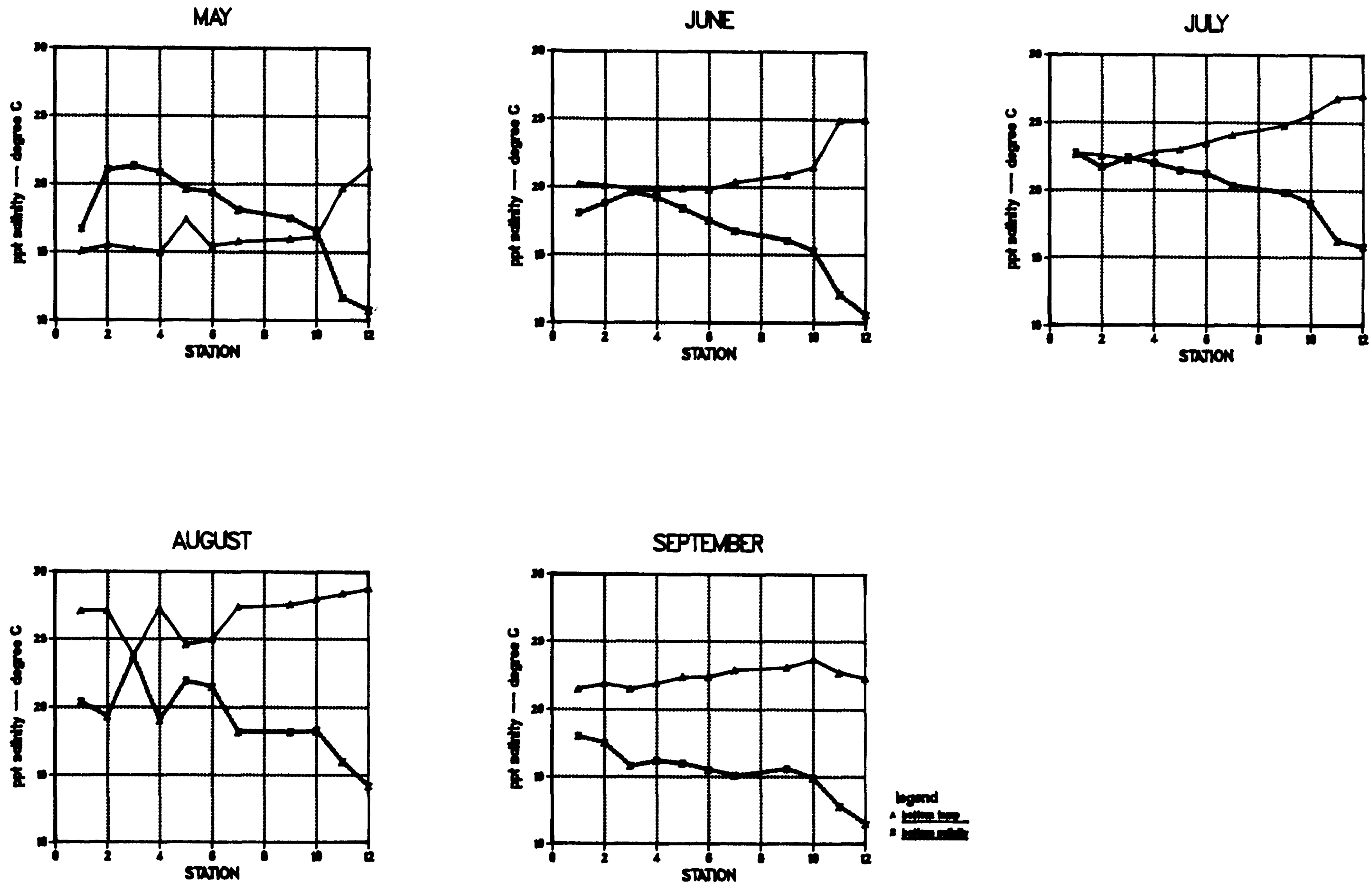
1971). Boesch (1971) characterized the James River as a horizontal boundary estuary with lower salinities occuring on the southern bank effectively diluting the inferior Elizabeth River outflow. This resulted in fresher James River water dominating the salinity structure of the mouth of the Elizabeth such that the highest salinities typically occur some 4000 meters from the most downstream station. Bottom hydrographic data for the months surrounding the spawning season (May - September 1984) are given in Figure 4. This reversed salinity structure at the river mouth most likely plays a significant role in the seasonal movements and reproductive ecology of _T. maculatus_ within the Elizabeth River.

The Elizabeth River has historically been a center of water-related industry since the founding of Norfolk in 1690 and currently is the home of the largest U.S. Naval facility on the East Coast as well as the site of civilian and military shipbuilding and shoreside commerce. The Elizabeth River has been recognized as the most heavily polluted system in the Chesapeake Bay as a result of previous wastes received from creosote wood treatment plants and several primary sewage treatment outfalls in addition to numerous industrial effluents. Bieri _et al_. (1982) reported heavy concentrations of polyaromatic hydrocarbons (PAH's) in sediments of the upper portion of the Southern Branch while Lu (1982) found concentrations of benzo [a] pyrene ranging from 10 ug g^{-1} in the top 2 cm to greater than 200 ug g^{-1} in cores taken from the most heavily contaminated sites. Downstream sites exhibit far less evidence of toxic contaminants.

An eleven meter shipping channel is maintained in the Southern Branch extending to Station 10, whereafter the channel depth is slightly reduced until it shoals abruptly to 4.3 meters (see Table 1). Boesch (1971) described the bottom sediments of the lower Elizabeth (corresponding to

Figure 4. Bottom temperatures and salinities for Elizabeth River stations plotted by month (May - September 1984).

BOTTOM TEMPERATURES AND SALINITIES — 1984



stations 1 - 4) according to Shepard's terminology as of the sand-silt-clay variety with finer sediments predominating. Beyond the dredged channel region (above Station 10) the bottom was liberally covered with terrigenous input and loose gravel. Anthropogenic debris was frequently encountered throughout the Southern Branch precluding trawling in many areas.

RESULTS AND DISCUSSION

Sex Ratio

Sex ratio of males to females was 1 : 1.4 over all stations combined from April through September 1984. No significant difference in sex ratios by station was noted between the months sampled ($P > .01$), but large fluctuations were observed when examining data between stations in combined sex ratios. Table 2 depicts the differences in the combined sex ratios for each station. Ratios varied from an observed low of 1 : 0.73 at the most downstream station to a high of 1 : 2.33 at Station 11. Although a general trend of increasing ratio of females with upriver progression appeared evident, this became increasingly pronounced in sexual distribution for the months associated with peak spawning activity (July and August) (Figure 5). During this period mature and maturing males congregated in the higher salinity region where spawning takes place (Dovel et al 1969). First indications of downriver male aggregations occurred in June at the onset of early spawning but prior to maximal spawn, when highest male concentrations appeared at mid-estuary sites. Subsequently, high male ratios occurred at the most downriver stations during the period of maximal spawning activity, tapering off to pre-spawning levels during September. Mansuetti and Pauly (1956) reported sexual separation of hogchokers in the Patuxent River during the summer months with females found primarily in the grassbeds and shoal regions prior to spawning. This did not appear to be a contributing factor

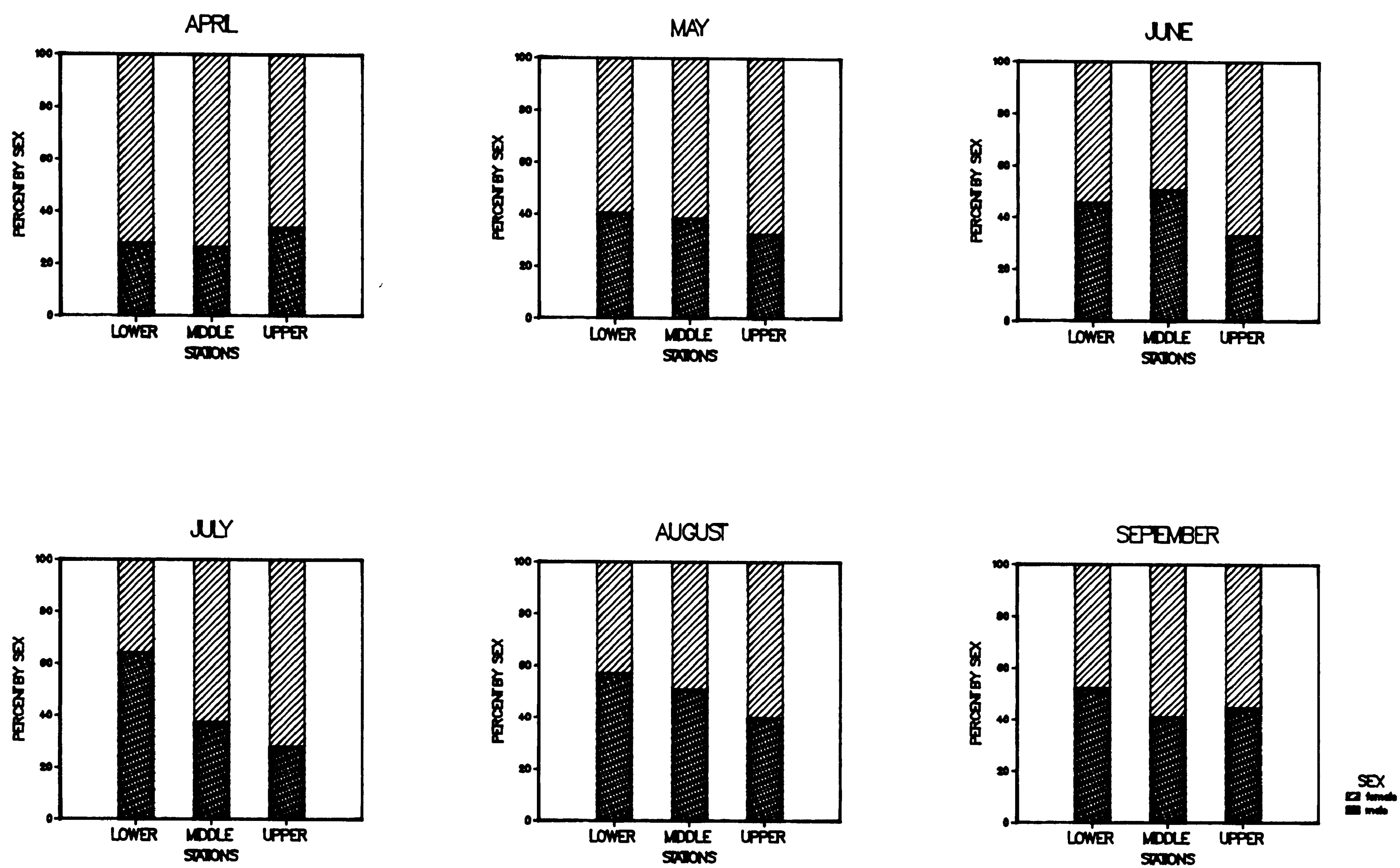
TABLE 2

TOTAL SEX RATIO

STATION	SEX male	SEX female	TOTAL	RATIO male:female
01	172	125	297	1 : 0.73
02	51	84	135	1 : 1.65
03	117	176	293	1 : 1.50
04	121	143	264	1 : 1.18
05	121	143	264	1 : 1.18
06	127	211	338	1 : 1.66
07	94	151	245	1 : 1.61
09	72	129	201	1 : 1.79
10	63	104	167	1 : 1.65
11	35	77	112	1 : 2.33
12	55	75	130	1 : 1.36
COMBINED	1028	1418	2446	1 : 1.40

Figure 5. Relative proportion of male and female _T_. _maculatus_ by month (March - September 1984) for each station grouping.

GROUPED STATION SEX RATIO — 1984



with Elizabeth River hogchokers as shoal and grassbed areas were extremely reduced or absent in the Southern Branch.

Two notable exceptions to the general trend were Stations 02 and 12, both of which may have projected misleading ratios as a result of sampling omissions. Station 02 would be expected to have had a somewhat lower percentage of female fish, however this station was not sampled during July when the distributional trend would suggest high concentrations of males at downriver sites. The given ratio then for Station 02 was probably artificially skewed towards females and not indicative of true sexual distribution. Similarly, May and June samples were unavailable for Station 12 when it was expected that females would predominate at the upper sites, resulting in a disproportionately high ratio of males. By clumping individual stations into lower (Stations 01 - 04), middle (Stations 05 - 07) and upper (Stations 09 - 12) station groups (see Figure 2), the effect of missing samples was minimized for any particular station. Figure 6 reveals a smooth progression of increasing male ratios in the down river direction for the peak spawning period (July and August). Pre and post-spawning time frames represented a more equitable sexual partioning between station aggregates. Weighted averages of the combined station grouping over all months sampled showed male percentages to be 45.2 at the lower stations, 40.8 and 36.9 at the mid and upper stations respectively. The progressive down river increase in the overall ratio clearly demonstrated the impact of a male spawning "pulse" at the lower station grouping at peak spawning periods.

Mean TL for male and female hogchokers from the Elizabeth river System revealed that females were on average 9.8 mm larger than their male counterparts at all stations for all months (Figure 7). Koski (1978) noted

Figure 6. Relative proportion of male and female _T. maculatus_ at the lower, middle and upper station groupings for April - September 1984.

MALE / FEMALE SEX RATIO

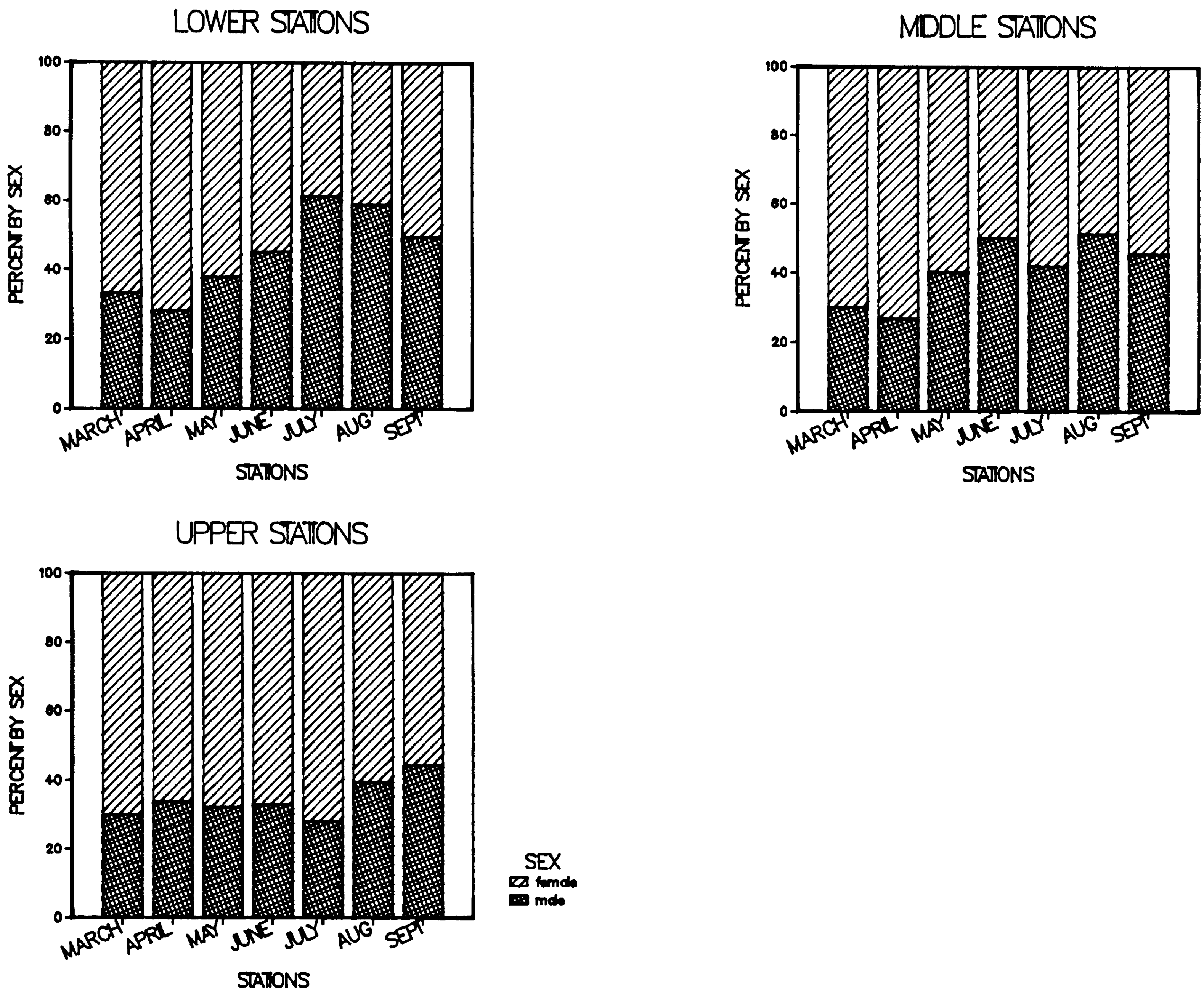
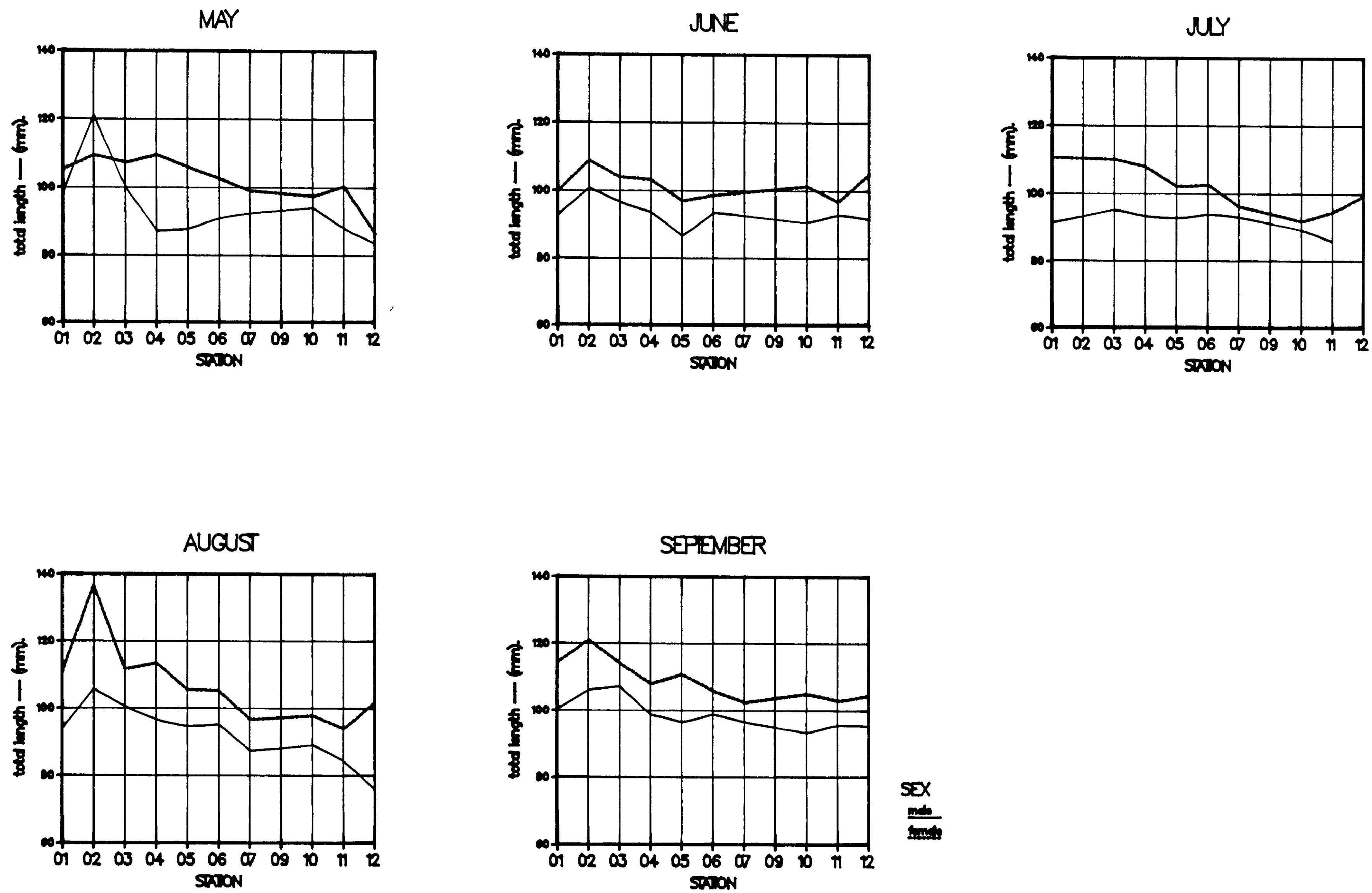


Figure 7. Mean male and female total length (TL) by station plotted for May - September 1984.

MEAN TOTAL LENGTH BY STATION — 1984



differential growth rates between male and female T. maculatus in the Hudson and Patuxent Rivers.

Backcalculated size from scale annuli showed that after the first year females grew more rapidly and demonstrated a 9 mm size difference by Age III. To test whether differences in sex ratio existed between similar age fish within stations, an average value of 10 mm was added to male TL to adjust the length data so that size at age was comparable for each sex. Size classes of 10 mm intervals (< 80 mm to > 120 mm) were then constructed and subjected to analysis of variance (ANOVA) to detect differences in sex ratio by size class. For each station, no significant effect ($P > .10$) of size class or age was observed to differ from the sex ratio attributable to the combined values given in Table 2. It was therefore probable that while T. maculatus were differentially distributed by size (Dovel et al 1969) and sex, the overall sexual ratio remained unaffected by disproportionate participation of differing size classes.

Female Maturity Stages

A total of 1,418 females (> 70 mm TL) were examined from April to September 1984 and assigned macroscopically to one of five maturity stages; immature, resting, developing, ripe and spent. Stage classification followed Mercer (1978) where ovaries appeared similar to the following description;

Immature- Ovaries greatly reduced in size with pale coloration and no posterior elongation. Ovaries generally thin and shaped as an equalateral triangle. No vascularization apparent and tissue appeard undifferentiated.

<u>Resting</u>- Ovaries of mature or maturing individuals appear light yellow in color with evidence of folicular development. Ovarian shape is more robust and posteriorly elongated such that the length is approximately 2X that of the height, often coming to a distinct point at the posterior end. Both ovaries are of equal dimension and rest high in the body cavity above the liver and spleen.

<u>Developing</u>- Ovaries exhibit a deep yellow coloration with some evidence of slight vascularization of the epithelium. The tissue appears granular in texture from increased folicular development. Ovaries are increasingly posteriorly elongated becoming more turgid and distended.

<u>Ripe</u>- Ovaries are extended to the most distal portion of the coelomic cavity, becoming very distended and vascularized on the surface of the tunic. Ovaries appear granular with distinct eggs visible through the epithelium and often appearing in the ovarian duct. Coloration is a dark yellow to orange.

<u>Spent</u>- Ovaries generally elongated, however extremely flaccid and having a deflated appearence. Folicular material is loose with some remaining atretic egg stages present. Coloration varies from pale to blotched darker yellow, often acheiving a reddish hue from disrupted vascularization.

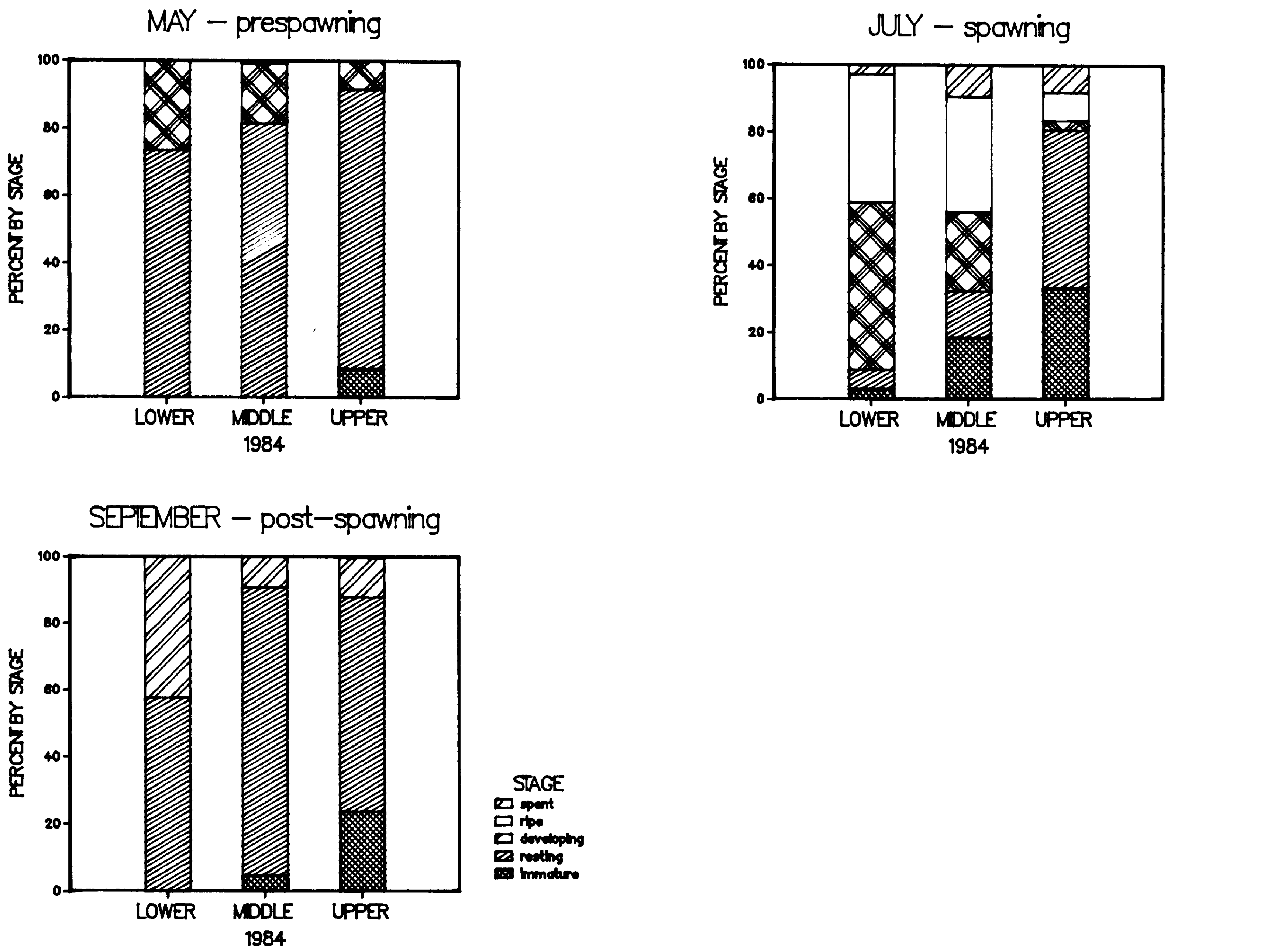
Typical samples of each developmental stage from fish of differing size groups and station were selected for histological examination to validate macroscopic staging assignment.

Analysis of the occurrence of female maturity stages at stations grouped into lower, middle and upper station aggregates revealed that spawning did not take place until June when the first ripe and spent individuals appeared. In May all station groups were dominated with resting females with the appearance of developing individuals increasing toward the lowermost stations (Figure 8). Immature fish occurred only at the upper station group during this time. The spawning period, as defined by the presence of ripe female,s extended from June through August when both ripe and spent fish predominated. Ripe females were most closely associated with the lower stations where spawning is postulated to take place. Females displaying developing and ripe conditions at the lower stations during the peak spawning month of July, accounted for 50 and 38.2 percent respectively, of all females taken. Progressing in an upriver direction these percentage values decreased in stepwise fashion representing only 2.8 percent developing and 8.3 percent ripe females at the upper stations (Figure 8). Conversely, immature and resting fish, presumably composed of two year old maturing females that would not participate in the year's spawn joined by previous spawners, were most concentrated in the upper portion of the estuary. Figure 8 shows 33.3 percent immatures and 47.2 percent resting fish at the upper station during July. The spawning period was characterized by the presence of of all five maturity stages with the distribution of spawners slanted most heavily towards the most saline downriver stations, while non or post-spawning fish were found predominantly in the mid to upper reaches of the estuary.

Spent females first appeared in June, and by July were present at all station groupings. In July slightly higher numbers of spent females were found in the middle station areas than in either the up or down river sites.

Figure 8. Relative proportions of female maturity states at the lower, middle and upper station groupings representative of pre-spawning, spawning and post-spawning months, 1984.

FEMALE MATURITY STAGES



This suggested that once they spawned at the lower station group, females subsequently commenced rapid movement upstream resorbing atretic eggs and follicular material, ulitimately contributing to the dominent grouping of resting fish noted at the upper stations. The hypothesis of net upstream movement by post spawners has been suggested by Dovel et al. (1969) in the Patuxent River and empirically corroborated by tagging data in this study of the Elizabeth River system.

By September all stations were dominated by spent and resting females with no fish exhibiting evidence of development or ripe condition. The abrupt cessation of spawning crresponded with a 6 C reduction in temperature (from 27°C to 21°C) in September from the previous month at the lower river stations. Spent fish were captured in highest concentrations at down river sites indicating that last spawning activity had occurred just prior to the 18 September 1984 sampling date.

Juveniles recruited as year old or 1+ immature adult females (generally 70 to 90 mm TL) began to appear during the summer months, most heavily concentrated in the upper stations (33.3 %) and ranging in progressively smaller numbers into middle (18.3 %) and lower (2.9 %) station groups. In the following months of late and post-spawn, these values became somewhat reduced by dilution with two to four year old fish on an upstream fall movement. Analysis of size composition by station (Figure 7) also indicated that larger or older fish became increasingly abundant at upriver stations during this time (September), raising the mean size at each station.

Gonad Histology

Typical samples of each male and female maturity stage were selected for histological examination of the gonads. All specimens were taken from samples collected during the July through September 1984 regular sampling cruises when all maturity stages were present. Samples were preserved in the field with 10 percent neutral buffered formalin and stored in Davidson's solution after dissection in the laboratory (Humason 1972). Samples were embedded in paraffin and sectioned transversely from the anterior portion to a thickness of 6 um (Luna 1967; Humason 1972; Gabe 1976). The paraffin sections were mounted on slides and stained with a regressive Harris' hematoxylin and eosin (H&E) stain (Luna 1967). Oviplasm in developing oocytes stains basophilically. Euvitelline nucleoli begin to appear along the perimeter of the nuclear boundary, the nucleus stains acidophilically signaling the beginning of yolk-vessicle formation and vitellogenesis (Wallace and Selman 1981).

Hogchokers are oviparous and normally possess paired ovaries that unite anteriorly into a common oviduct that exits the body through the genital pore located proximal to the ventral pelvic fin. The tunica albuginea comprises the peripheral wall of the gonad and is continuous with the ovigerous lamellae. Usually, both ovaries develop and spawn in tandem, however, unequal or retarded development was observed for some individuals. Figure 9 and 10 demonstrate typical female and male histological sections for each of the maturity stages.

Hogchoker eggs contain large numbers of oil globules and were described by Hildebrand and Cable (1938) as positively bouyant. Dovel et al. (1969) have suggested that this species may utilize the salt wedge transport system

Figure 9. Histology of _I_. _maculatus_ ovavian tissue.

A. Transverse section of immature ovary (formalin;H&E). Bar = 0.1 mm.
B. Section of developing ovary (formalin;H&E). Bar = 0.1 mm.
C. Maturing oocyte from 112 mm TL female (formalin;H&E). Bar = 0.04 mm.
D. Transverse section of distal portion of spent female (formalin;H&E). Bar = 0.2 mm.

1 Cytoplasm of oocyte stage III - IV (yolk granules and vacuoles)
2 Euviteline nucleoli
3 Oocyte stage I (oogonial nest)
4 Lumen of ovary
5 Oocyte stage II
6 Oocyte stage III
7 Ovigerous lamella with immature oocytes
8 Nucleus of oocyte (karyoplasm and provitelline nucleoli)
9 Tunica albuginea
10 Atretic oocytes
11 Zona radiata

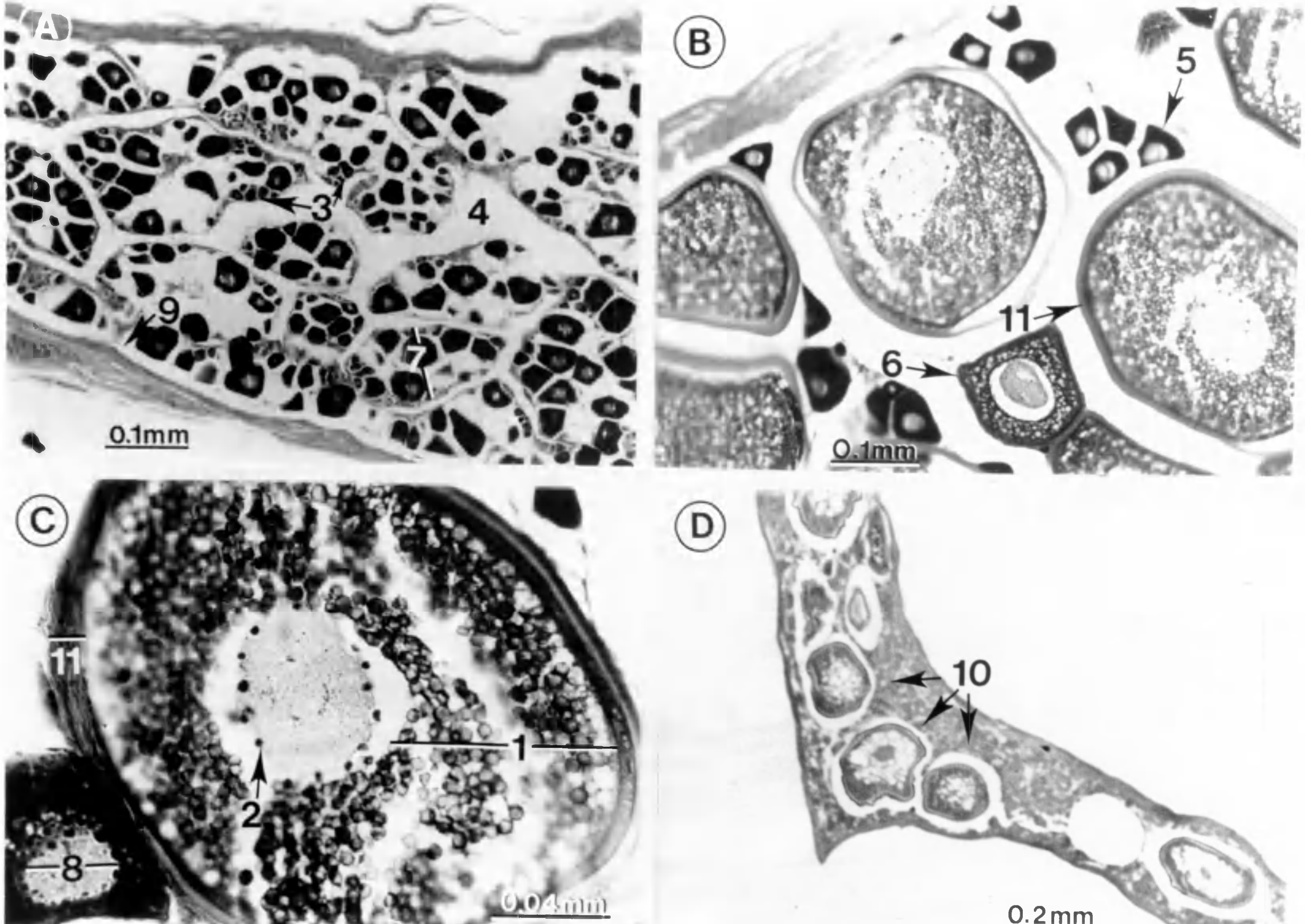
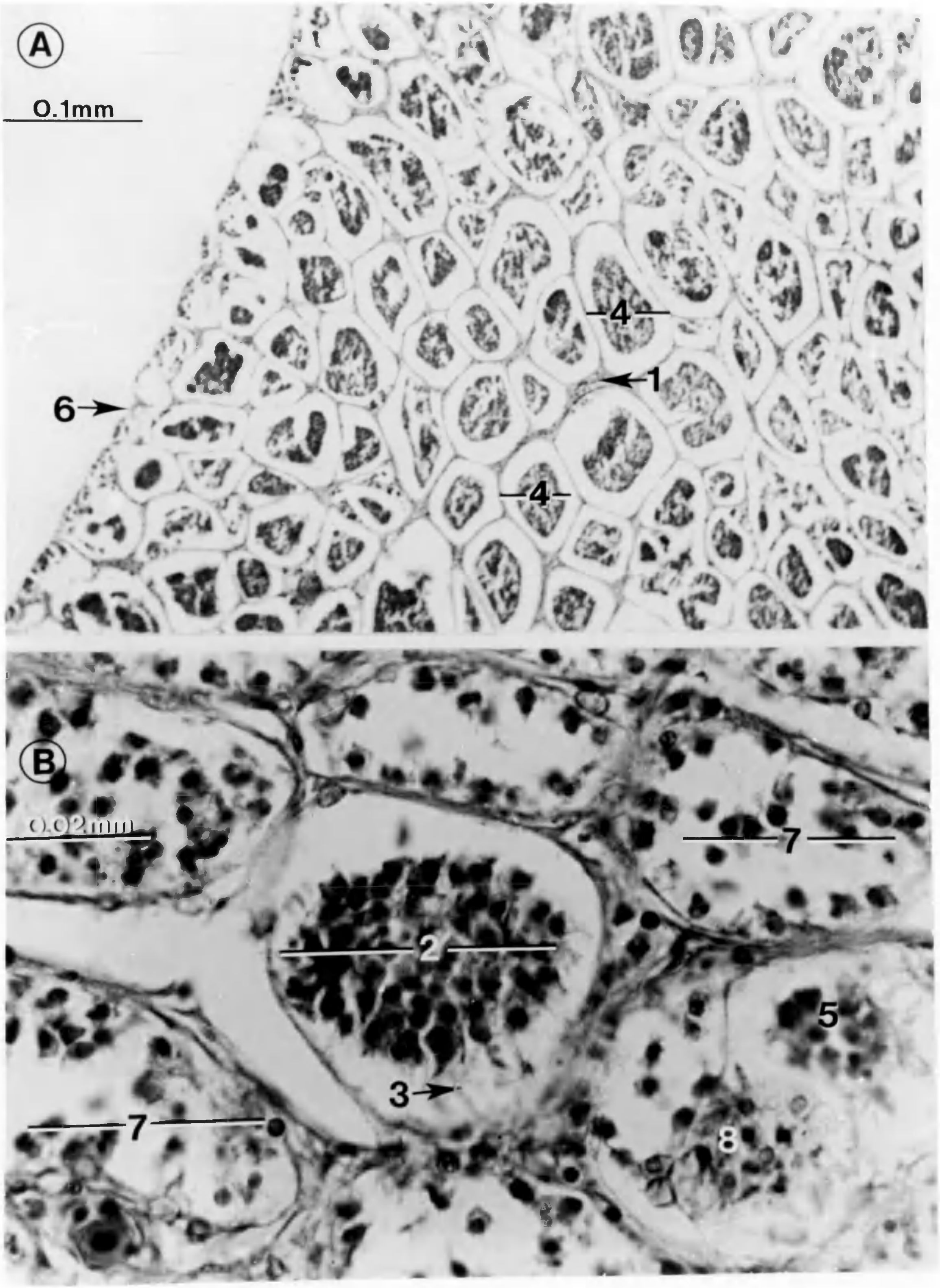

A
3
4
9
7
0.1mm
B
5
11
6
0.1mm
C
11
1
2
8
0.04mm
D
10
0.2mm

Figure 10. Histology of T. maculatus testicular tissue.

A. Section of immature testis from 79 mm TL fish(formalin;H&E). Bar = 0.1 mm.
B. Transverse section of seminiferous tubule of mature male, 123 mm TL (formalin;H&E). Bar = 0.02 mm.

1 Interstitial cells
2 Spermatazoa
3 Tails of spermatazoa
4 Seminiferous tubule (lobule)
5 Nest of secondary spermocytes
6 Fibrous connective tissue of the Tunica albuginea
7 Partially spent lobule
8 Seconary spermatogonia



A
0.1mm
4
1
6
4
B
0.02mm
7
2
5
3
7
8

(Pritchard 1955) from high salinity spawning grounds to low salinity hatching areas. A short egg incubation period (26 - 34 hours at 23.3 - 24.5^{o}C) (Hildebrand and Cable 1938), necessitates that the upriver transport occur rapidly after spawning. Measurement of eggs indicated a significant size-salinity relationship, where maximum egg size occurred at 15 ppt.

Results of egg and nucleus diameter measurements for Elizabeth River T. maculatus are given in Table 3 and the log transformed data presented graphically in Figure 11. Egg and nucleus diameter size increased for each maturity category through the ripe condition and subsequently declined in spent fish. Measurements from immature or juvenile females were not dramatically different from those of the succeeding resting stage and displayed considerable overlap due to presence of stage II and III oocytes in both maturity categories (see Figure 9). The lower end of the immature egg diameter range (< 0.025 mm) represented oogonial nests or stage I oocytes not present in more developed ovaries that acted to reduce the overall mean. Reduction in the number per field from the immature to resting stages resulted from the thickening of the ovigerous lamellae as more immature oocytes developed. Developing ovaries primarily contained stage IV and V oocytes with some residual egg stages that had not undergone development. Yolk vacuoles and euvitelline nucleoli first became evident during this stage along with a distinct zona radiata that could be clearly distinguished in the follicular epithelium (see Figure 9). Diameters of both eggs and nuclei typically exhibited maximum values after full hydration prior to spawning in ripe fish. Ripe eggs were spheriod to oval predominantly of the stage VI ova catagory containing oviplasm filled with large fat vacuoles and acidophilic yolk granules. Mean ripe egg diameter of 0.356 mm was very similar to 0.34 mm value reported by Castagna (1955).

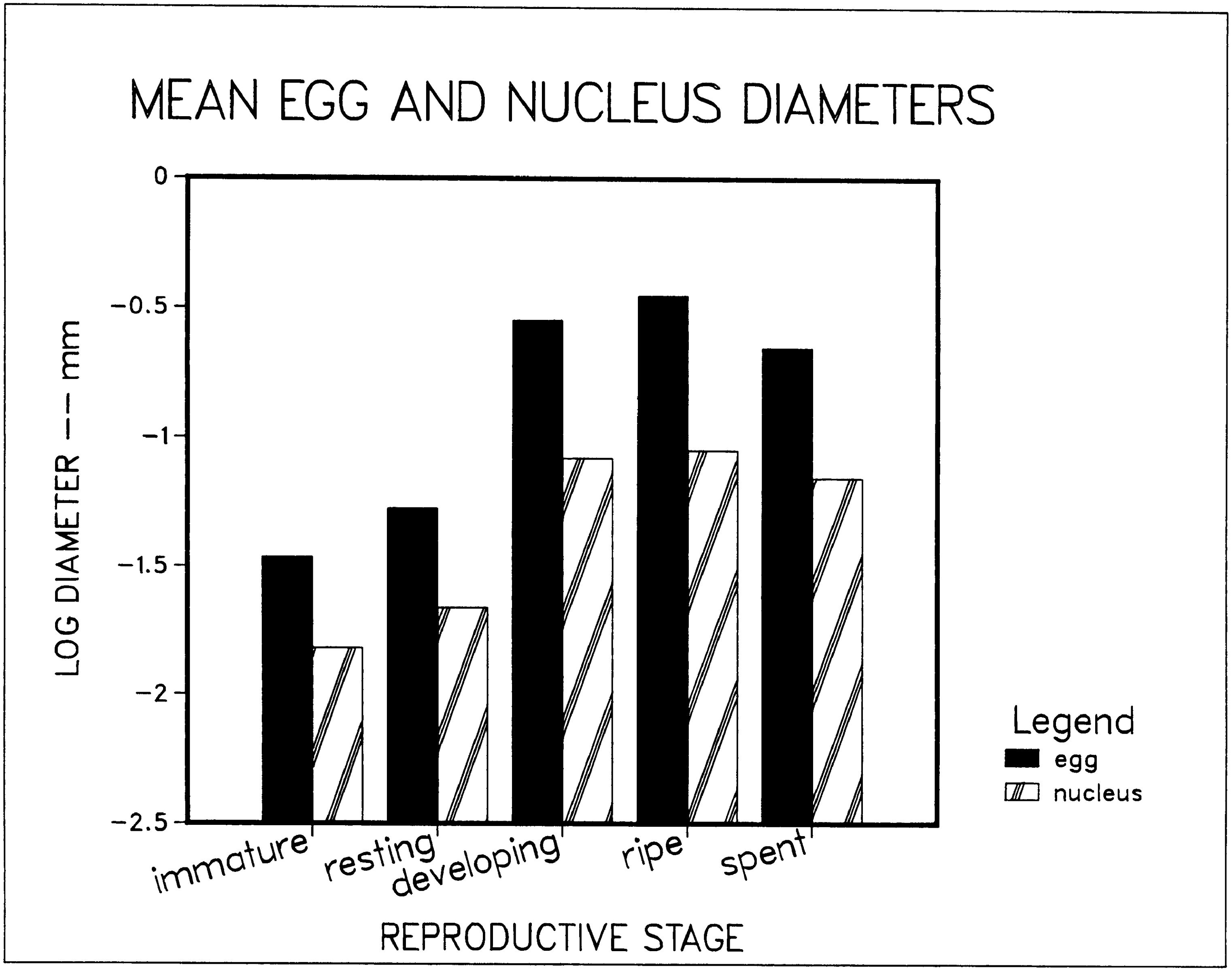
TABLE 3

EGG AND NUCLEUS DIAMETERS

millimeters

STAGE	MEAN	RANGE low	RANGE high	# PER 10X FIELD	STANDARD DEVIATION
IMMATURE					
EGG	0.036	0.016	0.070	178.4	0.012
NUCLEUS	0.016	0.008	0.031		0.001
RESTING					
EGG	0.054	0.031	0.084	134.0	0.012
NUCLEUS	0.022	0.013	0.035		0.005
DEVELOPING					
EGG	0.290	0.090	0.402	24.6	0.066
NUCLEUS	0.085	0.052	0.120		0.017
RIPE					
EGG	0.356	0.208	0.417	19.2	0.052
NUCLEUS	0.090	0.060	0.110		0.011
SPENT					
EGG	0.234	0.083	0.387		0.074
NUCLEUS	0.072	0.043	0.113		0.017

Figure 11. Log transformed mean values (mm) for egg and nucleus diameters from each maturity category.


MEAN EGG AND NUCLEUS DIAMETERS
LOG DIAMETER -- mm
0
-0.5
-1
-1.5
-2
-2.5
immature
resting
developing
ripe
spent
REPRODUCTIVE STAGE
Legend
egg
nucleus

Other researchers (Hildebrand and Cable 1938; Pearson 1941) have recorded higher values for spawned eggs collected in the plankton, however these eggs had most probably undergone several divisions or swelling due to water absorption during fertilization prior to examination.

Spent ovaries characteristically exhibited the greatest degree of variance in diameter measurements, with mean diameters slightly below those recorded for developing fish (see Table 3). The follicular lamellae appeared disrupted from spawning and the remaining oocytes were atretic, displaying progessive stages of resorption. The most distal portion of the ovary contained yolked oocytes which had not undergone hydration at the time of spawning (see Figure 10). These eggs subsequently became atretic, a process characterized by the breakdown of the zona radiata and the nuclear membrane and hypertrophy of the granulosa (Chubb and Potter 1984). Because of the disruption in the lumen of spent ovaries, number per field counts varied greatly and were inconclusive in describing maturation state.

Testes of male T. maculatus are bilobed organs connected ventrally by two collecting ducts (ductus deferens) that merge and exit the body through the genital orifice. Hogchoker testes are small milky colored glands that become only minorly distended in developing individuals and exhibit little macroscopic evidence of maturation. No spent males were observed either from macroscopic or histological examination suggesting that unlike the females, males were serial spawners capable or several fertilization events. Also unlike many other teleosts, no developed males were found to be "running ripe" or extruding testicular product during the spawning season indicating that perhaps this process is muscularly controlled by the thick squamous mesorchia that covers the testes.

The germ cells or primary spermatogonia were acidophilic with dense chromatin and a single nucleolus in each (Figure 10). Several different cellular stages could be differentiated in mature males including spematagonia, spermatocytes, spermatids and spermatozoa that occurred simultaneously prior to spawning. Mature spermatozoa possessed a basophilic head and a distinct acidophilic tail or flagellum. The heads of spermatazoa were clustered towards the center of the tubular lumen with the tails apparent on the periphery, completely opposite to the arrangement reported by James (1946) for striped bass.

Because the degree of the overall reduced size of the testes and the difficulty in macroscopically determining the degree of maturation, males were not included in Gonado-Somatic or Maturity Index analysis. Since it appeared that male hogchokers spawned repeatedly over a single spawning season, it was less important to report male development other than to document the presence of mature individuals in the proximity of ripe females.

Gonado-Somatic Index

A Gonado-somatic index (GSI) was calculated for females from each maturity stage using the formula;

$$gwt / wwt \times 100$$

where gwt is weight of both excised ovaries and wwt is the unevicerated wet weight of the fish. Alimentary tracts were not removed from individual fish as recommended by some researchers to offset the artifactual effect of feeding condition as this did not appear to contribute significantly to the

TABLE 4

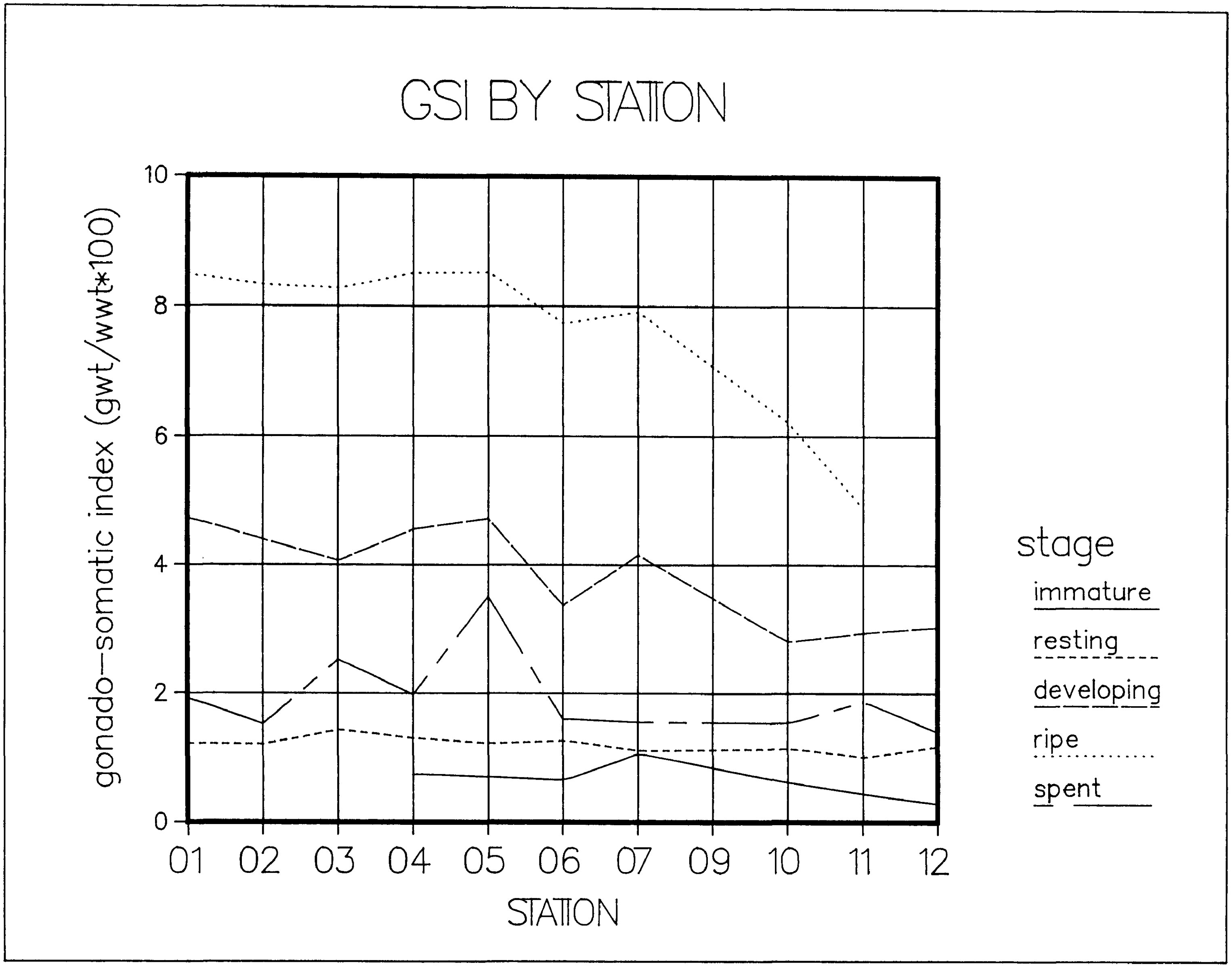
GONADO-SOMATIC INDEX

	IMMATURE	RESTING	DEVELOPING	RIPE	SPENT
JUNE					
mean (#)	1.14 (12)	1.20 (17)	2.34 (21)	7.09 (15)	1.45 (18)
range	0.89-1.38	0.82-2.23	1.41-5.66	2.94-12.54	1.04-2.79
JULY					
mean (#)	0.69 (8)	1.04 (15)	5.34 (36)	8.72 (32)	3.75 (16)
range	0.51-0.96	0.60-1.49	0.92-9.70	4.66-14.43	1.03-5.04
AUGUST					
mean (#)	0.61 (64)	1.51 (80)	4.08 (47)	7.68 (27)	3.10 (25)
range	0.15-0.84	0.37-3.81	1.07-6.37	4.15-12.18	1.67-5.71
SEPTEMBER					
mean (#)	0.45 (25)	1.08 (180)	absent	absent	1.49 (45)
range	0.20-0.85	0.50-1.80			1.47-2.10
TOTAL					
mean (#)	0.59 (109)	1.20 (292)	4.17 (104)	8.16 (73)	2.05 (104)
range	0.15-0.96	0.37-3.81	0.92-9.70	2.94-14.43	1.45-5.71

overall body weight of this species. A total of 1,308 fish were examined and included in the GSI analysis.

GSI ranges and means for each developmental stage are given in Table 4. Examination of these data showed good aggreement in mean GSI for immature, resting and ripe maturity stages throughout the months examined. Mean GSI of developing females showed a reduced value in June, indicating a preponderance of "early" developing fish in the sample as expected for a period preceeding maximum spawning. Developing GSI ranges, however, remained well within those calculated for the following months. Ripe females characteristically exhibited the greatest degree of variability in GSI values due to the large size range encompassed by this condition (80 - 190 mm TL) and variable fecundity at size (Hildebrand and Cable 1938; Dovel, et al. 1969; Koski 1978). This great variability was explained and illustrated by Figure 12, where mean ripe GSI vales were highest at down river localities, the region of proposed maximum spawning, and decreased in the upstream direction to approximately 3/5 their maximal values. Koski (1978), Dovel et al. (1969), Haven (pers. comm.) and present data have noted a size reduction in upstream direction, which coupled with lower fecundity for smaller fish, adequately explained the reduction in GSI by altering the gonad to body weight proportion. An alternate and complementary interpretation existed that the generalized trend of reduced ripe GSI values with upstream progression was attributable to the degree of ripeness within this catogery, where ripe females encountered at upstream sites exhibited an earlier or somewhat lesser degree of ripeness. Each of these interpretations agreed with the schematic view of a down river maximal spawning region. All mean values for ripe females remained higher than other stage values at all stations.

Figure 12. Relationship of mean Gonado-somatic Index (GSI) values for each maturity category plotted against station.

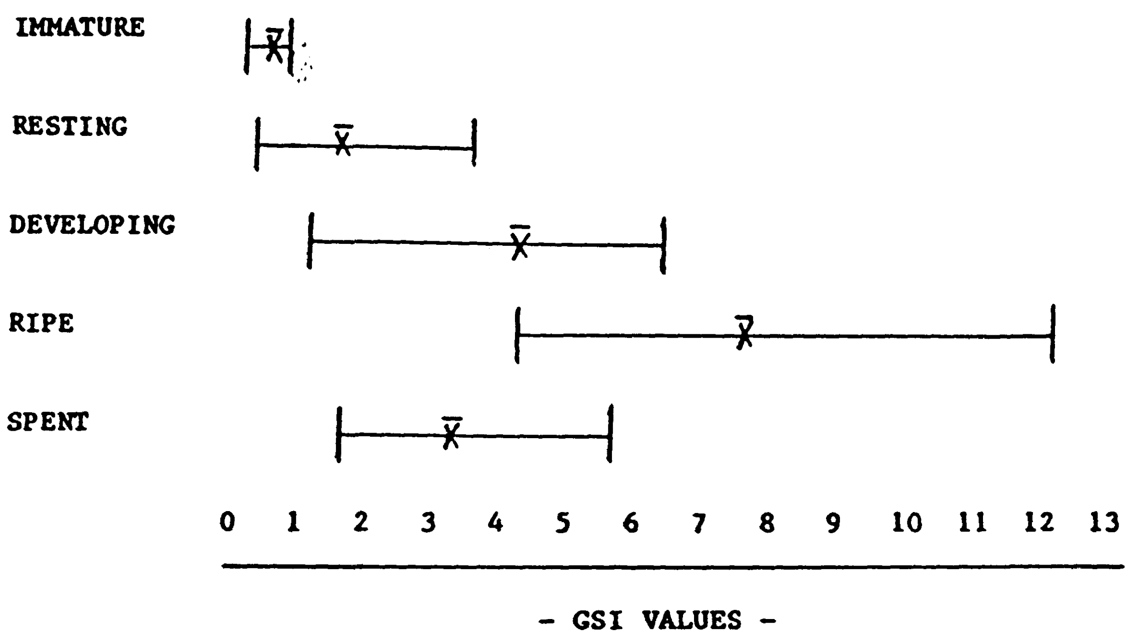

GSI BY STATION
gonado—somatic index (gwt/wwt*100)
10
8
6
4
2
0
01
02
03
04
05
06
07
09
10
11
12
STATION
stage
immature
resting
developing
ripe
spent

Spent GSI values depicted a decreasing trend from July through September, indicating a reduction in GSI for this category with decreased temporal proximity to maximal spawning activity. Resorption of remaining eggs and follicular material resulted in a decline in GSI values for spent individuals (Figure 12) with progression away from the proposed spawning region. Resting GSI values appeared consistent over all stations indicating uniform variability for pre-developing and quiescent females. By September, both the developing and ripe maturity conditions were notably absent, defining the abrupt end of all spawning activity. Spent and resting females undergoing recrudescense dominated at this time.

Figure 13 displays the typical range and overlap of GSI values from August 1984. This month was selected for demonstration as all maturity stages were represented during this time at the highest relative numbers. While considerable amount of overlap existed between succeeding developmental stages, exclusive ranges or areas of non-overlap also occurred for all but the spent catagory. By nature of the return to pre-spawning condition, the range for the spent stage encompassed ripe, developing and resting maturity GSI values. The increasing variability with progressive maturity reflected the common observation in teleost fishes that fecundity increases as a power function of length (Bagenal 1966, 1978; Wootton 1979), the exponent usually being about three. While the reasons are not readily apparent, Roff (1982) has suggested that space within the ceolomic cavity becomes more available for egg allocation with increasing fish size, hence introducing variability into the ovarian/body weight ratio at differing sizes. Since female _T. maculatus_ generally mature at >80 mm TL (Koski, 1978) and continue to spawn through adulthood, a large range of size classes contribute to the spawning stock.

Figure 13. Overlap and exclusive ranges of Gonado-somatic Index values (GSI) for each maturity category from August 1984.

AUGUST GSI RANGES



Maturity Index and Spawning Season

Maturity index (MI) values were calculated to reflect percent ovarian weight of total fish weight for females generally > 70 mm TL (Morse 1981). MI values provided a population wide method of quantifying spawning preparedness, whereas GSI differentiated between reproductive stages by assigning values to individual fish within each category.

Collections centered around the proposed spawning period for the Lower Chesapeake Bay region (June - September). Table 5 gives monthly means, standard deviations (SD) and ranges by month, separated into lower, middle and upper station groupings as well as combined for the entire system. Higher values of MI indicate spawning preparedness while low values describe sexual immaturity or quiescense.

The trend in mean and maximum MI indicated that spawning was most prevalent during July and August, with some precocious individuals commencing in June. Mean values for August were somewhat lower than the previous month, as more spent females with low MI values became intergrated in with ripe fish. Total range of MI for these months revealed that while spawning peaked during July and August, all maturity stages were present at the lower and middle station groupings. By September, MI had dropped to a maximum of 2.092 with a very restricted total range, suggesting a complete cessation of all spawning activity.

MI values for all months, were always highest at the lower station grouping, diminishing with upstream progression to the upper stations where mean MI values were comparable to pre and post-spawning periods. The post-

TABLE 5

MATURITY INDEX

MONTH		n	MEAN	S.D.	RANGE min	-	RANGE max	TOTAL RANGE
JUNE		63	2.123	1.903	0.824	-	12.537	11.713
	lower	40	2.223	2.018	0.824	-	12.537	11.713
	middle	23	1.949	1.715	0.895	-	7.914	7.017
	upper	--	-----	-----	-----		------	------
JULY		98	5.263	3.371	0.171	-	14.427	14.256
	lower	52	6.729	3.048	0.815	-	14.427	13.611
	middle	32	4.471	3.011	0.171	-	9.695	9.525
	upper	14	1.629	1.533	0.506	-	5.147	4.641
AUGUST		243	2.623	2.470	0.152	-	12.181	12.030
	lower	65	4.323	2.390	1.167	-	12.181	11.015
	middle	118	2.567	2.465	0.202	-	11.589	11.385
	upper	60	0.892	0.739	0.152	-	3.414	3.262
SEPTEMBER		250	1.087	0.337	0.202	-	2.092	1.980
	lower	81	1.234	0.289	0.400	-	2.067	1.667
	middle	105	1.122	0.267	0.598	-	2.092	1.494
	upper	64	0.845	0.367	0.202	-	1.660	1.458

spawning month of September was characterized by uniform MI values ($P > .01$) throughout the river system resulting from cessation of spawning and the breakdown of size-class stratification.

The wide range in MI during the spawning season indicated non-synchronous maturation of females and a relatively extended spawning season (Morse 1981). The length and peak of spawning period, as determined by MI, agreed with results from egg and larvae collections from the Chesapeake Bay region (Dovel 1971). Other researchers have reported analogous peak time of spawning in southern areas (Hidebrand and Cable 1938; Pearson 1941; Castagna 1955; Dovel et al. 1969; Dovel 1971). Koski (1978) has noted similar spawning time in the Hudson River, however spawning appeared to extend over a longer period of time commencing two weeks earlier and lasting three weeks longer than in the Chesapeake Bay.

TAGGING STUDY

Seasonal Movements

A total of 6,416 hogchokers (> 89 mm) were tagged and released into the Southern Branch of the Elizabeth River between 26 October 1984 and July 1985. Excluding same day and day after recaptures, 90 tagged fish were recovered of which 22 exhibited some degree of movement. Days at liberty (D.A.L.) for recaptured fish ranged from 2 to 350 days.

Table 6 indicates the number of recaptures separated into discrete D.A.L. groupings with number, percent and directional components shown. The first D.A.L. grouping of 1 to 3 days, represented an interim period of no observed movement for any of the recaptured fish. Thereafter, percent movement steadily increased for each successive time interval from 17.1% for the 4 to 30 D.A.L. to a high of 83.3% for the 101 to 150 D.A.L. fish, dropping somewhat to 66.7% for the > 150 group. Mean distance traveled for each D.A.L. group tended to reflect increased movement with additional time at liberty.

It is clear that each individual fish would have a greater opportunity for movement with each additional time increment and correspondingly pegister a higher degree of movement. It is equally true that within the constraints of this study it is impossible to know with certainty the exact movements, or duration of inactivity between the capture events. Therefore, it is most appropriate to use the short D.A.L. period fish for computation of maximum rate of movement, whereas long D.A.L. fish better reflect gross

TABLE 6

TAG RECAPTURES

D.A.L.	# Recap-tured	# exhibit movement	Direction N-S	S-N	% moved	Mean Distance (meters)
1 - 3	23	0	--	--	--	--
4 - 30	35	6	4	2	17.1	3,227
31 - 49	8	2	2	--	25.0	3,514
50 - 100	9	3	1	2	33.3	8,913
101 - 150	6	5	3	2	83.3	6,315
> 150	9	6	1	5	66.7	8,883
TOTAL	90	22	11	11	24.4	6,196

range of movement. Generalizations of movement, direction and rate, with reference to time of initial capture and recapture can be made utilizing combined tag return data to illustrate seasonal trends. Similarly, residence time can best be given as the maximum time observed at any particular area, where short observed periods of residence more correctly suggest the onset or continuation of migration activity.

A net upstream fall movement and subsequent return downstream migration was noted for all tagged hogchokers along the north - south axis of the Southern Branch. Fish movement was recorded for individuals tagged during October to December 1984 in an upstream or southerly direction to overwintering regions of lower salinity. Each of eleven recaptured fish exhibiting movement during this time demonstrated upstream movement with a maximum recorded rate of 461.8 m day^{-1} (Appendix I). One exception existed (tag # 0969), where a single fish showed a slight reversal of this trend, traveling 1692 meters north downstream over a period of 15 days (25 October - 09 November 1984). While this represented a fairly rapid northerly movement (112.8 m day^{-1}), in view of the other returns it was likely that this reflected local foraging or tidally mitigated movement rather than a seasonal trend. Each of four fish recaptured after the precipitous decline in bottom temperature during late December 1984 (9.8 - < 4.0^{o}C) were taken at station 10-A, a region of high abundance and apparent overwintering. No movement was noted from January through March 1985 when mean bottom temperatures remained well below 10^{o}C.

All fish tagged and recaptured from February through March showed no net movement, being retaken in the vicinity of release for all stations. From April 1985 through the termination of this study, fish tagged during the late winter and spring months were taken either at the original site or at sites downstream from their initial capture. All fish exhibiting gross movement (n = 11) during this time demonstrated the hypothesized downstream migration to higher salinity spawning grounds.

Rate of Movement

Estimation of rates of movement were caculated by dividing total observed distance moved by D.A.L. As previously noted, the maximum recorded rate was 461.8 m day^{-1} for a fish undergoing a fall upstream migration. This appeared to be a fairly accurate, if not somewhat conservative, estimate of a true rate of movement as a substantial distance had been travelled in a relatively short period that precluded time for excessive random meanderings. Other estimates that incorporated longer periods of time do not allow for periods of inactivity to be deducted from the true rate resulting in an observed rate of gross movement. It must also be assumed from the recapture data that all movement is unidirectional for either of the seasonal migrations.

Tag # 4837 showed the most rapid rate of downstream movement of 147.3 m day^{-1}, however this was most probably an underestimation of true rate as this figure was calculated from date of capture rather than the onset of seasonal movement. Five other fish (tag #'s 4662, 4665, 4685, 4805, 5013) were tagged at the same site and approximately the same time as # 4837, yet remained at station 10-A for periods of 45 - 55 days until 22 April 1985. It was therefore likely that # 4837 had not commenced downstream movement until at least this date, thereby reducing D.A.L. used to calculate movement, resulting in a rate of 417.5 m day^{-1}. This projected spring downstream rate was more comparable with the observed maximum upstream rate of 461.8 m day^{-1}.

Total distance traveled, or rate of movement, for fish tagged prior to overwintering and showing a net downstream movement over an extended period of time, did not reflect an upstream component that most probably occurred during the interval between capture events. For example, it was likely that # 1039 had undergone a fall migration to an upstream overwintering site (presumably in the region of 10-A) subsequent to initial capture and tagging at Station 04. By the time of recapture after 234 days at liberty at Station 03, this individual had most probably traveled at least 26,740 m along a north - south transect rather than the observed 1,692 m. Utilizing previous movement data, we could infer that # 1039 had arrived at the projected overwintering site prior to the late December decline in bottom temperature, and remained inactive at least until 22 April 1985. The overall north - south rate of movement would then be conservatively estimated at 219 m day^{-1} as opposed to the observered 7.2 m day^{-1}. Fish exhibiting no observed movement over an extended D.A.L. period may likewise have undergone seasonal migrations between initial capture and recapture, however it is impossible to know precisely either the direction or range of movement for any of these fish. It is important to recognize that individual tag returns yielded only a "snapshot" view of movements and directions. A more continuous picture could be constructed by examination of all tag returns to prescribe periods of movement and inactivity, net seasonal direction and probable distances covered. Beyond this it was difficult to interpret same site recoveries of varying duration. For instance, fish tag # 4538 was tagged and recaptured at Station 04 on 26 February 1985 after 75 D.A.L., while # 4568 tagged on the same date and station was recaptured nine days after # 4538 at the overwintering site 10-A. The differential locations of two fish released at identical sites and at liberty for essentially equal periods suggested that # 4538 did not undergo the the typical seasonal migration for several reasons. Time of recapture indicated that had # 4538 made the proposed upstream migration prior to the drop in bottom temperatures and remained inactive during the coldest winter months (January - February) before returning to Station 04, the rate of movement would have exceeded observed rates by a factor of two. Further, this individual would have had to preceed documented departure from the overwintering area by at least two months, traveling in waters substantially cooler (> $10^{o}C$) than those considered opportune for hogchoker movement. Therefore, it was probable that # 4538 did not undergo seasonal movement, but rather overwintered at the downstream site. Dovel et al. (1969) have reported that some Hudson River hogchokers are found in low abundance throughout the year at down river sites, presumably overwintering there buried in a semi-dormant state. From these conclusions we could crudely estimate the percent of fish that do not participate in a fall upstream migration by eliminating all other tagged fish that either exhibited this trend or possibly could have done so. The resulting statistic of 5.6% was interesting in that no previous attempts have been made to estimate the percent of fish overwintering downstream, but lacks reliability due to low numbers and high variance.

Residence time

For many of the same reasons given in the results and discussion of movement analysis by tag returns, residence time by hogchokers at any particular site rested largely upon examination of combined tag returns and analysis of sequential recoveries. Appendix II gives location and D.A.L. of fish recaptured at the original sites of marking.

Each of the three primary release sites (04, 07, 10) plus the overwintering site (10-A) showed sequences of capture and recapture with each successive visit for a period of at least fifteen days. Station 07, identified as the most severely impacted by toxic sediments (Lu, 1982; Bierri et et., 1982), showed the smallest observed periods of continuous residence for any of the sites. This suggested that while tagged hogchokers were available at all sites during the same time period, they tended to become less available in a shorter time period at Station 07 due to a more rapid rate of dispersion. Appendix II also showed that while all sites were sampled with equal intensity during October through December 1984, no fish were recaptured at Station 07 after a maximum period of 15 days, whereas Stations 04 and 10 showed residence times of up to 49 and 35 days respectively. Additionally, several fish released at Station 07 (#'s 1141, 1661, 2693, 2797) exhibited substantial upstream movement within 21 days and registered the highest rates of movement recorded. Whether this increased trend to rapid dispersion was a result of avoidance of toxic substrates, or that Station 07 may have represented an intermediate transitional site where fish were not truely resident but rather are in transit to an up or downstream site was not immediately clear. As little tagging emphasis was placed upon other intermediary stations comparisons were difficult, however, ancillary tagging at Stations 05 and 06 revealed rivaling and exceeding residence times (#'s 5149, 5178) with much less sampling effort.
Considering that greatest rates of movement were recorded from fish released at Station 07, coupled with the lowest observed residence periods, it was

probable that substrate avoidance played a role in fish movement over this impacted region.

The overwintering site 10-A, was identified on 08 February 1985 when all other stations yielded low numbers of hoghokers greater than 90 mm (< 4 fish per 7 minute tow). Two hundred and eighty-one fish were tagged at station 10-A between 26 - 28 February, constituting a single "pulse" that could be tracked through space and time. Although it was probable that the fish had arrived sometime prior to discovery, the documented residence time was 55 days until 22 April 1985, after which members of this group were found distributed downstream and no longer available at station 10-A. Sometime after the bottom temperatures climbed above 16.5^{O}C. recorded at this station during April, fish from the "pulse" group commenced a downstream directed movement and were taken at Stations 10, 07 and 04 (see Appendix I). It is interesting to note that while these recoveries were relatively few (n = 4), the largest TL was found at the most distant station and the smallest was recaptured in closest proximity to 10-A. This data stongly agreed with the hypothesis suggested by Dovel et al. (1969) that T. maculatus progressively increase their downstream range into higher salinity waters with increased size.

Population Dynamics

Three mark recapture methods were used to estimate population size of T. maculatus in the Southern Branch of the Elizabeth River. The Adjusted Petersen Estimate (Ricker 1975) was used to calculate fall 1984 and spring/summer 1985 population size by single census technique. The Schnabel and Schmacher Multiple Census (Ricker 1975) using combined serial tagging data was used to estimate population size over the entire sampling period. The Ricker Method (Ricker 1975) was employed to estimate survival rate from the beginning to the end of the tagging program and provide a correction factor to other estimates.

Because each tagged fish was individually recognizable by a unique number, it was possible to consider only particular groups or series of fish that most closely conform to the assumptions of the models used. Assumptions for any of the methods include that marked and unmarked fish suffer the same natural mortality and are equally vulnerable to capture. The rate of tag loss must be minimal or known. Previously cited tagging experiments had demonstrated no differential mortality due to tagging and no tag loss was noted during either the holding experiments or for the duration of the study. The assumption that marked fish become homogenously and randomly distributed with the unmarked population was satisfied by insuring that evidence of fish movement had occurred prior to recaptures being used for population estimates and that sufficient time had elapsed to allow tagged fish to resume normal activity. Since T. maculatus do not represent a commercial fishery or by-catch to any fishery, mortality due to fishing pressure was discounted. Similarly, as hogchokers probably do not constitute major prey items to other species present it was possible to deduct this component from total natural mortality. Complete recognition and reporting of tagged individuals was possible as hogchoker were only available to this researcher and others from cooperating institutions (CBI, ODU). Each captured fish was examined separately to insure detection of all tagged individuals. Any appreciable effect of immigration or emigration changing the ratio of marked to unmarked fish was considered negligible as the unique hydrographic conditions at the mouth of the system act to limit movement to and from the adjoining Hampton Roads area and no movement had been noted north of Station 02. Additionally, no tagged fish were taken during regular monthly VIMS survey cruises in the lower James River adjacent to the study area.

The effect of recruitment upon population estimates was kept minimal by two methods. Short term single census estimates limited appreciable recruitment by restricting the growth period. Measurement of recaptured fish showed negligible growth thoughout the overwintering period to the onset of warmer temperatures achieved by late April 1985. Thereafter, the minimum size considered in population estimates was adjusted to 95 mm TL to allow for growth of the smallest individuals.

Results of the Schnabel and Schmacher Multiple Census are presented in Table 7. This method divided the serial tagging and recapture samples into ten groups of sampling dates that considered only the recaptures from previous groups. Generally, sampling dates occurring within one week and encompassing all stations were grouped into a single unit where recaptures numbered at least three. Ricker (1975) noted that the probability of statistical bias could be ignored when recaptures number 3 - 4 or more. Because all recaptured fish were re-released live at the site of capture, it was not necessary to subtract recoveries from the total number tagged. The model used an iterative process where C_t was the number of fish caught in the sample at time t, R_t was the number of recaptures in the sample at time t and M_t was the number marked individual available at time t.

Total population estimates of _T. maculatus_ (> 89 mm TL) in the Southern Branch numbered 241,402. Upper and lower 95 % confidence intervals (C.I.) was constructed by calculating the variance from the mean of squares of deviations from the line R/C_t against M_t, where m equaled the number of

TABLE 7

-- Schnabel and Schumacher Multiple Census --

Period	C_t	R_t	M_t	C_tM_t	M_tR_t	$C_tM_t^2$	R_t^2/C_t
I	1112	21	3766	1,236,544	16,086	12,231,876	0.39658
II	418	7	4178	1,746,404	29,246	7.2964 exp 9	0.05024
III	361	9	4401	1,588,761	39,609	6.9921 exp 9	0.22438
IV	51	0	4575	233,325	0	1.0674 exp 9	0
V	300	7	4852	1,455,600	33,964	7.0625 exp 9	0.07000
VI	418	14	5150	2,152,700	72,100	1.1086 exp 10	0.46889
VII	194	7	5393	1,046,242	37,751	5.6424 exp 9	0.25258
VIII	537	4	5569	2,990,553	22,276	1.6654 exp 10	0.02979
IX	590	3	6313	3,724,670	18,948	2.3514 exp 10	0.01525
X	376	4	6418	2,413,168	25,672	1.5488 exp 10	0.04255
	4,357	76	50,615	18,587,947	295,625	9.4816 exp 10	1.55026

$$s^2 = \frac{\mathrm{SUM}(R_t^2/C_t) - (\mathrm{SUM}\ R_tM_t)^2/\mathrm{SUM}(C_tM_t^2)}{m - 1} \qquad N = \frac{\mathrm{SUM}(C_tM_t)}{R + 1}$$

t = 2.821 for 9 df (0.05 alpha, Sokal and Rohlf)

N = 241,402
95% C.I.
lower 164,379
upper 454,253

catches examined and m - 1 equaled the degrees of freedom (d.f.). Confidence limits were best computed from the more symmetrically distributed 1/N (DeLury 1958). The variance was described by the regression coefficient;

$$V(1/N) = \frac{S^2}{\Sigma\, C_t M_t^2}$$

Since t = 2.262 for 9 d.f. (Rohlf and Sokal 1969), the 95 % C.I. range for 1/N is +/- 2.262 times $s_{1/N}$ and the reciprocals gave the lower limit for N as 164,379 and the upper limit as 454,253.

This appeared to be a good estimate of total population size as the model included the entire sampling regime and has robustness from utilizing the maximum applicable mark and recapture data. The effect of natural mortality on the fish population was minimized by the additive nature of the model.

Estimates for the fall and spring/summer population size by the Adjusted Petersen Method corresponded closely to the estimates made using the Schnabel and Schmacher Multiple Census technique. Chapman (1951) and Bailey (1951) have shown that ordinary "direct" sampling tended to overestimate the true population, proposing the following formulae that would give an unbiased estimate;

$$N^* = \frac{(M + 1)(C + 1)}{(R + 1)}$$

where the variance of N^* was described as equal to;

$$V(N^*) = \frac{N^2\,(C - R)}{(C + 1)(R + 2)}$$

To estimate N^* during the fall, 3,766 fish marked (M) prior to 15 November 1984 were entered into the formula with 16 recaptures (R) from a total of 1,195 fish caught (C) between 15 November - 13 December 1984. All recaptured fish had been at liberty at least ten days and evidence of random mixing had been observed prior to calculating N^*. Total population size for this period was estimated as 265,020, within 10 % of the population size estimated by multiple census.

During the spring, 818 fish tagged between 26 February 1984 - 22 April 1985 served as the marked group of which four recaptures were taken in subsequent sampling of 1,569 fish sampled between 23 April - 26 July 1985. All fish had been at liberty for a minimum of 34 days and again, evidence of homogeneity of marked and unmarked fish was noted prior to using recaptures for population estimates. The estimate for N^* was 257,002, consistant with the fall estimate and within 6.5 % of the multiple census estimate.

In order to utilize combined seasonal mark and recapture data it was necessary to know the overwintering survival rate (S_1) from the time of first marking in year 1 to time of marking in year 2.

The Ricker Method of estimating survival rate when marking is done at the start of fishing in two consecutive years (Ricker 1975) could be applied to the two marking periods used in the single census estimates. Since the mark recapture ratio or rate of exploitation (u) (0.00425 and 0.00489 for period 1 and period 2 consecutively) were similar, it was appropriate to use data from both years to estimate survivorship using the formula modified for small numbers;

$$S_1 = \frac{R_{12}\ M_2}{M_1\ (R_{22} + 1)}$$

where,

M_1 = marked at start of 1st period (3,766)

M_2 = marked at start of 2nd period (818)

R_{11}= recaptures of the 1st period taken in the 1st period (16)

R_{12}= recaptures of the 1st period taken in the 2nd period (5)

R_{22}= recaptures of the 2nd period taken in the 2nd period (4)

The sample variance was obtained by substituting the estimates of Seber's (1972) general expression as;

$$V(S_1) = S_1^2 \; (1/R_{12} + 1/R_{22} - 1/M_1 - 1/M_2)$$

S_1 was calculated as 0.217066, the variance as 0.0211602, taking the square root to find the standard error equal to 0.1454655.

Using this estimate for S_1 we could assume that this proportion of the 4,575 fish tagged prior to overwintering, or 994 fish, survived to contribute to the total available marked population in year 2. Adding this total to the 819 fish tagged during year 2, it was possible to adjust M to reflect mortality. Total population estimate N^* was calculated from 11 recaptures of the 1,569 fish captured after 22 April 1985. By adjusting the first period number of marked fish to reflect survivorship into the second year, the population estimate N^* was 237,332 rather than 705,846 estimated using the unadjusted marking data. This estimate using combined marking periods was within 1.7 % of the multiple census estimates.

Conversely, by partitioning the 11 recaptures into those marked in the first and second periods it was possible to inflate the value of R to simulate the projected number of recaptures assuming no mortality. Seven of the recaptures (#'s 0229, 0641, 0956, 1039, 2384, 3857 and 4456) were marked in the first period prior to 14 December 1984, while four fish (#'s 4740, 4837, 5012 and 5178) comprised the recaptures from period 2. Had survivorship been complete from period 1 into the second year, it would be expected that 32 marked fish from the first year, in addition to the four second year recaptures, would comprise total R. Using the total values for M (5,394) and C (1,569), estimates of N^* equaled 228,923. This value was within 5.2 % of the multiple census estimate.

The estimates of population size by any method predicted only the population of *T. maculatus* > 89 mm TL, and did not consider the contribution of fish below the minimal size of marking. To crudely adjust N^* to reflect total population size, VIMS trawl survey data for the Southern Branch of the Elizabeth River were examined to determine the proportion of *T. maculatus* below 90 mm TL. VIMS trawl collections utilized a 1/4" mesh cod end liner that more effectively collected juvenile fish, however since no sampling was conducted in the juvenile nursery beyond Station 12, any subsequent estimates were limited to fish at and below this site. A weighted average of proportions (Snedecor 1946) was constructed for all stations for October - November 1984, encompassing the same time period as the first marking period. As no similar data was available for the second marking period, proportions from May - July 1984 were substituted to construct a weighted average for the second year. The weighted average of 1,546 fish collected concurrently with the first marking period showed that 0.8425 of all fish were 90 mm TL or larger, resulting in a sum of 314,526 fish in the total population. The period representing the spring/summer estimate consisted of 2,189 fish of which 0.7996 were larger than or equal to 90 mm TL and accounted for in the population estimate. From this figure, the total population consisted of 321,413 individuals.

The population estimates of all size fish were undoubtedly very low as the great majority of young-of-the-year and juvenile T. maculatus < 89 mm TL occupy regions not sampled. As a consequence, a substantial proportion of juvenile fish within the total population were not included an estimation of N^*.

Temperature and Salinity Interaction

The Elizabeth River supports an abundant breeding population of *T. maculatus* that may possibly complete their entire life span within the system. Hogchokers were collected thoughout the summer months at all stations, however tagging evidence suggests that for most Elizabeth River fish, the lower station group comprises the limit of their downstream range. Abundance of hogchokers at the river mouth station (Station 01) was consistantly lower than at adjacent upriver sites and probably represented a mixing of Elizabeth River and Hampton Roads/James River populations.

Dovel *et al*. (1969), Koski (1974) and the present study have shown that size and maturity are positively associated with higher salinities during the summer months such that mature spawning individuals are found at the highest salinities of their range. The decline in salinity at the Elizabeth River mouth during the summer and fall months (see Figure 3) most probably acts to limit movement into the Hampton Roads area and restrict genetic exchange between populations.

Reproductive periodicity is discussed in this study with reference to the bottom temperature and salinity. The commencement of spawning was signaled by the warming of bottom temperatures to above 18^{o}C in June 1984 and continued at the higher salinity stations through peak temperatures (> 23^{o}C) in August. Spawning ceased abruptly during September while bottom temperatures were above critical levels, yet down an average of 3.7^{o}C from the August high. Salinities were variable at the downriver spawning site during this period, ranging from a 15.8 ppt in September to 23.7 ppt in the peak spawning month of July. The inconsistant trend tended to suggest that bottom salinities were probably not a critical factor in stimulating either the commencement or termination of spawning behavior or migration to spawning sites.

Analysis of female maturity state showed that fish tended to leave the spawning area for upriver localities shortly after spawning, however, the preponderance of tagging data indicated that the main upstream migratory activity did not commence until November 1984 when bottom temperatures dropped below 12^{O}C. Koski (1974) and Castagna (1955) have noted that physical activity in hogchokers became greatly reduced in temperatures below 10^{O}C, requiring that all migratory activity be completed prior to attainment of this temperature. Additionally, as a result of the reduction of activity fish became less available to trawl gear, yielding lower catch per unit effort (CPUE) during the winter months (Koski 1974). The effect of reduced activity led to artificially low population estimates at the overwintering site (10-A) due to unequal catchability of tagged and untagged fish.

Hogchokers remained inactive at the overwintering site through March 1985 as temperatures remained at or below 10^{O}C. As temperatures rose to 16.9^{O}C during April, movement was noted from Station 10-A to downstream locations. Mark and recapture attempts to estimate overwintering population size at 10-A during February, March and April yielded progressively increasing, yet unrealistically low, numbers as temperatures warmed and more untagged fish became available for capture with those previosly tagged.

The interaction of bottom temperature and salinity appeared to regulate several factors affecting seasonal movements. The conservative thermal properties of deeper channel water tended to establish temperature as the more stable character, while salinity showed seasonal trends that were more variable as a result of runoff, freshwater input and tidal activity. Bottom temperature was likely the controlling parameter for stimulating migratory activity and salinity was most important in spawning site selection. Laboratory studies have suggested that the synergistic effect of cold water and high salinity is physiologically damaging to the hogchoker's ability to regulate osmotic concentrations (Koski 1974). It was considered that the energetic expense of seasonal movement to upriver overwintering sites served to reduce mortality by departing high salinity spawning regions.

Overwintering site selection also appeared to include the effect of channel depth. The major overwintering site (Station 10-A) was located just below abrupt shoaling of channel bottom from 10.3 to 5.3 m. During the winter months no mature hogchokers were captured beyond Station 10-A where the bottom depth averaged < 4.3 m. Koski (1974) has noted preference for depths > 5 m for this species in the Hudson River. The region of dramatic channel shoaling appeared to act as a southern boundary for upstream migration in the Elizabeth River.

Pearson (1929) and Gunter (1945, 1950) suggested that for many fishes of the Gulf of Mexico there is a distinct cycle of spawning, growth and movement related to salinity, and that lower than "characteristic" adult salinities may be required for early development. Offshore or polyhaline spawned pelagic fish eggs have vitelline membranes that are impermeable to salts (Rollefsen 1932) and water (Zotin 1965) that protect the egg during it's passage to low salinity hatching grounds. Hogchokers appeared to employ this spawning strategy and utilized the entire estuarine salinity regime during their life history.

Incidence of Reversal

Reversal and other morphological abnormalities have long been known among pleuronectiform flatfishes and reported upon by many researchers (Dawson 1962; Moe 1968; Dawlberg 1970; Wilkins and Lewis 1971; Moore and Posey 1974; Gartner 1986). Gartner (1986) noted that abnormal characteristics seemed to be most frequently exhibited in fishes of the Bothidae and Pleuronectidae families, and only rarely among the Cynoglossidae or Soleidae.

Reversal, or sinistrality was first reported for *T. maculatus* by Moore and Posey (1972) when eleven "left handed" specimens, including one partially albinistic, were collected in the Patuxent and Potomac Rivers. The rate of occurrence of sinistral hogchokers from the total catch was approximately 0.055 percent. In a later study, Moore and Posey (1974) published frequencies of occurrence of partial and total ambicoloration and albinism for the same regions at 0.54 and 0.15 percent repectively. While pigmentation anomalies were quite common in the Elizabeth River system, only two sinistral specimens were taken from a sample of 2,871 observations. Both specimens were male (95 and 96 mm TL), completely reversed with full rotation of both eyes to the left, yet within the dorsal and anal ray counts given for this species in the Chesapeake Bay (Hildebrand and Schroeder 1928). Coloration and pigmentation patterns were also completely reversed, with the typically dark banded configuration on the eyed side and the light spotted pattern displayed on the blind side. The frequency of occurrence (0.069 percent) was slighty greater than that reported for other localities (Moore and Posey 1974) but not differing significantly from expected at the .01 probability level.

The causal relationship between the reversed condition and the frequency of occurrence is not fully known for this or any other species of flatfish. Reversal in soleids is sparsely documented limiting comparisons of frequencies from differing geographical areas, however, Moore and Posey (1974) indicated that the Patuxent and Potomac River populations contained an unusually high (0.055 percent reversed) incidence of sinistral T. maculatus. They further suggested that thermal effluents from nearby electric power plants may be involved as the causal agent, citing previous work done by Houde (1971) on larval rearing conditions and Dawson's (1962) belief that low temperatures experienced during larval development likely result in higher frequencies of abnormalities. Subnormal temperatures have been implicated as the cause of white spotting in winter flounder (Pseudopleuronectes americanus) (Lux 1973).

Since atypical thermal conditions existed in the Patuxent and Potomac Rivers as well as the Elizabeth River system, thermal stress during early development may explain the similar degree of reversal. Pollution from industrial toxins in the Elizabeth River may have contributed additional stress upon developmental stages accounting for the somewhat more frequent incidence of reversal. However, as no ambient levels of morphological anomolies are known for this species, further investigation in other more typical geographical regions are needed to establish the "normal" incidence of reversal for T. maculatus. Whether the influence of temperature, light or any number of other conditions or combinations thereof, results in morphological abnormalities including reversal remains a pertinant question to be addressed by future research.

SUMMARY AND CONCLUSIONS

(1) Collections were made from the southern Branch of the Elizabeth River from March through September 1984 to examine reproductive ecology of *T. maculatus*. Hogchokers were individually tagged from October 1984 - June 1985 to determine timing, extent, rate and range of proposed seasonal migrations as well as population parameters.

(2) Overall male to female sex ratio was 1 : 1.4 with males predominating at downriver localities. Females were most prevalent at upriver sites. Temporally, males occurred at the highest ratios during peak spawning activity (July and August) at the lower station group spawning site.

(3) Spawning occurred in the Elizabeth River from June through August when bottom temperatures ranged from 18^{o}C to 23^{o}C. Spawning ceased abruptly during September when bottom temperature fell an average of 3.7^{o}C from August highs.

(4) Female MI and GSI values indicated that hogchokers spawned in the high salinities encountered at the lower station group located upstream of the river mouth. Females exhibit non-synchronous maturation over a relatively extended spawning season.

(5) Histological examination of gonadal tissue suggested that males are capable of serial spawning. Mean egg diameter was determined to be 0.354 mm with females spawning once per season.

(6) Females were an average of 9 mm (TL) larger than males of similar age. Hogchokers were distributed by size, with the largest individuals found in the highest salinities during the summer and fall. Overwintering population showed a breakdown of size stratification with all size classes occurring together.

(7) An upstream fall migration to low salinity overwintering sites was empirically demonstrated by tag return data. All migratory activity was shown to cease when bottom temperatures dropped below 10^{0}C. A corresponding downstream return migration to higher salinity spawning areas commenced for sexually mature individuals when bottom temperatures rose to 16.9^{0}C.

(8) Maximum rate of movement was calculated to be 461.8 m day^{-1}. Residence time was shown to be reduced at the most pollution impacted site (15 days at Station 07), however it is not known whether this effect is related to specific avoidance or the site's intermediate geographic position. Maximum residence time over similar time periods was observed to be 49 and 35 days for Stations 04 and 10 respectively, while the overwintering site (10-A) demonstrated residence times in excess of 55 days.

(9) Multiple and single census techniques were used to estimate population size and survival rate. Agreement was found between all methods with the

total population (> 89 mm TL) estimated at 241,402 (95 % CI 164,379 - 454,253). Overwintering survivorship was calculated as equal to 0.217.

(10) Incidence of sinistrality occurred at a similar rate of 0.069 percent in the Elizabeth River as compared to other studies.

(11) Lower salinities encountered at the Elizabeth River mouth may act to limit movement into the Hampton Roads area and restrict genetic exchange between populations.

(12) Bottom temperature appeared to be the controlling factor for migratory activity, while salinity and channel depth were important parameters in spawning and overwintering site selection.

APPENDIX I

Tag return data of individual fish exhibiting movement (23 October 1984 - 28 July 1985).

APPENDIX I TAG RETURNS - MOVEMENT -

TAG #	TL mm	LOC_1	LOC_2	D.A.L.	Distance meters	$Date_1$ $Date_2$	Rate m day^{-1}
0969	105	04	03	15	1,692	25/10/84 09/11/84	29.5
1039	120	04	03	234	1,692	25/10/84 23/05/85	7.2
1146	116	07	10	21	4,618	25/10/85 15/11/84	219.9
1412	107	07	10-A	132	5,917	26/10/84 07/03/85	44.8
1661	116	07	10	15	4,618	31/10/84 15/11/84	307.9
2384	94	10	04	222	11,225	05/11/84 26/06/85	48.2
2394	94	10	10-A	123	1,299	08/11/84 08/03/85	10.6
2693	110	07	10	10	4,618	05/11/84 15/11/84	461.8
2743	105	07	10	38	4,618	05/11/84 13/12/84	121.5
2797	112	07	09	15	2,515	05/11/84 20/11/84	167.6
2958	98	07	10-A	114	5,917	06/12/84 28/02/85	51.9
3031	102	07	02	350	10,320	06/11/84 23/10/85	29.5
3405	114	07	10	166	5,917	07/11/84 22/04/85	35.6
3739	103	10	11	34	2,409	09/11/84 13/12/84	70.9
3857	100	10	04	222	11,225	15/11/84 06/25/85	50.6
4456	103	10	03	221	12,917	13/12/84 22/07/85	58.4
4568	112	04	10-A	84	12,524	13/12/84 07/03/85	149.1
4740	113	10-A	04	146	12,524	26/02/85 22/07/85	85.8

(Appendix I continued)

4837	104	10-A	04	85	12,524	27/02/85 23/05/85	147.3
5012	109	10-A	07	140	5,917	07/03/85 28/07/85	42.3
5344	93	10-A	10	14	1,299	22/04/85 06/05/85	92.8
5969	155	03	02	60	1,692	23/05/85 22/07/85	28.2

APPENDIX II

Tag return data from fish recaptured at initial site of release (22 October 1984 - 25 June 1985).

APPENDIX II TAG RETURNS - SAME SITE -

TAG #	TL mm	LOC	D.A.L.	$DATE_1$	$DATE_2$
6263	126	02	119	25/06/85	22/10/85
0229	125	04	234	24/10/84	22/05/85
0318	113	04	14	24/10/84	07/11/84
0320	128	04	14	24/10/84	07/11/84
0462	98	04	49	24/10/84	10/12/84
0525	113	04	27	24/10/84	20/11/84
0540	121	04	14	24/10/84	07/11/84
0622	122	04	49	24/10/84	10/12/84
0641	104	04	235	24/19/84	23/05/85
0956	100	04	245	25/10/84	28/06/85
0969	105	04	15	25/10/84	25/10/84
1965	99	04	20	31/10/84	20/11/84
1972	116	04	20	31/10/84	20/11/84
1957	117	04	20	31/10/84	20/11/84
3201	106	04	36	07/11/84	13/12/84
3503	103	04	11	09/11/84	20/11/84
4538	123	04	75	13/12/84	26/02/85
5149	96	05	13	08/03/85	21/03/85
5178	110	06	30	21/03/85	23/04/85
1260	92	07	15	25/10/84	09/11/84
1350	100	07	11	26/10/84	06/11/84
1511	100	07	14	26/10/84	09/11/84
2224	102	07	5	01/11/84	06/11/84
2634	106	07	2	05/11/84	07/11/84
2647	97	07	4	05/11/84	09/11/84
2650	92	07	2	05/11/84	07/11/84
2660	98	07	2	05/11/84	07/11/84
2703	96	07	2	05/11/84	07/11/84
2706	117	07	4	05/11/84	09/11/84
2709	99	07	2	05/11/84	07/11/84
2716	106	07	4	05/11/84	09/11/84
2730	107	07	2	05/11/84	07/11/84
2740	103	07	2	05/11/84	07/11/84
2862	98	07	3	06/11/84	09/11/84

(Appendix II continued)

2877	105	07	2	05/11/84	07/11/84
2942	100	07	2	05/11/84	07/11/84
2943	98	07	3	06/11/84	09/11/84
2949	108	07	2	05/11/84	07/11/84
3039	107	07	3	06/11/84	09/11/84
3419	102	07	2	07/11/84	09/11/84
3464	107	07	2	07/11/84	09/11/84
3465	95	07	2	07/11/84	09/11/84
2399	105	10	10	05/11/84	15/11/84
2518	106	10	35	05/11/84	10/12/84
3894	103	10	25	15/11/84	10/12/84
3927	95	10	5	15/11/84	20/11/84
4137	108	10	25	15/11/84	10/12/84
4277	91	10	3	10/12/84	13/12/84
5071	106	10	14	07/03/85	21/03/85
4580	115	10-A	9	26/02/85	07/03/85
4603	101	10-A	9	26/02/85	07/03/85
4630	101	10-A	2	26/02/85	28/02/85
4637	98	10-A	2	26/02/85	28/02/85
4635	96	10-A	2	26/02/85	28/02/85
4640	109	10-A	9	26/02/85	07/03/85
4647	98	10-A	9	26/02/85	07/03/85
4662	130	10-A	55	26/02/85	22/04/85
4665	129	10-A	55	26/02/85	22/04/85
4673	98	10-A	9	26/02/85	07/03/85
4685	109	10-A	55	26/02/85	22/04/85
4693	111	10-A	9	26/02/85	07/03/85
4711	104	10-A	9	26/02/85	07/03/85
4717	120	10-A	2	26/02/85	28/02/85
4735	97	10-A	2	26/02/85	28/02/85
4762	105	10-A	10	26/02/85	08/03/85
4763	100	10-A	2	26/02/85	28/02/85
4799	117	10-A	8	27/02/85	07/03/85
4805	130	10-A	54	27/02/85	22/04/85
5013	108	10-A	45	07/03/85	22/04/85

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