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Estimating population parameters of American shad in the York River, Virginia : Final report, 2001

K. L. Maki
Virginia Institute of Marine Science

J. E. Olney
Virginia Institute of Marine Science

J. M. Hoenig
Virginia Institute of Marine Science

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Prepared by:

K. L. Maki[1], J. E. Olney[2] and J. M. Hoenig[3]

School of Marine Science
Virginia Institute of Marine Science
The College of William and Mary
Gloucester Point, Virginia 23062

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(1) Office: 804-684-7308, email: makik@vims.edu
(2) Office: 804-684-7334, email: olney@vims.edu
(3) Office: 804-684-7125, email: hoenig@vims.edu

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Preface and Acknowledgments

This document is the final report for P.L. 89-304, AFC 34 project, titled "Estimating population parameters of American shad in the York River, Virginia." The funded project period was 1 June 2001 to 31 May 2002, but sampling occurred just prior to this period during the spring spawning run. This is the fourth report in a series documenting efforts to develop and implement new stock assessment techniques for American shad (*Alosa sapidissima*) in Virginia's rivers.

Virginia's river fisheries for American shad have been under moratorium since 1994. Current research efforts of the Anadromous Fishes Program of the Virginia Institute of Marine Science have three objectives: 1) to determine current status of the stocks relative to historical levels, 2) to determine appropriate target catch-rate levels for restoration, and 3) to develop new assessment tools so that a future moratorium can be avoided. Current status is being evaluated by monitoring catch rates of staked gill nets fished by commercial watermen who are paid to fish with historical methods in historical locations. Appropriate restoration targets are being proposed on the basis of staked gill net catches that were logged in the 1950s. To accomplish this, we are comparing the catch rates of multi-filament nets used in the 1950's to those of modern monofilament nets. New assessment tools, such as the index-removal and the change-in-ratio methods under investigation in this final report, are being developed based on pound net catches. These, and other ongoing efforts (including pilot tagging studies, annual juvenile abundance surveys and otolith screening for hatchery-marked juveniles and adults), are intended to satisfy research and monitoring mandates of the Atlantic States Marine Fisheries Commission and to produce appropriate stock assessment tools required by the Virginia Marine Resources Commission (VMRC) to manage future commercial and recreational fisheries for American shad in Virginia.

We thank commercial fishermen Raymond and Tony Kellum, Marc Brown, and James Saunders for providing the foundation of our research and monitoring program on American shad, and the staff of the Anadromous Fishes Research program at VIMS for their hard work and dedication.

Objectives

1) Develop and compare gross and histological criteria to judge maturity stage in male American shad.

2) Monitor the sex ratio of ripening and spent fish in a research pound net to evaluate the assumptions of the change-in-ratio method of population estimation.

3) Monitor the catch rate of ripening and spent females in a research pound net to evaluate the assumptions of the index-removal method of population estimation.

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Figure 3. A diagrammatic representation of the change-in-ratio method. Before upstream removals, the ratio of the indexes of abundance of ripening males and females is 1:1. After fishing, the ratio of indexes of post-spawning males and females is skewed to male fish, suggesting that 2/3 of the females have been harvested in a sex-selective fishery.

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Executive Summary

(1) A stock assessment strategy for American shad based on index-removal (IR) and change-in-ratio (CIR) estimation of run strength and exploitation rate requires that the relative abundance of pre-spawning fish (upriver migrants) and post-spawning fish (downriver migrants) be assessed. Our approach is to test the assumptions of these two methods during a moratorium when few fish are being harvested. For index-removal estimation, the index of pre-spawning fish should be approximately equal to the index of post-spawning fish. For change-in-ratio estimation, the sex ratio of pre-spawning fish should approximately equal the sex ratio of post-spawning fish. In previous sampling using pound nets at the York River mouth , we found that the catch rate of post-spawning fish was higher than that of ripening fish suggesting either unequal catchability or that a mixture of stocks was being sampled. This invalidates the use of the IR method based on pound nets at the river mouth. The CIR method based on these catches showed promise, however.

(2) Studies completed in prior years indicated some potential problems with utilizing pound nets at the river mouth as well as with the use of haul seines. Therefore, sampling activities in 2001 were designed to investigate whether catches in a research pound farther upstream in the York River were consistent with the expectations of the IR or CIR methods during a moratorium.

(3) A total of 147 (81 female, 66 male) American shad were collected during 15 weekly sets of the research pound net from 20 February to 6 June 2001. An additional 118 American shad were collected in a second set of weekly sets (as part of a separate tagging study) from 21 February to 27 March.

(4) Six stages of cellular development were identified to classify sperm maturation in male American shad: primary and secondary spermatogonia; primary and secondary spermatocytes; spermatids; and spermatozoa. Presence or absence of these cell types and associated mitotic and meiotic cell divisions were used to develop criteria for determining the maturity stages of the collected testes. Macroscopic determination of the maturity stage of the testes was based on such characteristics as coloration, thickness, bifurcations, GSI, and flowing milt.

(5) The first post-spawning fish appeared in catches from the research pound net on April 10. After April 17, catches were dominated by post-spawning fish. Overall, more pre-spawning fish (catch index = 366.37) than post-spawning fish (catch index = 197.32) were captured. However, the research pound net was not fished for two weeks in mid-May due to vandalism of the gear. Thus, the peak of the down-migration may have been missed.

(6) The relative number of males increased over the period of sampling. The sex ratio of pre-spawning fish was 0.59:1 (males to females) and the sex ratio of post-spawning fish was 1.63:1.

(7) The assumptions of the index-removal (catch rates of ripening and spent fish are equal under the moratorium) and change-in-ratio (sex ratios of ripening and spent fish are equal under the moratorium) were not validated by this single year of sampling the research pound net.

Introduction

The American shad (*Alosa sapidissima*) is the largest clupeid in North America. The species is native to the western Atlantic Ocean and was introduced to the Pacific coast in 1870. Each spring, adult American shad migrate from mixed population assemblages at sea into the freshwater portions of rivers to spawn. Juveniles exit the natal stream by late fall and remain in the ocean until they reach sexual maturity. Most sexually mature fish return to the streams of their birth to spawn (Talbot and Sykes, 1958; Walburg, 1960; Carscadden and Leggett, 1975; Melvin et al., 1986) and spawning populations constitute genetically distinct assemblages (Bentzen et al., 1989; Nolan et al., 1991). Spawning runs of American shad exist in approximately 193 rivers from the St. Johns River, Florida, north to Atlantic Canada (Rulifson, 1994). Along the latitudinal gradient, populations of American shad may be either semelparous in southern rivers from Florida to North Carolina or predominately iteroparous in more northerly rivers (Leggett and Carscadden, 1978).

American shad are highly prized for their large ripe ovaries and delicate meat that is sold as fresh product. Historically, the species supported large commercial fisheries with landings along the Atlantic coast of approximately 30 million kg at the turn of the 20th century (Walburg and Nichols, 1967). Since that time, there has been a steady decline in coast-wide landings (Figure 1), and most populations are in serious decline (ASMFC, 1999). Today, there are relatively strong spawning runs (and commercial fisheries) in only a few systems including the Hudson and Connecticut rivers (ASMFC, 1999).

Fisheries for American shad in the York River, Virginia (a tributary in the Chesapeake Bay system), were closed in 1994. Prior to the closure, the York River supported a large and active fishery using fish traps (pound nets and fyke nets), haul seines, staked gill nets and drift gill nets. Following the moratorium, the status of the York River stock became uncertain in the absence of scientific monitoring. Currently, drift-net fishing by two small native American tribal governments and the taking of brood stock by federal and state agencies for stock restoration is permitted on the spawning grounds. Tribal landings are unknown but believed to be small since only a few fishermen participate. Fish caught by the Virginia Department of Game and Inland Fisheries for brood stock are sacrificed for egg taking and the numbers of females killed are recorded (in 1997, 854 females; 1998, 1,610; 1999, 1,417; 2000, 1533; 2001, 1359).

When the riverine fisheries for American shad in Virginia are eventually reopened, it will be important to have stock assessment methods for estimating the size of the shad runs and the fraction that is being harvested. In 1998-1999, the Virginia Institute of Marine Science (VIMS) initiated a monitoring program to evaluate stock status and begin the development of new stock assessment tools (the index-removal and change-in-ratio methods, see Figs 2-3). There are three analytical approaches that can potentially be used to estimate population size (run size) and in-river exploitation rate of Virginia's stocks of American shad: mark-recapture, index-removal estimation and change-in-ratio methods. Theoretical aspects of these techniques have been a focus of research at VIMS (Chen et al,. 1998a,b; Hoenig and Pollock, 1998; Pollock and Hoenig, 1998). Preliminary tagging experiments suggest that we can tag shad using pound nets, and hold them for up to seven days in net pens with little tag loss or mortality. The index-removal method does not appear to work for shad caught in pound nets at the mouth of the York River due to the fact that the catch rate of spent fish tends to be higher than that of ripening fish suggesting unequal catchability (Olney and Maki, 2001). The change-in-ratio method based on pound net catches at the mouth of the river shows promise. However, there is some question as to whether or not pound nets at the river mouth sample mixed stocks or solely the York River stock of American shad. We have rejected haul seines as a reliable fishing gear for stock assessment in the York River because past catches of American shad by the gear were sporadic and small. Another possibility is to apply the assessment methods to catch data from a pound net farther upstream. A research pound net offered the potential of good catches based on preliminary trials in late spring, 2000 (Olney and Maki, 2001). Fishes taken in the new trap are likely committed to the spawning run since the trap is situated in the middle reaches of the York River. Evaluation of a research net began in 2000 and continued under this study in 2001. The general components of this program are: monitoring catch rate of migrating shad, assessing reproductive condition, and determining the total number of shad caught by sex. The new methods require that the reproductive status (pre-spawning versus post-spawning) of the fish in the samples be known. We have developed criteria to assess maturity stage of females (Olney et al., 2001) and began studying patterns of maturation of males in this study.

Index-removal (IR) estimation involves examining how an index of abundance changes due to a known removal. For example, if the index of abundance of pre-spawning fish in a pound net is 100 and the index of spent fish is 25 (Figure 2B), then under the assumption that the catch rate is an index of abundance we can conclude that three-fourths of the fish have been removed (harvested) upstream or have died due to natural causes. This requires that pre-spawning and post-spawning fish have the same catchability. Under a moratorium, the in-river harvest is presumed to be close to zero, and the catch rate of pre-spawners should approximate the catch rate of spent fish (Figure 2A). This allows a check on the assumptions. It is necessary to evaluate index-removal estimation in the absence of a fishery in order to "calibrate" the method; thus, the current moratorium on fishing in the York River provides an important and timely opportunity to develop a new assessment tool. The method is described by Hoenig and Pollock (1998) and has been used by Dawe et al. (1993). The application of the index-removal method to a river fishery for an anadromous species is novel (Olney and Hoenig, 2001).

The change-in-ratio method (Figure 3) is useful when the harvest is selective for a component of the population. In the case of American shad, the fishery is a roe fishery and is selective for females (Olney et al., 2001). The catch obtained from the VIMS staked gillnet monitoring program in the York River was 84% female in 1998, 94% female in 1999, 84% female in 2000, and 94% female in 2001. In the absence of a fishery, the sex ratio of spent fish in pound net catches should approximate the sex ratio of ripening fish. A fishery that selectively removes females ought to shift the sex ratio so that the sex ratio of spent fish (males:females) should be higher than that for ripening fish (i.e., more males than females). If the total catch in the river is known separately for males and females, then it is possible to estimate the exploitation rate and run size from the change in sex ratio (see Pollock and Hoenig, 1998 for a review).

Materials and Methods

Collections of American shad with a haul seine in previous years were sparse and unreliable, and deploying the gear was expensive. Thus, we chose not to sample with this gear in 2001. Additionally, since the pound nets at the mouth of the York River were potentially sampling a mixed stock, we did not collect any specimens from these nets. Instead we focused sampling on the new research pound net located 13 miles (20.9 km) above the mouth of the river near Penniman Spit (Figure 4). It was anticipated that the location would alleviate the potential problem of mixed stocks at the river mouth while remaining downstream of traditional fishing locations. The gear mimicked the commercial design and was fished once weekly (48 hour set) from 20 February to 6 June 2001 by commercial watermen accompanied by scientists. The net was not fished between 2 May and 15 May because the net was damaged by vandals and had to be repaired. The catch was sorted on a flowing water table to reduce injury and bycatch was released alive. Whole catches or subsamples of American shad were taken to the laboratory for processing.

The gear was also fished for an additional set (of varying time) once a week between 21 February and 27 March 2001. In these second fishing events, total catches of American shad were recorded and the fish were measured (fork and total length), tagged, and released as part of a separate study. The weekly sex ratio of pre-spawning and post-spawning fish was determined by applying percentages ripening and percentages female from the first sampling event to the second. This procedure is known as double sampling (Tennenbein, 1972).

In the laboratory, all specimens from the first weekly sample were measured and weighed on a Limnoterra FMB IV electronic fish measuring board interfaced with a Mettler PM 3000-K electronic balance. The board records lengths (fork and total) to the nearest mm, receives weight (to the nearest g) input from the balance, and allows manual entry of collection data, sex and gonad maturity stage into a data file for subsequent analysis. Scales were collected from each specimen, pressed in acetate, and aged following the method of Cating (1953). Otoliths were also collected but were not aged due to evidence suggesting a large disagreement between otolith and scale ages (Maki et al, in revision). The paired gonads were removed, weighed (± 0.1 g) and fixed in 10% formalin. A gonosomatic index (the percent of somatic weight that is gonad weight; GSI) was calculated for each specimen (GSI=gonad weight/somatic weight x 100). After a period of one to four months, the fixed gonads were washed in fresh water, and a small subsample was dissected from the middle region of each gonad. The subsamples were weighed, soaked in fresh water for 24 h and stored in 70% ethanol. Samples were embedded in paraffin, sectioned to 5-6 μm thickness, placed on clear glass slides, and stained with Harris' hematoxylin and eosin. Sectioned tissue was examined with a compound microscope at 10x. Criteria for microscopic staging of ovaries had been established prior to this study (Olney et al., 2001) and included identification of stain reactions and presence or absence of cellular characteristics (nucleoli, nuclear migration, oil globules, yolk vesicles, atresia, and postovulatory follicles).

To our knowledge, there has been no scientific documentation on the maturation of testes in American shad. We based our initial assessment of shad testes on descriptions of other species including common snook (*Centropomus undeceimalis*, Grier and Taylor, 1998), redfish (*Sciaenops occellatus,* Grier et al., 1987), sailfin molly (*Poecilia latipinna*, Grier et al., 1980), spotted sea trout (*Cynoscion nebulosus*, Brown-Peterson et al., 1988), and striped bass (*Morone saxatilis*, Groman, 1982). Based on these examples, six stages of cellular development were identified to classify sperm maturation: Primary and secondary spermatogonia; primary and secondary spermatocytes; spermatids; and spermatozoa. Presence or absence of these cell types and associated mitotic and meiotic cell divisions were used as criteria for determining the maturity stages of the collected testes (Table 1). Macroscopic determination of the maturity stage of the testes was based on such characteristics as coloration, thickness, bifurcations, GSI, and flowing milt (Table 1).

Results and Discussion

A total of 147 American shad (81 females, 66 males) were captured during monitoring of the research pound net from 20 February to 6 June 2001 (Tables 2-3, Figure 5). Scale ages were determined for 119 of the 147 fish (Table 4). The remaining fish could not be aged due to regeneration or absence of appropriate scales. An additional 118 American shad were captured from 21 February to 27 March as part of the associated tagging study (Table 5).

Gonad maturity stages were first determined macroscopically and, later, verified by histological examination of sectioned gonadal material (Tables 6-7, Figures 6-10). Both ripening (maturing) and post-spawning (partially spent, spent, and resting) female and male American shad were observed. There was high agreement (92.4%) between macroscopic and microscopic maturity determinations (Table 8) for males. In only one instance was a pre-spawning fish (as determined microscopically) falsely identified macroscopically as post-spawning. All other instances of disagreement were cases where all fish were correctly identified as post-spawning but the specific stage of postspawning (partially spent, totally spent, or resting) was misidentified macroscopically. There was also high agreement (91.4%) between macroscopic and microscopic maturity determinations for females (Table 9). These results indicate that the assumption that pre and post-spawning American shad can be discriminated from each other is supported.

The majority of pre-spent fish were captured up to and including 10 April while the majority of partially spent or spent fish were captured on or after 17 April (Figure 5). The catch index (area under the curve of catch rate versus time of year) of pre-spawning fish (index = 366.37) was higher than that of post-spawning American shad (index =197.32) in the research pound net. We observed an increase in the relative abundance of post-spawning males in the research pound net. The sex ratio of pre-spawning fish (those captured prior to 17 April) was 0.59:1 males to females, and the sex ratio of post-spawning fish (those captured after 17 April) was 1.6:1.

During the moratorium, we expected to observe approximately equal numbers of pre-spawning and spent fish in the research pound net but this was not the case. In spring 2001, the catch rates of pre-spawning fish in the new net exceeded those of post-spawners (Figure 5). This is a somewhat surprising result since this pattern is the reverse of previous observations at the river mouth (Olney and Maki, 2001). These results potentially indicate a problem with utilizing the index-removal methodology. However it is important to note that these results represent only one season of sampling and suggest several possible explanations. First, the method may not have worked because the net was not fished due to vandalism for two weeks during the down-migration period. Second, the catchability of spent and ripening fish may be different at the river mouth than it is farther upstream. Third, infrequent sampling and small sample size may have confounded the results. Lastly, exploitation of American shad by native American fisheries and the taking of brood stock by state biologists (these activites are allowed by the Virginia Marine Fisheries Commission) may have caused the decline in the catch rates of post-spawners. The results, at this time, do not validate the assumption (catch rates of pre- and post-spawning individuals are approximately equal) of the index-removal method under a moratorium for the research pound net. Sampling will continue in 2002 with two weekly sampling events devoted to this monitoring program. Perhaps with this increased effort, the problems associated with small sample sizes can be eliminated.

During the first three years of sampling (1998-2000), the sex ratio of both ripening and spent fish was close to 50:50 in the commercial pound net catches (Olney and Hoenig, 2001). This suggests that the change-in-ratio method could be used to estimate run size and exploitation rate when the fishery reopens even if pre-spawning and spent fish have different catchabilities. However, as previously mentioned, we believe that the stocks may be mixed at the river mouth. In spring 2001, the sex ratio of pre-spawning fish (0.59:1, males to females) did not equal that of post-spawning fish (1.6:1). The results, at this time, do not validate the assumption (sex ratios of pre- and post-spawning individuals are approximately equal) of the change-in-ratio method under a moratorium for the research pound net. The results may possibly indicate that the removal of female American shad by native American fisheries and the taking of brood stock may be large enough to influence the catch rates of post-spawning fish in the pound net. However, the results may also be explained by unequal catchabilities of males and females at the river mouth and further upstream. Additionally, the small sample size mentioned above may account for this change in sex ratios of pre- and post-spawning fish. In 2002, we will continue to evaluate these and other possible explanations as we add another year of increased sampling.

Recent Publications Supported by this and Previous Awards:

Olney, J. E., and J. M. Hoenig. 2001. Managing a fishery under moratorium: assessment opportunities for Virginia's stocks of American shad (*Alosa sapidissima*). Fisheries 26(2):6-12.

Olney, J. E., S. C. Denny, and J. M. Hoenig. 2001. Criteria for determining maturity stage in female American shad, *Alosa sapidissima*, and a proposed reproductive cycle. Bulletin Français de la Pêche et de la Pisciculture 362/363: 881-901.

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Table 1. Criteria used to determine gonadal reproductive stages of male American shad collected in the research pound net, spring 2001.

Stage	Macroscopic Appearance	Microscopic Appearance
Immature	Testes small, thin, transparent in some areas. Light pink in color. GSI- (have not collected enough specimens to provide range).	Only primary spermatogonia present.
Maturing	Testes thickening. Becoming very pale pink to creamy white (when more mature or fully developed). There may be some lobes (or bifurcations) evident as testes thickens. May express milt when pressure applied. GSI- 0.56-9.42	Presence of primary and secondary spermatogonia, primary and secondary spermatocytes, and spermatids. In later maturing individuals, secondary spermatocytes, spermatids, and mature spermatozoans predominate and very few primary and secondary spermatogonia are present.
Running Ripe	Testes very thick and wider from dorsal to ventral edges. Milt flows freely when cut or pressure applied. More white than pink. Tissue is extremely delicate and easily "torn" during dissection process. Testes fill large percentage of body cavity. GSI- (have not collected enough specimens to provide range).	Mostly spermatozoa, spermatids, and secondary spermatocytes. Spermatozoa completely fill the seminiferous tubules and are evident in ductus deferens (main collecting duct).
Partially Spent	Testes look similar to running ripe testes but appear less "full." GSI- 1.08-4.93.	Spermatozoa only partially fill the tubules and are most abundant in ductus deferens.
Spent	Testes very small, thin, and flaccid. Light pink to light red in color but still opaque. GSI- 0.58-2.39	Spermatozoa present in some tubules. The tubules are smaller with only primary and secondary spermatogonia present.
Resting	Testes even smaller and flat. Often appear to be transparent. Light pink to light red in color. GSI- 0.09-0.67.	Primary and secondary spermatogonia present.

Table 2. Total number, total weight and catch rates (numbers per day, kg/day and lbs/day) of female American shad taken in the research pound net during spring 2001.

Date	Number	Numbers/day	Total Weight (g)	Catch Rate (kg/day)	Catch Rate (lbs/day)
2/20/01	7	3.5	10811.4	5.4	11.9
2/27/01	1	0.5	1747.7	0.9	2.0
3/6/01	16	8.2	21123.2	10.8	23.8
3/13/01	6	3.0	7925.0	4.0	8.7
3/20/01	8	4.0	11412.5	5.7	12.6
3/29/01	10	5.0	13527.8	6.8	14.9
4/3/01	9	4.2	11235.5	5.3	11.6
4/10/01	9	4.6	11508.1	5.9	13.1
4/17/01	0	0	0	0	0
4/24/01	3	1.5	2283.6	1.1	2.5
5/1/01	9	4.5	8346	4.2	9.2
5/16/01	2	1.1	1882.2	1.0	2.3
5/24/01	1	0.5	887.1	0.4	0.9
5/29/01	0	0	0	0	0
6/6/01	0	0	0	0	0

Table 3. Total number, total weight and catch rates (numbers per day, kg/day and lbs/day) of male American shad taken in the research pound net during spring 2001.

Date	Number	Numbers/day	Total Weight (g)	Catch Rate (kg/day)	Catch Rate (lbs/day)
2/20/01	11	5.5	10078.7	5.0	11.1
2/27/01	3	1.5	2945.3	1.5	3.3
3/6/01	11	5.6	10527.8	5.4	11.8
3/13/01	5	2.5	4767.5	2.4	5.2
3/20/01	4	2.0	3559.6	1.8	3.9
3/29/01	3	1.5	2330.1	1.2	2.6
4/3/01	5	2.3	3711.4	1.7	3.8
4/10/01	0	0	0	0	0
4/17/01	3	1.6	1857.1	1.0	2.1
4/24/01	1	0.5	499.2	0.2	0.5
5/1/01	9	4.5	5464.2	2.7	6.0
5/16/01	7	3.9	4862.6	2.7	6.0
5/24/01	4	1.9	2567.0	1.2	2.7
5/29/01	0	0	0	0	0
6/6/01	0	0	0	0	0

Table 4. Summary of scale ages for American shad taken from the weekly catch of the research pound net in spring 2001. NA indicates the number of fish for which the age could not be determined from collected scales.

Sex	Year Class	Number	Total Weight (kg)
Male	1998	3	2.1
	1997	22	16.0
	1996	19	15.5
	1995	3	2.9
	1994	0	0
	1993	0	0
	NA	19	16.6
Female	1998	0	0
	1997	19	20.0
	1996	30	36.9
	1995	12	16.2
	1994	10	16.9
	1993	1	1.6
	NA	9	10.0

Table 5. Total number and presumed sex ratio (based on 48-hour monitoring sample from same week) of catches in the research pound net during the second weekly set. These specimens were tagged and released as part of a separate study.

Date	Total Number	Presumed Sex Ratio (male:female)
2/21/01	2	0.61:0.39
3/1/01	10	0.75:0.25
3/16/01	27	0.45:0.55
3/23/01	36	0.33:0.67
3/27/01	43	0.23:0.77

Table 6. Reproductive condition (histological determination) of female American shad taken in the research pound net spring 2001.

Date	Total	Unknown	Maturing	Hydrated	Partially Spent	Spent
2/20/01	7		7			
2/27/01	1		1			
3/6/01	16		16			
3/13/01	6		6			
3/20/01	8		8			
3/29/01	10		10			
4/3/01	9		9			
4/10/01	9	1	7	1		
4/24/01	4				3	1
5/1/01	9		2		5	2
5/16/01	2		1		1	

Table 7. Reproductive condition (histological determination) of male American shad taken in the research pound net spring 2001.

Date	Total	Unknown	Maturing	Hydrated	Partially Spent	Spent	Resting
2/20/01	11		11				
2/27/01	3		3				
3/6/01	11		11				
3/13/01	5		5				
3/20/01	4		4				
3/29/01	3		3				
4/3/01	5		4	1			
4/17/01	3		3				
4/24/01	5		1			2	2
5/1/01	9				1	8	
5/16/01	7				1	3	3

Table 8. Comparison of macroscopic and microscopic gonad stage determination for 66 male American shad collected in the research pound net, spring 2001.

Macroscopic Stage	**Microscopic Stage** Maturing	Running Ripe	Partially Spent	Spent	Resting
Maturing	**44**	0	0	0	0
Running Ripe	0	**1**	0	0	0
Partially Spent	1	0	**1**	0	0
Spent	0	0	1	**13**	3
Resting	0	0	0	0	**2**

Table 9. Comparison of macroscopic and microscopic gonad stage determination for 81 female American shad collected in the research pound net, spring 2001.

Macroscopic	**Microscopic Stage**				
Stage	Maturing	Running Ripe	Partially Spent	Spent	Resting
Maturing	**65**	1	0	0	0
Running Ripe	0	**0**	0	0	0
Partially Spent	2	0	**5**	0	0
Spent	0	0	4	**3**	0
Resting	0	0	0	0	**0**

American Shad Landings

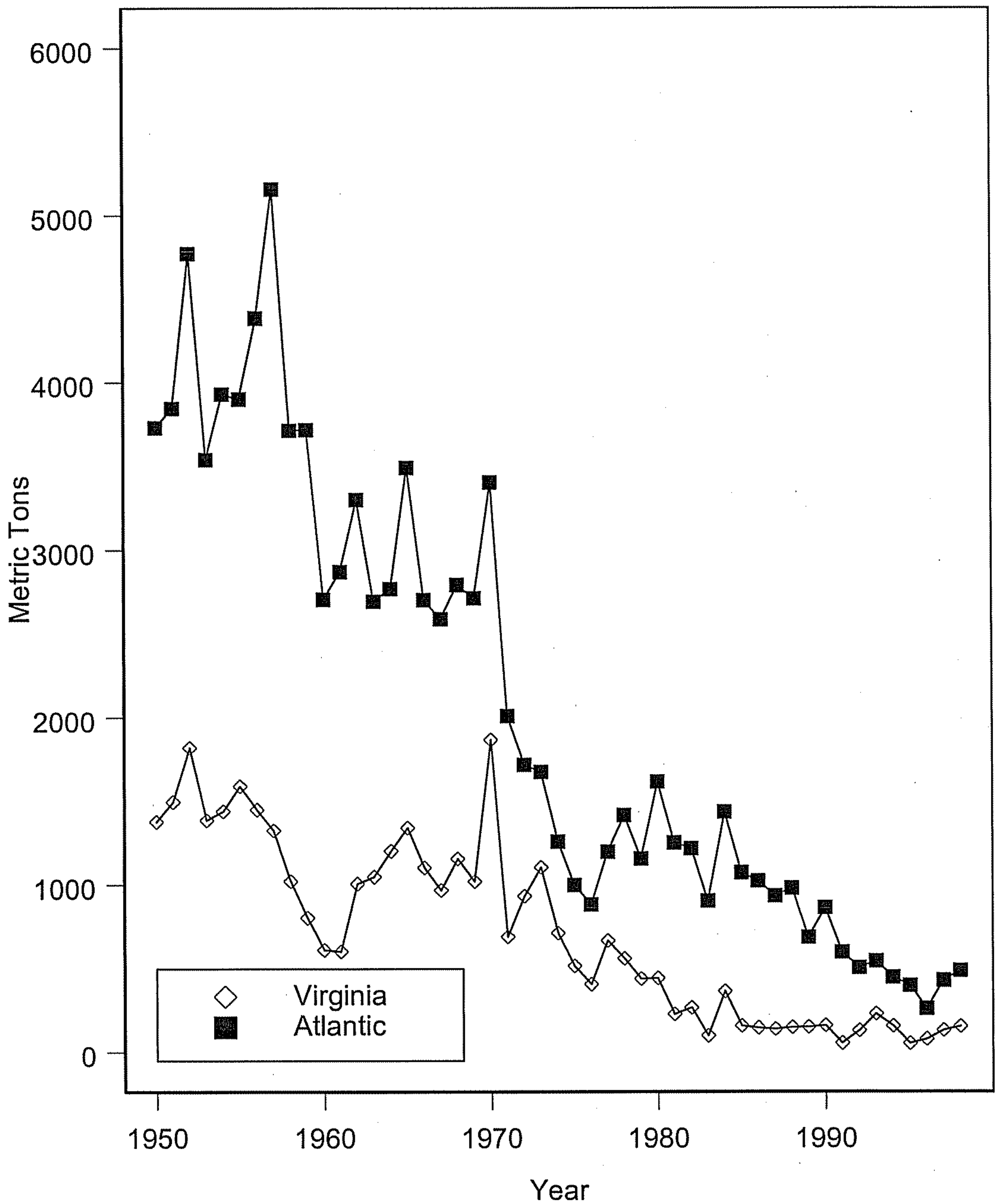
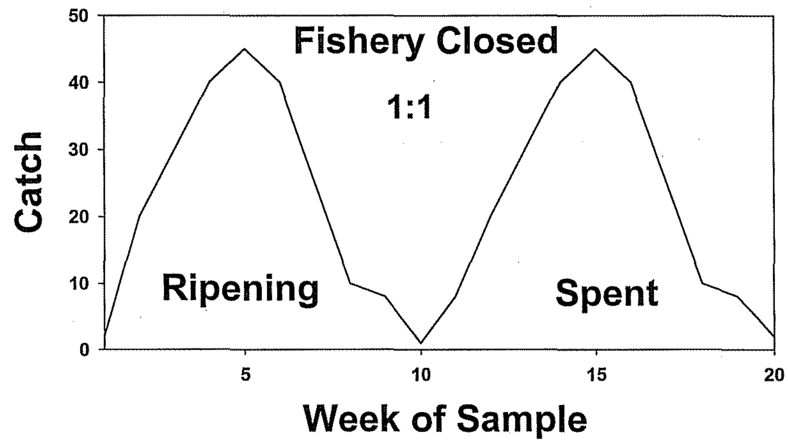


Figure 1. Commercial landings of American shad along the Atlantic coast and in Virginia since 1950. Data source: National Marine Fisheries Service, Fisheries Statistics and Economics Division.

A



B

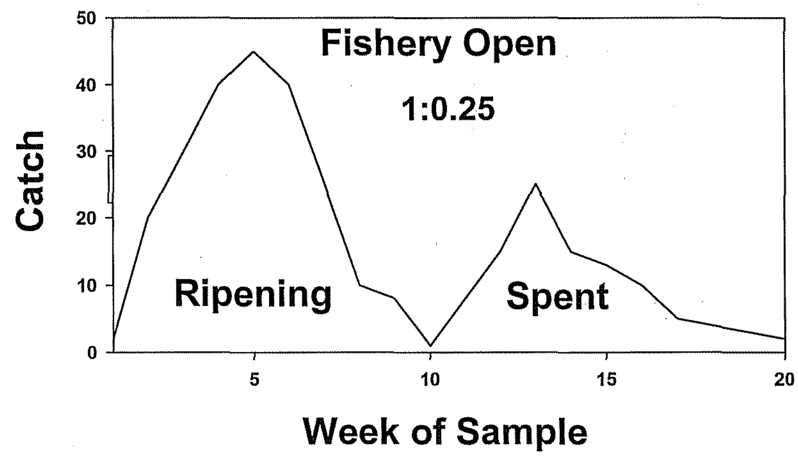


Figure 2. A diagrammatic representation of the index-removal method. A. In the absence of fishing, an index of abundance of ripening fish is equivalent to an index of abundance of spent fish at the river mouth; B. With fishing, the index of post-spawning fish is 1/4 as large as the index of ripening fish at the river mouth suggesting that 3/4 of the run has been harvested.

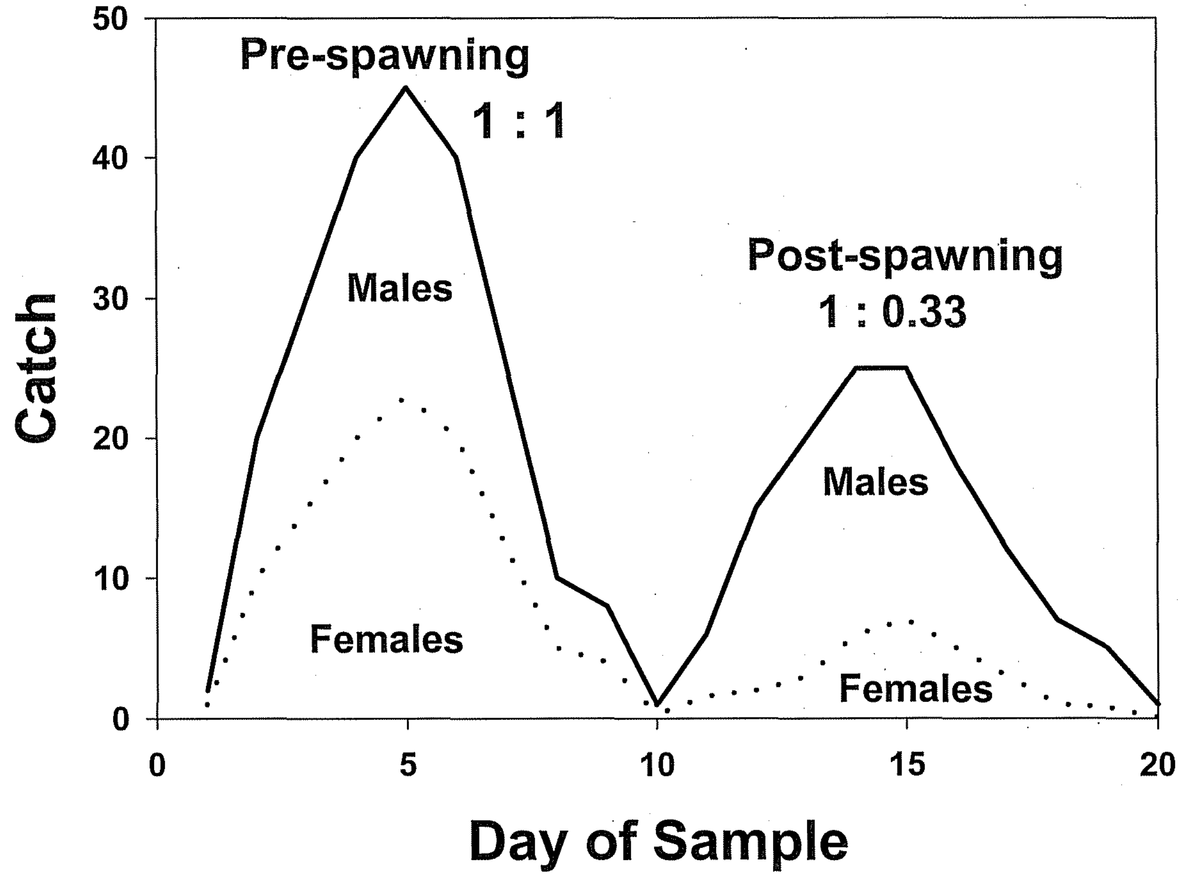


Figure 3. A diagrammatic representation of the change-in-ratio method. Before upstream removals, the ratio of the indexes of abundance of ripening males and females is 1:1. After fishing, the ratio of indexes of post-spawning males and females is skewed to male fish, suggesting that 2/3 of the females have been harvested in a sex-selective fishery.

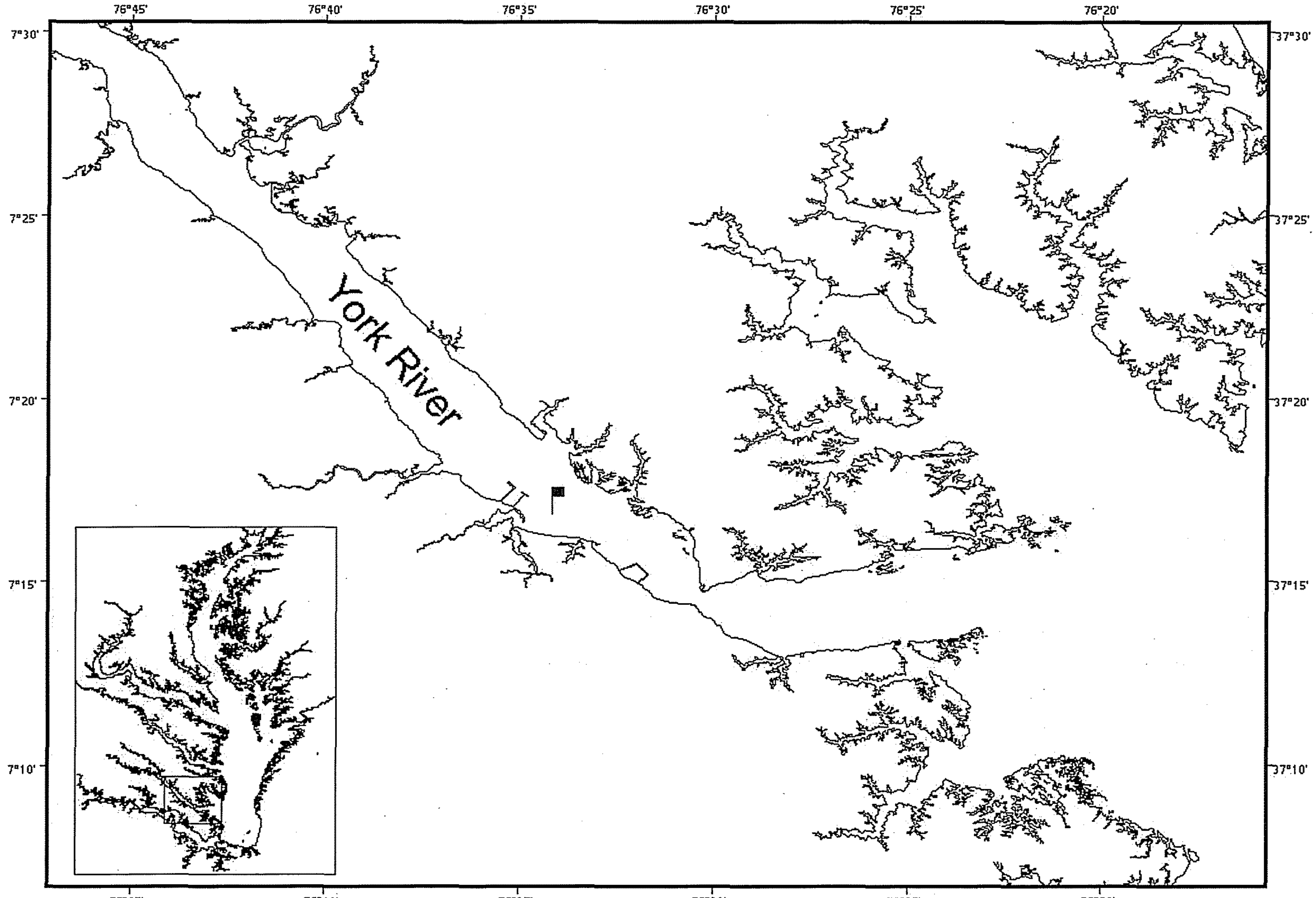


Figure 4. Location of the research pound net near Penniman Spit in the York River, Virginia.

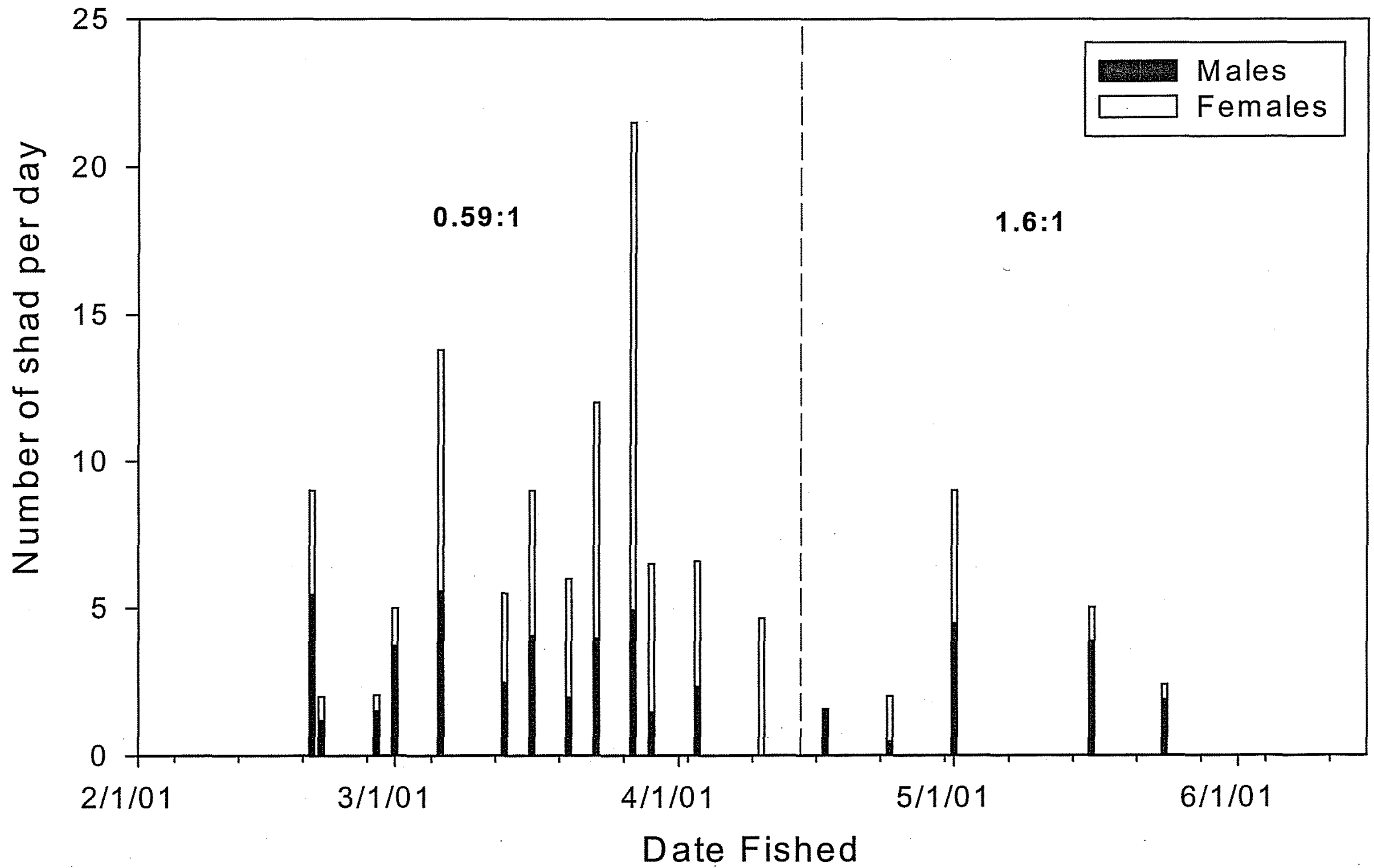


Figure 5. Catch rates (number per day) of male and female American shad taken in a research pound net in the York River, Virginia in spring 2001. The sex ratios for fish that were tagged on February 21, March, 1, 16, 23, and 27 were determined from the monitoring sample collected in the same week. The vertical line approximates the date after which the majority of post-spawning fish were captured.

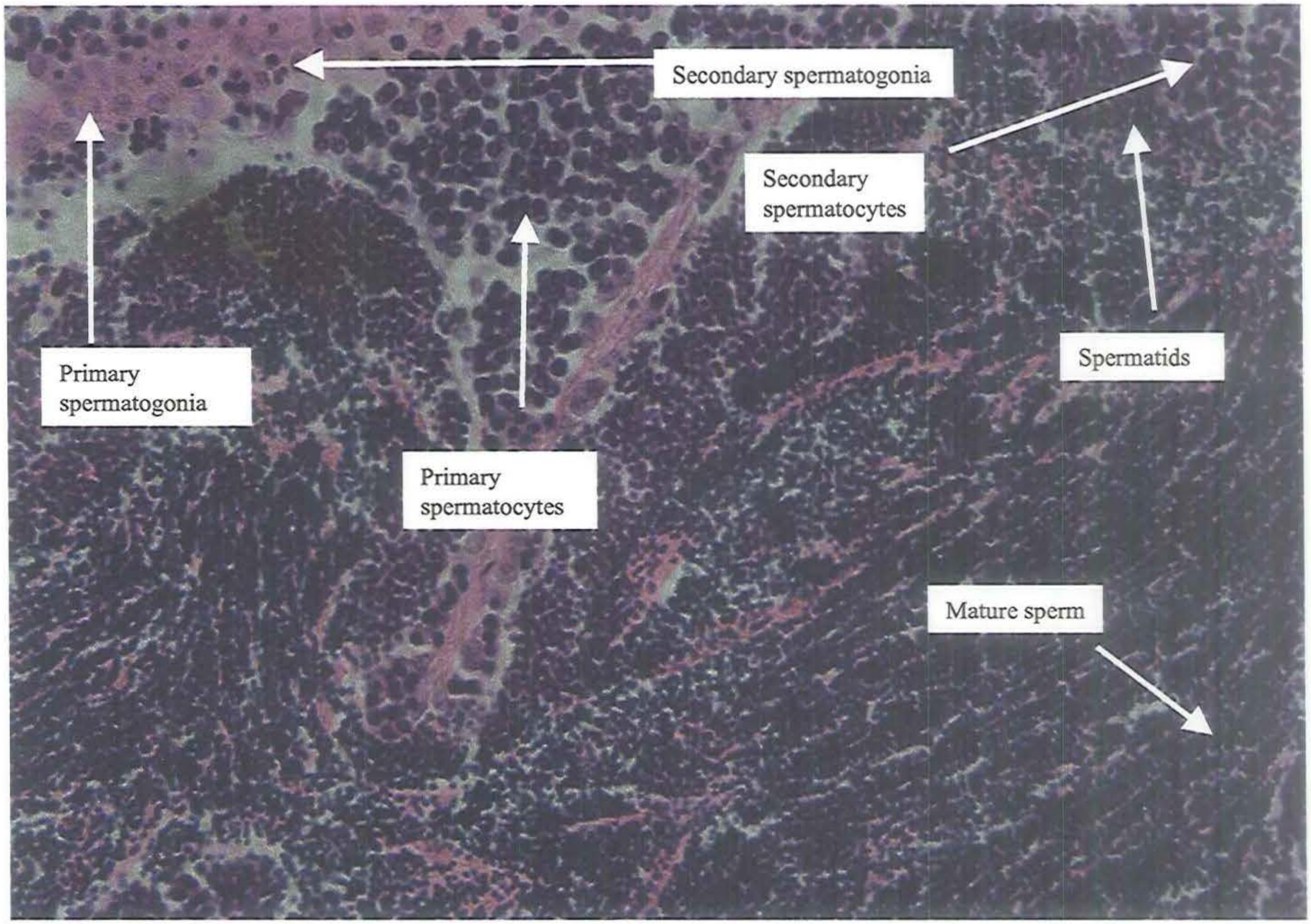


Figure 6. Histological section from the testes of a maturing male American shad. Six cellular stages are present: primary and secondary spermatogonia, primary and secondary spermatocytes, spermatids and mature sperm.

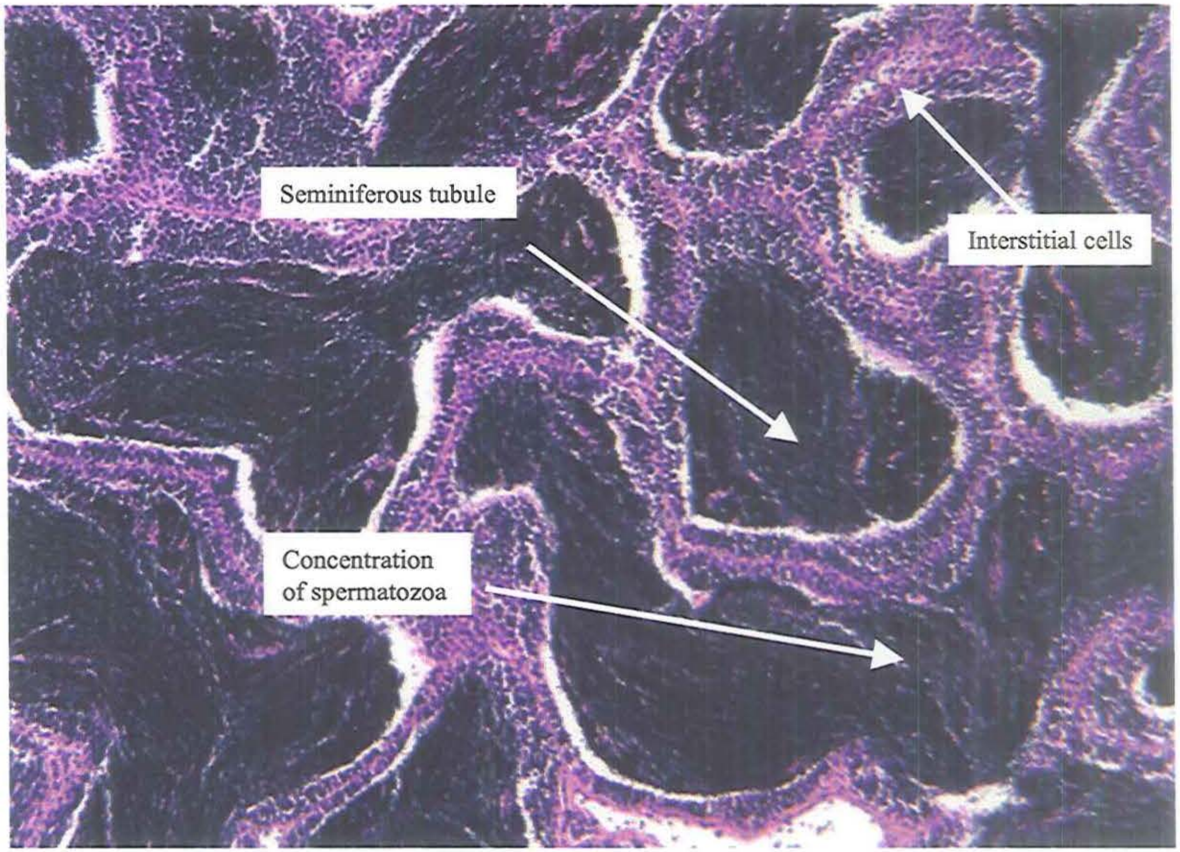


Figure 7. Histological section from the testes of a running ripe male American shad. Spermatozoa completely fill the seminiferous tubules.

Figure 8. Histological section from the testes of a partially spent male American shad. Spermatozoa only partially fill the tubules.

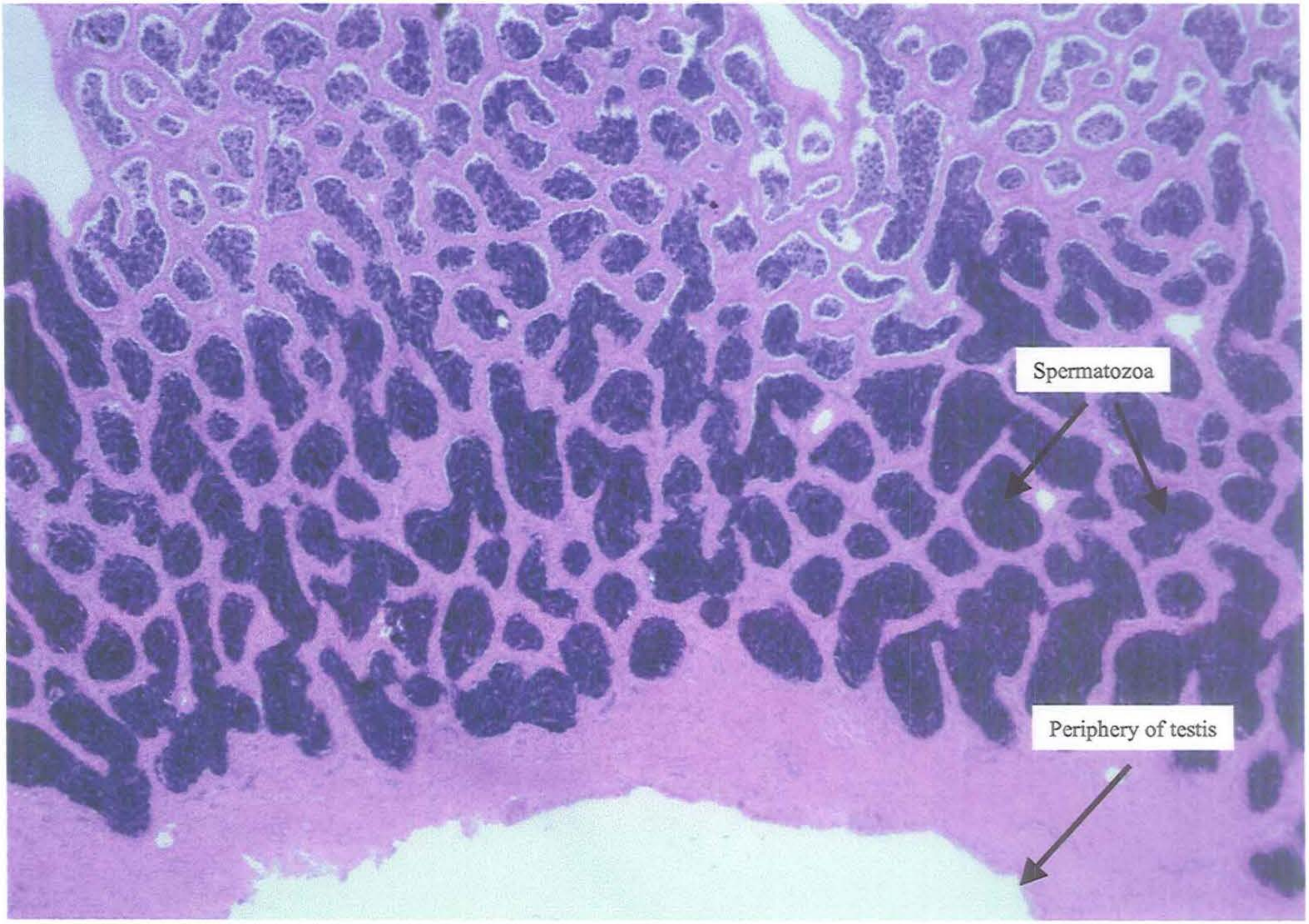


Figure 9. Histological section from the testes of a spent male American shad. Tubules are smaller and spermatozoa are still present in tubules at the periphery of the testes.

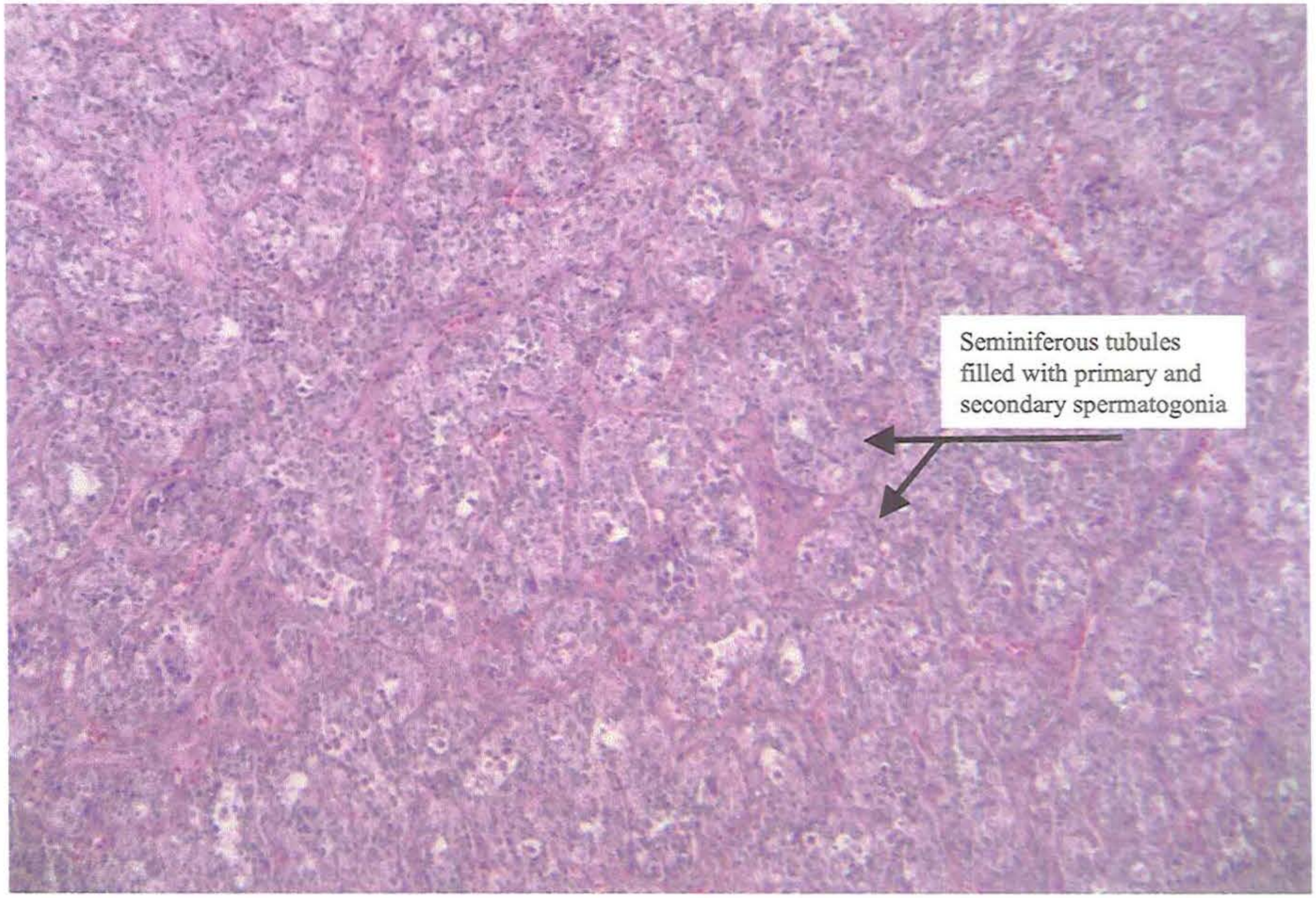


Figure 10. Histological section from the testes of a resting male American shad. Primary and secondary spermatogonia are present.