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Growth and Yield-Per-Recruit Modeling of Spot (*Leiostomus xanthurus*) in the Chesapeake Bay, and a Comparison of Biological Reference Points

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GROWTH AND YIELD-PER-RECRUIT MODELING OF SPOT (*LEIOSTOMUS XANTHURUS*) IN THE CHESAPEAKE BAY, AND A COMPARISON OF BIOLOGICAL REFERENCE POINTS

by

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ABSTRACT

GROWTH AND YIELD-PER-RECRUIT MODELING OF SPOT (*LEIOSTOMUS XANTHURUS*) IN THE CHESAPEAKE BAY, AND A COMPARISON OF BIOLOGICAL REFERENCE POINTS.

Kevin Ray Piner
Old Dominion University, 1999
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Spot were sampled from the Chesapeake Bay commercial fishery from 1993-1995 to determine if spot are overfished. Transversely sectioned otoliths were determined to be the most appropriate structure for ageing spot. It was determined that spot have a high natural mortality rate (M=0.9) and fast growth (K=0.6). This combination of M and K makes spot relatively impervious to growth overfishing as determined by yield-per-recruit modeling. Because spot are nearly impervious to growth overfishing, management thresholds based on yield-per-recruit modeling may be inappropriate. In addition, the combination of high M and fast K makes it possible to completely fish out a cohort before it reaches its first potential spawning event and still not growth overfish the stock. Spawner Potential Ratios (SPR) per recruit were developed to assess the potential of recruitment overfishing spot. At current levels of fishing mortality (F), less than 20% of the potential reproductive effort of a cohort is available for spawning. Levels of F should be reduced to F=1, to allow SPR=20%. Levels of F should not, however, be reduced much below F=1 to avoid under-utilizing the potential cohort biomass.

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CHAPTER I

INTRODUCTION

"Stock assessment involves the use of various statistical and mathematical calculations to make quantitative predictions about the reaction of fish populations to alternative management choices".

Hilborn and Walters 1992

Overview

The commercial exploitation of fish stocks is an important source of protein and jobs worldwide. An estimated 100 million tons of fish each year are caught commercially worldwide (King 1995), a figure that is thought to be the sustainable limit of world production. It is also estimated that 50 million people are employed or otherwise involved in small-scale fisheries globally (Saila and Gallucci 1996). Discovery of new fishing grounds and unexploited stocks has dwindled since the 1970s, making prudent management of existing stocks imperative. However, development of increasingly effective fishing techniques and gears, which more efficiently deplete stocks, makes stock assessment a challenging and continuing task.

Age specific models, such as yield-per-recruit and virtual population analysis require specific information on the longevity, mortality, reproduction, growth, and, exploitation patterns of a fish stock to make adequate predictions of the effects

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This dissertation follows the format of the journal Fishery Bulletin.

of fishing on these stocks. Among these measures, the von Bertalanffy growth model (von Bertalanffy 1938), an age-based model in fisheries research, is widely used to describe length or weight at age. Though sometimes criticized (Knight 1968; Roff 1980), the von Bertalanffy growth model has the advantages of being widely used (Cerrato 1990) and also being based on physiological and bioenergetic principles (Lopez-Veiga 1979). The model assumes growth rate is equal to the differences in the rates of anabolism (tissue synthesis) and catabolism (tissue breakdown) (Wooton 1990). The yield-per-recruit model which incorporates parameters from the von Bertalanffy growth model was developed by Beverton and Holt (1957), and is used to estimate the yield (g) that can be expected for an individual fish from a cohort under a specific fishing scenario.

Aged-based data has not existed for most of the important Chesapeake Bay fishes, such as the sciaenids, until the work of Barbieri et al. (1993), Lowerri-Barbieri (1994) and Jones and Wells (1998). The previous studies of spot (*Leiostomus xanthurus*) from the Chesapeake Bay region, described only the basic life history and biology; few quantitatively estimated the stock parameters necessary to manage a commercially exploited stock. A review of the biology of spot from the Mid-Atlantic is as follows.

Distribution

Spot are found from the Gulf of Mexico along the Atlantic Coast to Massachusetts (Smith and Goffin 1937; Bigelow and Schoeder 1953; Dawson 1958). Maximum water depth from which spot have been taken is 204 m, but it is usually found in depths less than 100 m (Pearson 1932 ; Dawson 1958). Adult spot enter bays and estuaries in the spring and leave during fall for deeper coastal waters (Hildebrand and Schroeder 1928; Hoese 1973) in the Middle Atlantic portions of their range. Spot are not year-round residents of the Chesapeake Bay, but are caught only from April through October. Spot exodus from shallow bays and estuaries may be temperature related (Gunter and Hildebrand 1951; Dawson 1958) because, in general sciaenids are susceptible to low temperature mortality (Gunter and Hildebrand 1951; Hoss et al. 1988).

Spawning Biology

Spot spawn offshore in the Mid-Atlantic from late fall through early spring (Welsh and Breeder 1923; Lewis and Judy 1983). Studies, based on the seasonal appearance of spot larvae and juveniles, estimate spawning off North Carolina occurs from November through March (Hildebrand and Cable 1930; Lewis and Judy 1983; Flores-Coto and Warlen 1993) with the majority of spawning activity in December and January (Warlen and Chester 1985).

Bottom temperatures of at least 17°C are needed for spot spawning, and the most northerly Western Atlantic area with 17°C bottom water temperatures during winter is on the outer continental shelf off North Carolina near the Gulf Stream (Norcross and Bodolus 1991). Because of this area's proximity to the Chesapeake Bay, spot recruiting to the Bay are thought to come from spawning stock south of Cape Hatteras, North Carolina.

Little information exists in the literature on spot fecundity or spawning schedules. Spot age and size at sexual maturity is still in question and may be variable with stock. Age and size at sexual maturity also respond to changes in fishing pressure (Wooton 1990; Reznick et al. 1997), and this may occur in spot. Spot reach sexual maturity at one year of age according to Smith (1907) however, Townsend (1956) reported the age of maturity to be older than 1 year.

Early Life History

Recruitment dates and size at recruitment in bays and estuaries vary along the South and Mid-Atlantic coast of the United States. Post-larval and juvenile spot recruit to the Chesapeake Bay between March and May (Welsh and Breeder 1923; Cowan and Birdsong 1985; Olney and Boehlert 1988). The initial reported size of spot recruited to the Chesapeake Bay varies from 11 mm (Olney 1983) to 85 mm (Pacheco 1962). In contrast, spot recruit to North Carolina estuaries primarily between January and March (Lewis and Mann 1971; Lewis and Judy 1983).

Many studies of spot early life history have concentrated on growth (Beckman and Dean 1984; Warlen and Chester 1985; Siegfried and Weinstein 1989). Juvenile growth rates reported for the Chesapeake Bay (Hildebrand and Cable 1930; McCambridge Jr. and Alden 1984) are higher than those reported in South Carolina (Dawson 1958), Florida (Townsend 1956) or Texas (Parker 1971). Higher juvenile spot growth rates in the Chesapeake Bay may indicate that the Chesapeake Bay is a near optimal environment for the growth of zero-age spot (McCambridge Jr. and Alden 1984).

The Chesapeake Bay contains many nursery areas for juvenile spot, in the abundance of its tidal marsh creeks (Massmann 1954; Weinstein 1983), and eelgrass beds (Weinstein 1983; Weinstein and Brooks 1983). Although juvenile spot use the estuaries as nursery grounds, there are conflicting reports of whether they overwinter in the Chesapeake Bay. Hildebrand and Schroeder (1928) indicate that at least some zero-aged spot overwinter in deep water areas of the bay. Pacheco (1962) indicates that juvenile and zero-age class spot occur in the Chesapeake Bay only from Spring through late Fall. Whether spot migrate to shelf waters during winter may be linked to the development of mature gonads as well as water temperature.

Food Habits

Spot food habits change from planktonic to benthic feeding with increasing fish size. Spot <30 mm standard length are selective planktivores (Oneill and Weinstein 1987), whose main food source is copepods. Spot >30 mm standard length switch to more opportunistic feeding on epifaunal and infaunal food sources. Juvenile spot diets include polychaetes, amphipods, clam siphons, copepods and organic detritus (Chao and Musick 1977), whereas adult spot diets also include fish (Mercer 1989).

Ages

Maximum age of Chesapeake Bay spot is greater than that found in the South Atlantic and Gulf of Mexico. The maximum age reported for spot from the Chesapeake Bay is four years (Pacheco 1962) and five years (2 fish) from North Carolina (DeVries 1982). In comparison, three years is the oldest reported age from the Gulf of Mexico (Hata 1985). Although spot as old as four or five years are periodically reported, the typical maximum age reported in most studies is three years old. Joseph (1972) reports that spot three years old or older comprised only 0.2% of the 1961-1964 Virginia spot catch. It may be inappropriate, however to compare ages because those studies used different structures to estimate age; including scales (Welsh and Breeder 1923; Pacheco 1962; Devries 1982), length frequency distributions (Townsend 1956; Hata 1985) and otoliths (Sundararaj 1960). Few studies have attempted to validate spot ageing methods (Hata 1985).

Sizes

The age classes of Chesapeake Bay spot are difficult to separate on the basis of length because they have rapid early growth and overlapping sizes after the first year. Pacheco (1962) estimates spot are 170 mm fork length after their first year and 220 mm fork length at the end of the second year.

Maximum length reported for spot in the Chesapeake Bay and northern waters of North Carolina is greater than along the South Atlantic coast or in the Gulf of Mexico. Hildebrand and Schroeder (1928) reported 345 mm in the Chesapeake Bay and Devries (1982) reported 346 mm in North Carolina. The largest spot reported outside of this area is 330 mm from New Jersey. Length-weight regressions were developed for spot populations in South Carolina (Dawson 1958), Georgia (Musick and Pafford 1984) and the Gulf of Mexico (Hata 1985).

Mortality Rates

Little information on spot mortality rates exists in the literature. One exception is Pacheco (1962) who estimated total mortality of Virginia spot after the first year was approximately 80% based on age composition analysis.

Sex Differences

What sparse literature that exists on adult spot, indicates that male and female spot do not differ enough to require separate management strategies. It has generally been assumed for management purposes that spot sex ratios are 1:1 (Mercer 1989). Hata (1985) found no significant difference between male and female length to weight regressions. There are no reports of differing mortality rates or maximum ages between sexes.

Commercial Catch

Spot are an important commercial finfish species in the Chesapeake Bay and Mid-Atlantic region of the United States. The Mid-Atlantic commercial fishery for spot is located along the Virginia North Carolina and South Carolina coasts (Mercer 1989). Before 1960, reported commercial spot catches usually exceeded recreational catches

(Richards 1960), but recently commercial and recreational catches have been more variable so that there is no clear trend. Reports of large historical commercial catch fluctuations is typical of a short lived fish species (Joseph 1972), and historical spot catches have exceeded 8,000,000 lbs and dipped as low as 400,000 lbs (Pacheco 1962). Preliminary estimates of Virginia's commercial spot catch exceeded 4,300,000 lbs and 3,600,000 lbs in 1994 and 1995 respectively with dockside values of $1,600,000 and $1,800,000 (VMRC, Plans and Statistics 1996), making spot one of the five most valuable commercial finfish fisheries in the Chesapeake Bay.

Virginia's commercially caught spot are primarily captured in pound nets, haul seines and gillnets. Bottom trawls are also used in North Carolina to capture spot. Large-meshed gillnets generally catch larger spot than do haul seines or pound nets. Pound nets capture the greatest poundage of food grade and scrap spot in Virginia. Spot are part of a multi-species assemblage caught in those gears. Commercially important fish species caught along with spot include croaker (*Micropognias undulatus*), weakfish (*Cynoscion regalis*), and striped bass (*Morone saxatilis*).

A Virginia scrap fishery exists which consists of spot considered too small to be marketed as food. Scrap spot are caught primarily in Virginia poundnets and North Carolina winter trawls (Mercer 1989). Undersized spot are either sold to reduction plants or as crab bait (McHugh 1960) or thrown away as trash. Pacheco (1962) found that spot <170 mm were not considered food quality and were sold as scrap. He estimates that of the 1956 year class which entered the Chesapeake Bay fishery, 30% by numbers were caught as scrap and therefore not reported. Because of the large size of the 1957 year-class, the 30% estimate of bycatch may be an upper limit value.

Objectives

Accurate and current information on age structure, mortality rates and fecundity schedules is necessary for adequate management of the spot stock found in the Chesapeake Bay. Information for short-lived species such as spot can only be derived from large and recent data collections. Given the variety of ageing techniques that have been used; an updated assessment of ageing techniques is needed. Accurate and reliable ageing is crucial to the estimation of growth and mortality. Past studies of spot stock dynamics have aged fish using scales (Young 1953; Pacheco 1957), which have been shown to underage older sciaenid fish (Barbieri 1993). Underestimates of age result in overestimates of growth and underestimates of mortality, and can lead to overfishing if these biased parameters are used to manage exploited stocks (Lai and Gunderson 1987). Determination of an accurate and precise ageing method and validation of that method is essential first step towards managing spot in the Chesapeake Bay. Ageing information will then be used to estimate growth and mortality parameters of Chesapeake Bay spot. Parameters to be estimated include growth rate, asymptotic length and weight, as well as instantaneous (total, natural and fishing) mortality rates.

Using growth and mortality parameters, yield-per-recruit modeling will be done to simulate possible fishing scenarios, and to estimate instantaneous fishing mortality (F) corresponding to maximum sustainable yield (MSY) and the potential for growth overfishing under those scenarios. Since MSY estimates the yield under stable environmental and biological conditions, a more conservative fishing strategy needs to be developed to protect stocks from overharvest during low production years. Using the precautionary approach (Garcia 1994) to fisheries management, fishing mortality at MAX

(F_{LRP}) will be used as the Limit Reference Point (LRP); a fishing mortality that should not be exceeded. A series of more conservative fishing mortalities (F_{TRP}), corresponding to yields considered Target Reference Points (TRP) will be determined based on variation in fishing mortality (F) and levels of an acceptable probability of fishing mortality exceeding the LRP (Caddy and McGarvey 1996).

The potential of recruitment overfishing will be assessed by estimating size and age at maturity as well as Spawner Potential Ratios (SPR) developed to describe the potential spawning stock biomass that is actually spawning given the most likely fishing scenario. Optimal levels of F will be developed based on a comparison of the Y/R and SPR models.

CHAPTER II

DETERMINATION AND VALIDATION OF THE MOST PRECISE AND LEAST BIASED HARDPART FOR AGEING SPOT FROM THE CHESAPEAKE BAY

Introduction

Spot (*Leiostomus xanthurus*) are a seasonal but important component of the Chesapeake Bay commercial fishery (Joseph 1972; McHugh and Conover 1986). At the present, there has been no substantial stock assessment work on this fishery in the Mid-Atlantic Region (Mercer 1989); which leads to uncertainty about the health of this important fish species in the Chesapeake Bay. Modern stock assessments are based upon age-based models (Megrey 1989), such as growth, yield-per-recruit and virtual population modeling. Ageing errors can directly influence the validity of the results based on those models, with systematic underageing errors more serious, since they increase the likelihood of overfishing when regulations are based on those results (Lai and Gunderson 1987). To prevent these errors accurate and precise ageing techniques need to be developed before beginning stock assessments. Although some work on spot has been done in the Gulf of Mexico (Barger and Johnson 1980), at the present, there has been no quantitative study to determine the most appropriate structure for ageing spot in the Chesapeake Bay.

The evaluation of an age determination procedure should include measures of both bias and precision (Campana et al. 1995), as well as a measure of accuracy (Beamish and McFarlane 1983). The costs, in time or money, may be a factor as well, when large samples sizes need to be aged inexpensively (Worthington et al. 1995). In this paper, bias refers to systematic ageing differences between readers or ageing techniques. Precision refers to the reproducibility of the age assignment. Accuracy reflects the ability of the ageing procedure to predict true fish age. Whenever possible, accuracy should be tested not only within, but across cohorts and over consecutive years to insure that periodicity of annulus formation does not change.

The objectives of the study were to compare four hard parts commonly used in ageing fish (dorsal spine, pectoral finrays, sagittal otoliths and scales), to determine which is the most appropriate structure for ageing spot from the Chesapeake Bay. Measures of bias and precision, both between and within readers were calculated. Age validation of the hard part selected as the most appropriate for ageing spot was also done. The validation determined the periodicity of annulus formation, within and across cohorts as well as across consecutive years of an individual cohort. A comparison of ages assigned by the most appropriate hard part and ages assigned using scales was performed to determine if there was significant systematic ageing differences between the two hard parts. A comparison with scales will be useful because, historically, scales have been used to age spot from the Mid-Atlantic region (Welsh and Breeder 1923; Pacheco 1957 and Music and Pafford 1984).

Materials and Methods

Fish Collection

We collected spot weekly from July of 1993 until November of 1995, during the months that spot were present in the Chesapeake Bay (typically April-November). Collections of spot were made by purchasing a box of each available size grade from Chesapeake Bay commercial fishermen and fish distributors. Spot were collected from all major commercial gears (poundnets, haul seines, and gillnets) used to catch spot in the Chesapeake Bay. During the winter months, when spot were not present in the Chesapeake Bay, I purchased spot from North Carolina commercial fishermen whenever possible.

We randomly selected fish from each box and both sagittal otoliths were taken along with dorsal spines, pectoral finrays and scales. Dorsal spines and pectoral finrays were removed by excising the structure off below the insertion into the body. Scales were removed from the area behind the extended pectoral fin and just below the lateral line. I stored otoliths and scales dry. Dorsal spines and finrays were frozen until processed.

Transverse sections of otoliths, dorsal spines and finrays were made. Approximately 150-200 um sections were cut from a random choice of the left or right otolith as well as from the largest dorsal spine and pectoral finray. The structures were initially mounted on a microscope slide using thermoplastic and cut with a Buehler low-speed saw. Icut two sections from each structure before permanently mounting them to a clean microscope slide using crystal bond adhesive. Otolith sections taken from the nucleus towards the posterior end of the otolith. Sections from dorsal spines and finrays were cut starting from the base of each structure. At least two unregenerated and readable scales were also selected, cleaned and mounted between clean microscope slides.

Otolith sections were read for annuli using a dissecting microscope and transmitted light at 12-24 x magnification. Dorsal spine and finray sections were read using a compound microscope and transmitted light at 100x magnification. Scales were read using a microfiche reader containing 15 and 20 mm lenses. Presumed otolith, dorsal spine and finray annuli were located by the presence of opaque bands, and by the consistency of those bands between sections. Presumed annual marks in scales were identified following the ageing criteria described by Bagenal and Tesch (1978) and Ross (1988).

Hardpart Comparison

We randomly chose 45 fish to determine which hardpart is the most precise structure for ageing spot. The commercial spot catch from the Chesapeake Bay has historically been composed almost entirely of age-1 fish (Joseph 1972). A simple random sample of 45 fish from all the fish I collected would have produced mostly one year old fish and probably not have included any individuals from the oldest age-classes, since they make up a relatively small percentage of the total catch. To assess the validity of the criteria used to age spot, the hard part comparison should include individuals from all the age-classes present in the commercial catch. I included all age classes represented in our samples by stratifying the sampling based on preliminary ageing. Four fish from each age-class were randomly chosen from the pool of available fish in each age-class. Initial age classes were determined from age assignment based on otoliths which was done at least one year before the hard part comparison. In addition, I randomly selected 29 other fish from the remaining sample by simple random sampling to insure that the number of fish used in the hard part comparison from each-age class would not be known.

We calculated measures of both precision, (Beamish and Fournier 1981) and bias (Hoenig et al. 1994) to determine the most appropriate hardpart for ageing spot. Two readers independently and blindly read each of the randomized hardparts and assigned an age based on the number of annual marks identified. Each reading, by the same reader on the same hard part, was done at least two weeks apart to insure that the first reading did not influence the second. Percent agreement and coefficient of variation (CV) (Chang 1983) both within and among readers, were calculated to determine the precision of age assignment. A Chi-square test of symmetry (Hoenig et al. 1994) was used to determine if there was evidence of systematic ageing bias between or within readers for each hard part tested. A Chi-square test of symmetry was also used to compare the ages assigned using otoliths and scales; the two most commonly used hardparts for ageing spot.

Validation

The most precise and leased biased hard-part was validated using the marginal increment method (Casselman 1987; Hyndes et al. 1992). All fish that were collected from the 1991-1993 cohorts were used in the analysis. For each age-class, the translucent margin from the last annulus to the edge of the structure was measured using an image analysis system and Optimus software. Measurements of margin length were taken along the dorsal side of the sulcal groove. Margin lengths were averaged within the months of collection and age-class.

Results

General

Three thousand two hundred fish were collected from commercial fishermen of the Chesapeake Bay and North Carolina from 1993-1995. No fish were collected during the winter of 1994-1995. Of the 45 fish I selected to use in the hardpart comparison, the ages determined, using all four structures, never exceeded 3 years (Table 1). The 45 fish

Table 1

The number of spot, *Leiostomus xanthurs*, assigned to each age-class by 2 readers using 4 different hardparts.

		Reader 1				Reader 2			
		Age				Age			
		0+	1+	2+	3+	0+	1+	2+	3+
Otoliths	reading 1	4	33	4	4	4	36	1	4
	reading 2	4	33	4	4	5	35	2	3
Dorsal	reading 1	5	32	6	2	7	25	11	2
Spines	reading 2	4	34	5	2	4	33	5	3
Pectoral	reading 1	5	32	7	1	6	23	13	3
Finrays	reading 2	7	31	5	2	4	32	8	1
Scales	reading 1	6	30	7	2	7	23	13	2
	reading 2	4	32	7	2	3	32	8	2

ranged in age from 0-3 years, with all 4 age-classes found by both readers in all 4 structures.

All 4 hardparts had concentric structures that were presumed to be annuli (Figure 1). Presumptive otolith annuli were very clear and identifiable by the presence of opaque, amber colored bands (Figure 1a). Typical otolith structure was an opaque area surrounding the nucleus with alternating translucent and opaque areas extending to the margin. Presumed annuli, in both dorsal spines (Figure 1b) and pectoral finrays (Figure 1c) were also identified by opaque regions surrounded by translucent regions, however, sections of both structures were often fuzzy and difficult to interpret. Scale annuli (Figure 1d) were most often determined by the presence of cutting over in the lateral fields and by clear zones in the anterior field where circuli were widely spaced or broken.

Precision

The assignment of age was more precise for transverse sections of otoliths than for the other three structures. Age assignment to the same fish, by both readers, was never off by more than 1 year when using otoliths. There was one or more instances of age disagreement, of a magnitude of at least 2 years, for the same fish when ageing was done using dorsal spine and finray sections or scales. The percentage agreement, within reader, using otoliths was 100 and 96 % for reader 1 and 2 respectively, but was not higher than 73% for both readers using the other 3 structures (Table 2). Percentage agreement between the two readers was also highest for otoliths. The 93 and 89% agreement between readers for otolith sections was much higher than that found between readers for the other 3 structures (Table 2).

Analysis of CV also indicated that otoliths were the most precise hard part for

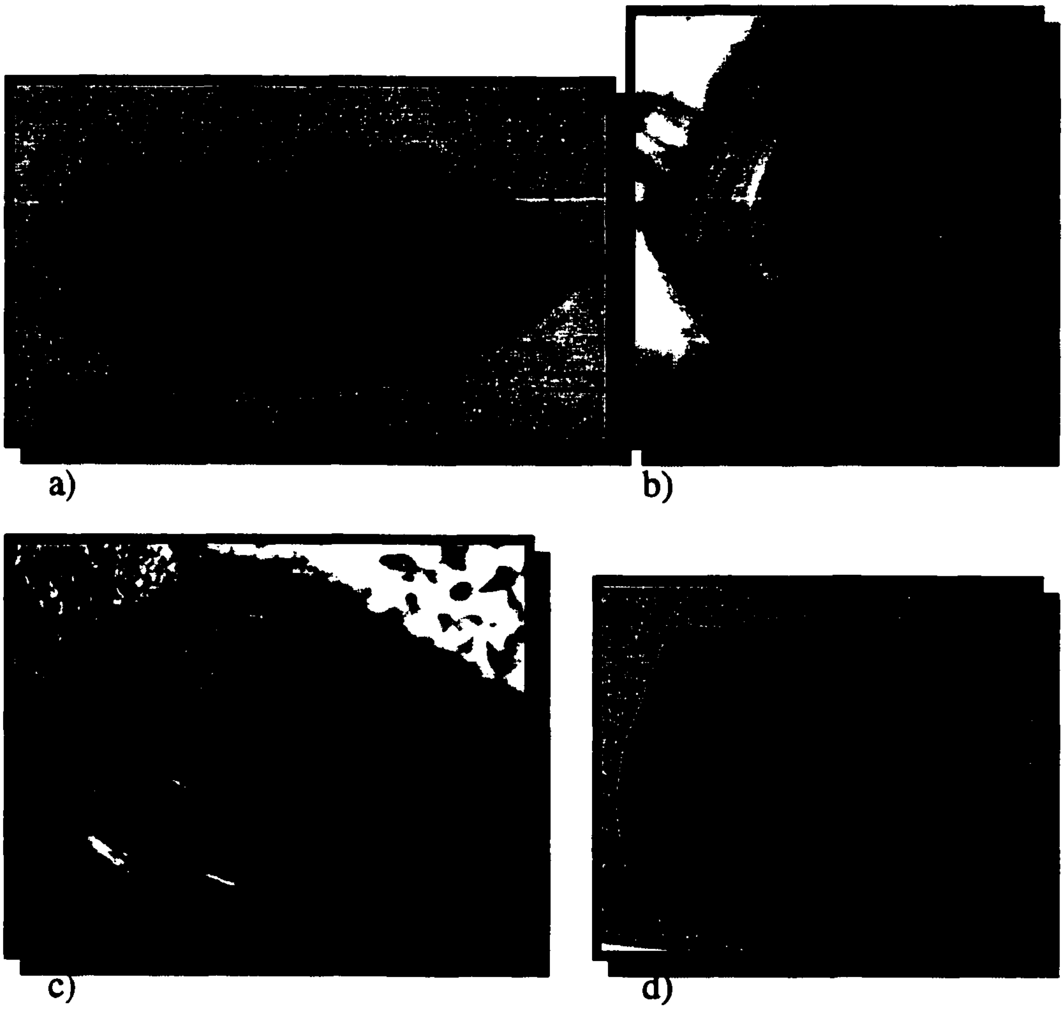


Figure 1
Transverse sections from an a) otolith, b) dorsal spine, c) pectoral finray and d) a scale. All structures were taken from a 3 year-old spot, *Leiostomus xanthurus*, taken from the Chesapeake Bay.

ageing spot. Otolith sections had the lowest CV, both within and between readers (Table 2). Within reader CV was less than 4% for otoliths but was greater than 20% for the other structures. Between reader CV for otoliths was less than 8%, but finrays and scales generally had CV's greater than 30% while dorsal spine sections had the highest between reader CV.

There was generally more precision within readers than between readers as measured by percent agreement and CV (Table 2). Age assignment using dorsal spine sections showed the greatest disparity of within and between readers ageing differences.

Bias

There was not significant ageing bias, either within or between readers, for otolith and dorsal spine sections, which indicated neither structure had systematic errors associated with the ages assigned using those structures. Chi-square tests of symmetry were not significant within reader 1 for all 4 hardparts ($p>.1$); which indicates that reader 1 had no systematic ageing errors between readings. Chi-square tests of symmetry, within reader 2, were significant for finray sections ($p<.025$) and scales ($p<.05$) , but within reader tests of symmetry for reader 2 were not significant using otoliths ($p>.1$) or dorsal spines ($p>.05$). There were no asymmetrical ageing differences between readers for any of the four hardparts ($p>.05$).

Validation

Plots of the mean marginal increment of otoliths over time yielded one low period of mean margin length every twelve months; indicating an otolith annulus was formed only

Table 2

Average percent agreement and CV (in parenthesis) within and between readers, in the comparison of mark counts on spot, *Leiostomus xanthurus*, hardparts.

		Otoliths	D. spines	P. finrays	Scales
Within Readers	reader 1	100 (0.0)	69 (39.4)	69 (31.4)	73 (35.9)
	reader 2	96 (3.4)	69 (36.5)	71 (25.5)	71 (31.1)
Between Readers	reading 1	93 (4.4)	53 (49.0)	62 (32.3)	67 (40.3)
	reading 2	89 (7.7)	60 (46.8)	73 (33.5)	73 (29.6)

once every year (Figure 2). The same pattern of annulus formation was seen across three different cohorts (1991, 1992 and 1993), and over three different age-classes (0-2). Forty-four fish used to validate the 1991 cohort were collected from September 1993 through September 1994 (Figure 2a), after which this cohort disappeared from our samples. The 1991 cohort was made up of 2+ year-old fish in 1993. Four-hundred and fifty-seven fish used to validate the 1992 cohort (Figure 2b) were collected from September 1993 through October 1994, and then disappeared from our collections. The 1992 cohort was made up of 1+ year-old fish in 1993. One-thousand four-hundred and twenty-five fish used to validate the 1993 cohort were collected from August 1993 through September of 1995 (Figure 2c). The 1993 cohort was made up of 0+ year-old fish becoming 2+ year-old fish over the 25 months of the study. The plot of mean margin length of the 1993 cohort also showed the same pattern of yearly annulus formation over two consecutive years. The time of peak annulus formation as determined from margin length plots was in May-July for all age-classes and cohorts.

Scale-Otolith Comparison

The overall agreement between ages assigned using otoliths and scales to the same fish was poor (Table 3). Age assignment, by both readers, using otoliths consistently produced more 3 year old fish than age assignment using scales (Table 1). In only one instance did ageing with scales produce a 3 year-old fish when ageing with otoliths using the same fish did not (Figure 3a). Ageing with otoliths, however, produced 3 year-old fish when scales did not in every reading (Figure 3).

There were also differences between readers in the kinds of ageing discrepancies between otoliths and scales. For those fish assigned different ages using the two

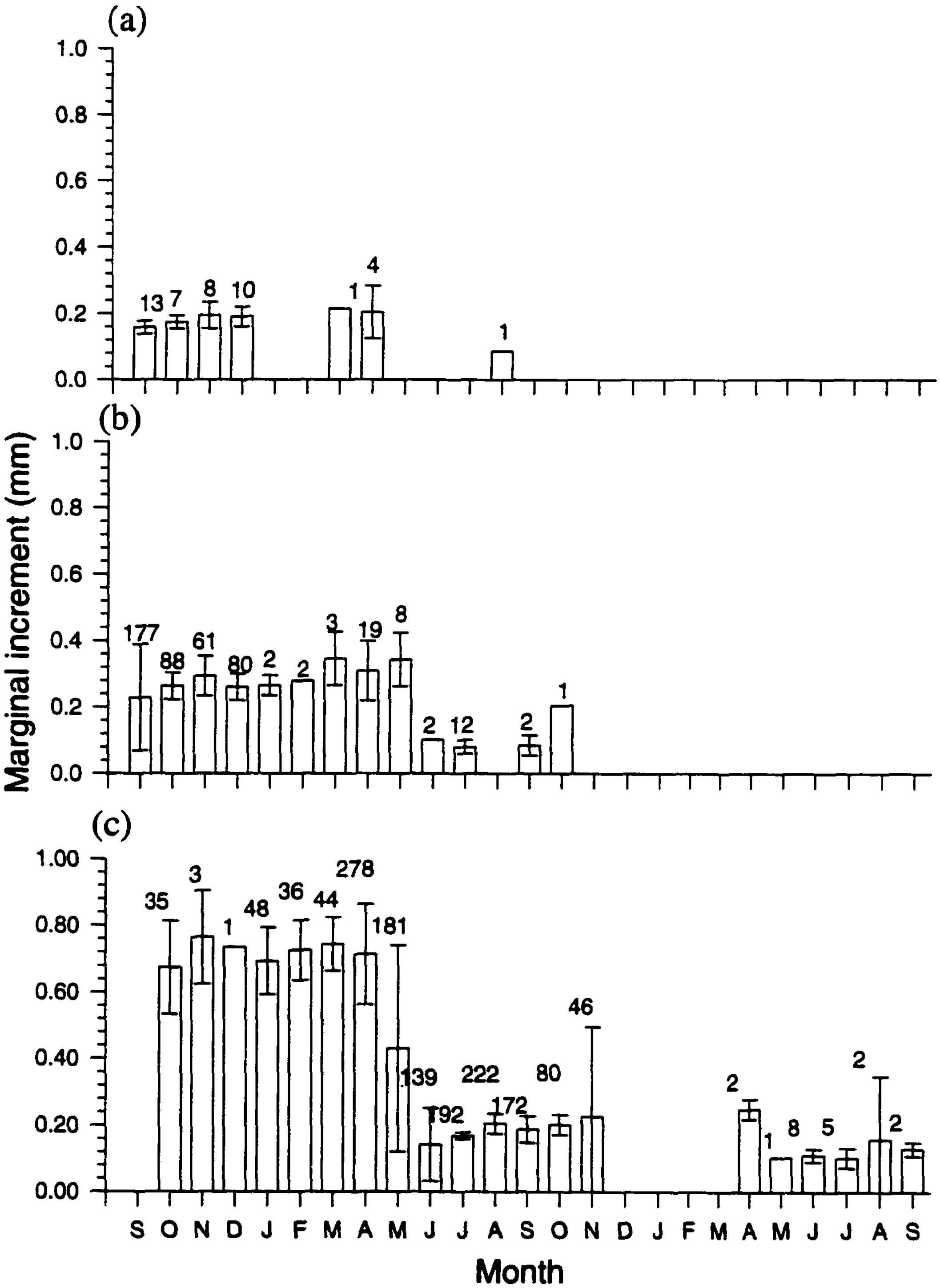


Figure 2

Mean monthly otolith marginal increment for spot, *Leiostomus xanthurus*, from cohorts born in: a) 1991, b) 1992, and c) 1993, collected from September 1993- September 1995. Vertical bars are ± one standard deviation. Numbers above the bar represent sample size.

Table 3

Percent agreement of spot, *Leiostomus xanthurus*, scale- and otolith-assigned ages within reader.

		% Agreement
Reader 1	Reading 1	60
	Reading 2	64
Reader 2	Reading 1	55
	Reading 2	71

structures, reader 1 assigned older ages using otoliths 56% and 50% of the time there were differences, for reading 1 (Figure 3a) and 2 (Figure 3b), respectively. There were no significant systematic ageing differences in age assignment between scales and otolith for reader 1 ($p>.1$). Reader 2 assigned older ages to the same fish using otoliths only 40% and 23 % of the time there were ageing differences, for reading 1 (Figure 3c) and 2 (Figure 3d), respectively. Reader 2 did have significant ($p<.025$) systematic ageing differences within reader in the first reading, but not in the second reading ($p>.05$).

Discussion

Sectioned otoliths are the most appropriate of the four hardparts for ageing spot from the Chesapeake Bay. The use of otoliths for ageing spot meet the criteria of consistency required in careful laboratory studies (Campana et al. 1995). Age assignment using otoliths was consistently the most reproducible (precise), both by the same reader and between the two readers, and ageing using otoliths was consistently without bias either over time or between readers. Although reproducibility of ages does not necessarily constitute accuracy, it does indicate that the criteria used to determine age was more easily identified within the otolith structure than within the other three hardparts. The ease of identifying consistent annuli and lack of bias when using otoliths indicates that ageing programs using multiple readers should show consistent and unbiased readings when using transversely sectioned spot otoliths.

Transversely sectioned otoliths were an accurate predictor of age as well. The same pattern of yearly annulus formation (May-July) was seen, within and across cohorts as well as over consecutive years. Accurate estimates of fish age is especially important

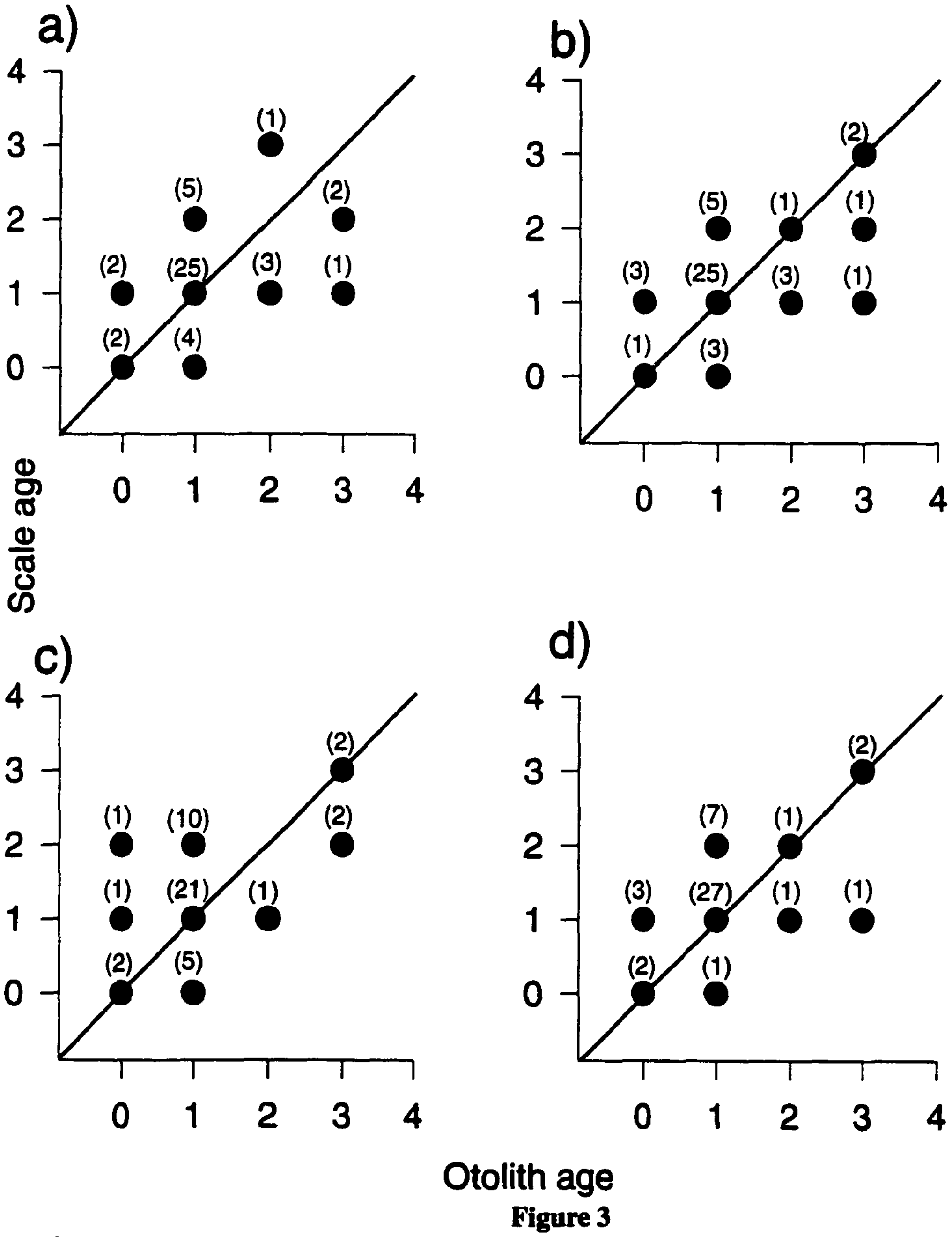


Figure 3

Counts of presumed scale annuli compared with otoliths taken from spot, *Leiostomus xanthurus*. Each figure represents the following: a) reading 1 by reader 1, b) reading 2 by reader 1, c) reading 1 by reader 2, and d) reading 2 by reader 2. The number of fish each point represents is indicated, and the 45° line represents 100% agreement.

when ages are used in age-based fisheries models, because ageing errors seriously affect the reliability of those results (Lai and Gunderson 1987). It is likely that the timing and periodicity of annulus formation does not change over the lifespan of a cohort, or vary significantly between cohorts. Ages determined from otoliths should be a good predictor of true age regardless of the age-class of the fish or the cohort to which it belonged. The timing of annulus formation for spot is similar to that observed in other Sciaenids from the Chesapeake Bay, such as croaker (*Micropogonias undulatus*) (Barbieri et al. 1994) and weakfish (*Cynoscion regalis*) (Lowerre-Barbieri 1994). The relatively long period of annulus formation along with long spawning period and fast growth may make determining the retrospective length at age through back calculation, an inexact process. I would like to have validated all age-classes present in the fishery as Beamish and McFarlane (1983) suggest, but 3 year old fish were so few in the commercial catch that validation using marginal increment analysis was not possible.

Comparisons of age assignment using otoliths versus scales indicates that ages determined from scales may consistently underage the oldest age-classes (3+). Although the limited number of 3 year-old fish used makes these conclusions tenuous, it is common for fish species to have an age above which there is consistent variability in age assignment when ageing with different structures or techniques (Kimura and Lyons 1990). Barber and McFarlane (1987) found that char (*Salvelinus alpinus*) at age 8 began showing systematic variability in ages assigned using whole otoliths compared to burnt otoliths, and Donald et al. (1992) found for goldeneye (*Hiodon alosoides*) that scales consistently underaged, starting at age 7 in comparison to otoliths. Spot around age 3 seem to begin showing this variability in assigned ages using scales in comparison to otoliths. This same pattern of underageing sciaenids with scales in comparison to otoliths, beginning at age 3, has been detected in croaker (Barbieri 1993), and at age 6 in weakfish (Lowerre-Barbieri et al. 1994) from the Chesapeake Bay. Review of past work on spot in the Mid-Atlantic shows that scales have been used extensively to estimate spot age (Welsh and Breeder 1923; Pacheco 1957 and Music and Pafford 1984). Although a reader's experience with scales may make systematic errors small or nonexistent, the pattern of errors shown in this work indicates that errors are likely to include the consistent underestimating of the ages of the oldest aged fish. Spot in the Mid-Atlantic Region have been aged to at least 4 years of age by Pacheco (1962) in the Chesapeake Bay and to 5 years of age by DeVries (1981) in North Carolina. Considering the ages spot have historically reached in the Chesapeake Bay region; past work using scales may have underestimated the contribution of the oldest age-classes to the fishery.

CHAPTER III

GROWTH AND MORTALITY ESTIMATES OF SPOT FROM THE CHESAPEAKE BAY REGION

Introduction

Spot (*Leiostomus xanthurus*) are a wide-ranging species distributed from the Gulf of Mexico along the Atlantic Coast to Massachusetts (Smith and Goffin 1937; Dawson 1958). Spot are a seasonal component of the Chesapeake Bay fauna, resident in Virginia waters during Spring through late Fall (Hildebrand and Schroeder 1928). Fall migrations out of the Chesapeake Bay, which may be linked to spawning, are southward into 17°C waters off the continental shelf of North Carolina (Pacheco 1962b; Norcross and Bodolus 1991), where fish potentially overwinter. Spawning takes place in these waters from November through February (Lewis and Judy 1983; Flores-Coto and Warlen 1993) with peak spawning activity occurring throughout December and January in the Middle-Atlantic Region (Warlen and Chester 1985). Young-of-the-year spot then recruit to the Chesapeake Bay during March through May (Cowan and Birdsong 1985; Olney and Boehlert 1988), where they reside until the late fall migrations out of the Chesapeake Bay.

Commercial exploitation of spot is centered in the Mid-Atlantic from Virginia to South Carolina (Mercer 1989). Spot are commercially fished in the Chesapeake Bay Region from late April into November or until spot have migrated and commercial catches decline. Three commercial gears are used to capture spot in Virginia, which include gillnets, pound nets and haul seines. All three gears are used in a multi-species fishery which also catches: striped bass (*Morone saxatilis*), weakfish (*Cynoscion regalis*), and croaker (*Micropogonias undulatus*), in addition to spot. Considerable research effort aimed at stock assessment and management has been done in the Mid-Atlantic Region on striped bass (ASMFC 1995; Field 1997), weakfish (Lowerre-Barbieri al. 1994; Lowerre-Barbieri et al. 1996), and croaker (Barbieri et al. 1994; Barbieri et al. 1997). However, little research has been done that is directly applicable to the management of spot (Mercer 1989), even though spot are one of the 5 most valuable finfish fisheries in Virginia coastal waters (personal comm. VMRC Plans and Statistics 1996).

Management of spot needs to be based on accurate estimates of parameters intrinsic to the population such as lifespan, growth, population size and sex ratio. Management decisions must also be based on accurate estimates of extrinsic factors such as fishing mortality and ages captured in the fishery, and the potential changes in the intrinsic factors that are due to the extrinsic factors. With the decline in stock sizes of historically targeted fisheries in the Chesapeake Bay (McHugh and Conover 1986), more commercial interest has turned to less popular species such as spot. Increasing commercial interest has placed additional stresses on stocks and made management of stocks based on sound scientific advice imperative. The characterizations of the age and size structures of commercial catches are an important first step in this process. Useful parameter estimations can only come from current collections to accurately describe potential changes in the stock due to recent changes in fishing practices that accompany changes in commercial practice.

The objectives of this study were to characterize the commercial catch of spot from the Chesapeake Bay, and to describe the age and size distribution of spot taken in each of the major commercial gears. The parameters useful in stock assessment modeling were estimated, including parameters intrinsic to the stock such as growth (K and L_∞ from the von Bertalanffy growth model) and natural mortality (M) along with extrinsic parameters resulting from fishing, such as mean age of capture (t_c), instantaneous total (Z) and fishing mortality (F). Comparisons of estimated parameters between both sexes were done to determine if sexes should be managed separately. A separate estimation of basic fishery parameters from spot caught in North Carolina waters was also done to determine if that fishery was substantially different from the one in Chesapeake Bay.

Materials and Methods

Fish Collection

Spot were collected from July 1993 until November 1995 in the Chesapeake Bay, by purchasing a box of each available size grade directly from commercial fishermen or through fish dealers. I collected spot during the months they were taken commercially (typically April-November). All three major commercial gears used in the spot fishery were sampled (pound nets, haul seines, and gillnets). Although boxes could not be randomly purchased, Chittenden (1989) found that there were few differences in the length distributions among boxes of Atlantic croaker (*Micropogonias undulatus*), a fish species caught and processed identically to spot. Based on that study, I assumed that each box of spot would contain fish representative of the fish lengths made available by fish dealers across all boxes of each size grade. Fish were randomly chosen from within the box for data collection.

Spot were also collected during the winter months (December-March) of 1993-1994 from North Carolina commercial fishermen who use trawls or sinknets, because spot migrate from the Chesapeake Bay in the fall and overwinter and spawn in offshore waters off the North Carolina coast. Fish collected were used to estimate basic fishery parameters for the purposes of comparing the parameters with those from the Chesapeake Bay. The North Carolina samples were not combined with Virginia samples to estimate growth or mortality parameters.

Fish collected were measured for total length (TL±1.0 mm) and total weight (TW±0.1 g), sex was determined by direct gonadal observation, and both sagittal otoliths removed for aging. Transverse sections, of a random choice of the left or right otolith, were used to determine age, since that structure was found to be the least biased and most precise and accurate structure for aging spot (Chapter II).

Ageing

Annulus counts were based on a January 1st birthdate, which corresponds to the midpoint of the spawning period of spot along the Mid-Atlantic coast (Lewis and Judy 1983; Warlen and Chester 1985; Flores-Coto and Warlen 1993). Fish were assigned to the next oldest age-class on January 1st despite annulus formation not occurring until May-July (Chapter II). Each sectioned otolith was read twice by 2 independent readers, and age disagreements were resolved by a cooperative third reading. Because spot are a short-lived species, and fractions of a year are relatively more important for spot than for a longer-lived species, ages used to determine total instantaneous mortality (Z) and mean age of the catch (t_c) were calculated using 2 methods. Ages used for estimating growth and mortality parameters were calculated as the number of annuli + the fraction of the year past the January 1st birthdate until the month the fish was caught. An example would be, a fish aged 2 years with otoliths that was caught in June would be 2.5 years old. Ages used to estimate other parameters were calculated as annulus counts alone. I generally used annulus counts alone when the comparisons were made about age-classes and I used annulus counts + the fraction of the year when intrested in specific age information.

Growth Modeling

A $\log_{10}$ linear relationship of length and weight was determined for all spot collected from the Chesapeake Bay. Fish used in the regression ranged in size from 157-284 mm TL and 44.9-382.4 g TW. Linear relationships were found for both sexes separately and an ANCOVA was used to test for differences between sexes. F-tests from the ANCOVA were derived from Type III Sums of Squares (Freund and Littell 1986). Next, a pooled-sexes regression of $\log_{10}$ length-weight relationship was determined. A t-test was used to determine if growth was isometric (b=3). A 95% confidence interval around b was developed from re-sampling 1000 random pairs of $\log_{10}$ TL and $\log_{10}$ TW observations, and recalculating the regression for each run. The 5th and 95th percentile values of the slope formed the endpoints of the confidence interval. The assumptions of normality were evaluated using SAS PROC UNIVARIATE, and the fits of the linear relationships were checked with residual plots.

Growth (length at age) was modeled with the von Bertalanffy growth model (von Bertalanffy 1938; Ricker 1975) using SAS nonlinear regression (PROC NLIN) and Marquardt's algorithm. The von Bertalanffy growth model was fit using all fish collected from the Chesapeake Bay. Ages used in the von Bertalanffy were calculated as the number of annuli + the fraction of the year past January 1st. The parameters estimated from the von Bertalanffy model included: L_∞ = the asymptotic length, K= Brody growth coefficient and t_0= hypothetical age when length= 0. Separate von Bertalanffy models were fit to males and females. An approximate randomization test (Manly 1991) was used to test for differences in growth curves between sexes following the procedures described by Helser (1996), before combining the sex data and fitting a combined-sexes growth curve. One-hundred independent runs were used to determine the significance of the observed differences between male and female growth curves.

Mortality Estimation

Total instantaneous mortality (Z) and instantaneous natural mortality (M) were estimated using maximum age techniques of Royce (1972) and Hoenig (1983). The maximum age of spot routinely reached in an unfished population which can be used to calculate M, was estimated from historical records and trophy spot caught and saved by a Chesapeake Bay fisherman. The maximum ages I used to calculate were based on whole annulus as well as fractional annulus counts. I also estimated Z using a time-specific catch curve (Chapman and Robson 1960) derived from all three years of data collected. Instantaneous fishing mortality (F) was estimated from the relationship of F=Z-M (Ricker 1975), I estimated F separately for each Z calculated from each separate mortality estimation method and aging technique. Annualized mortality rates were calculated based on the relationship $A=1-e^{-Z}$.

Results

Size and Age Compositions

By Gear

Plots of length-frequency distributions (TL) from haul seines and poundnets were similar, but gillnets captured a slightly different size range of spot (Figure 4 a,b, and c).

Gillnets captured the largest mean and median sized fish (mean= 234.7 mm, 50^{th} percentile= 234 mm, SE = 0.4, n= 993). Haul seines captured the smallest mean and median sized fish (mean=212.6 mm, 50^{th} percentile= 213 mm, SE=0.7, n=717). Pound nets captured the widest range of lengths (mean= 215.1 mm, 50^{th} percentile= 215 mm, SE= 0.7, n= 1014). The mean size of fish captured from the Chesapeake Bay from all three gears was 221mm (SE= 0.4, n= 2704) and the median size was 225mm. The largest fish was 284mm, however 95% of all spot collected were <266mm. The smallest fish was 157mm. Age composition of the commercial catch from the Chesapeake Bay was similar among gears and was dominated by a single age-class (Figure 5 a, b, and c). The mean age of spot I collected from the Chesapeake Bay was 1.0 yr (SE= 0.01, n= 2694) and the 50^{th} and 99^{th} percentiles of the cumulative age distribution were 1 and 2 yr, respectively, when aged with whole annuli. The mean age of spot was 1.6 yr (SE= 0.1, n= 2694) when aged fractionally, and the 50^{th} and 99^{th} percentiles of that cumulative age distribution were 1.7 and 2.75 yr, respectively.

Spot had fully recruited to all three gears after just one year (Figure 5 a, b, and c). Fish 1^+ years of age comprised 89.9, 88.3 and 92.3 % of the total fish sampled from gillnets, haul seines and pound nets, respectively. Fish 3^+ years of age made up less than 0.5% of the total number of fish taken. Spot less than 1 year of age comprised just over 5% of the total catch of haul seines and poundnets but less than 1% of total catch from gillnets.

By Month

The mean and median age of spot, calculated as whole annuli, was relatively constant (Figure 6 a) from April (mean= 1.1 yr, 50^{th} percentile= 1 yr, SE= 0.03, n= 181) through September (mean= 1.0 yr, 50^{th} percentile= 1 yr, SE 0.01, n= 571). Thereafter,

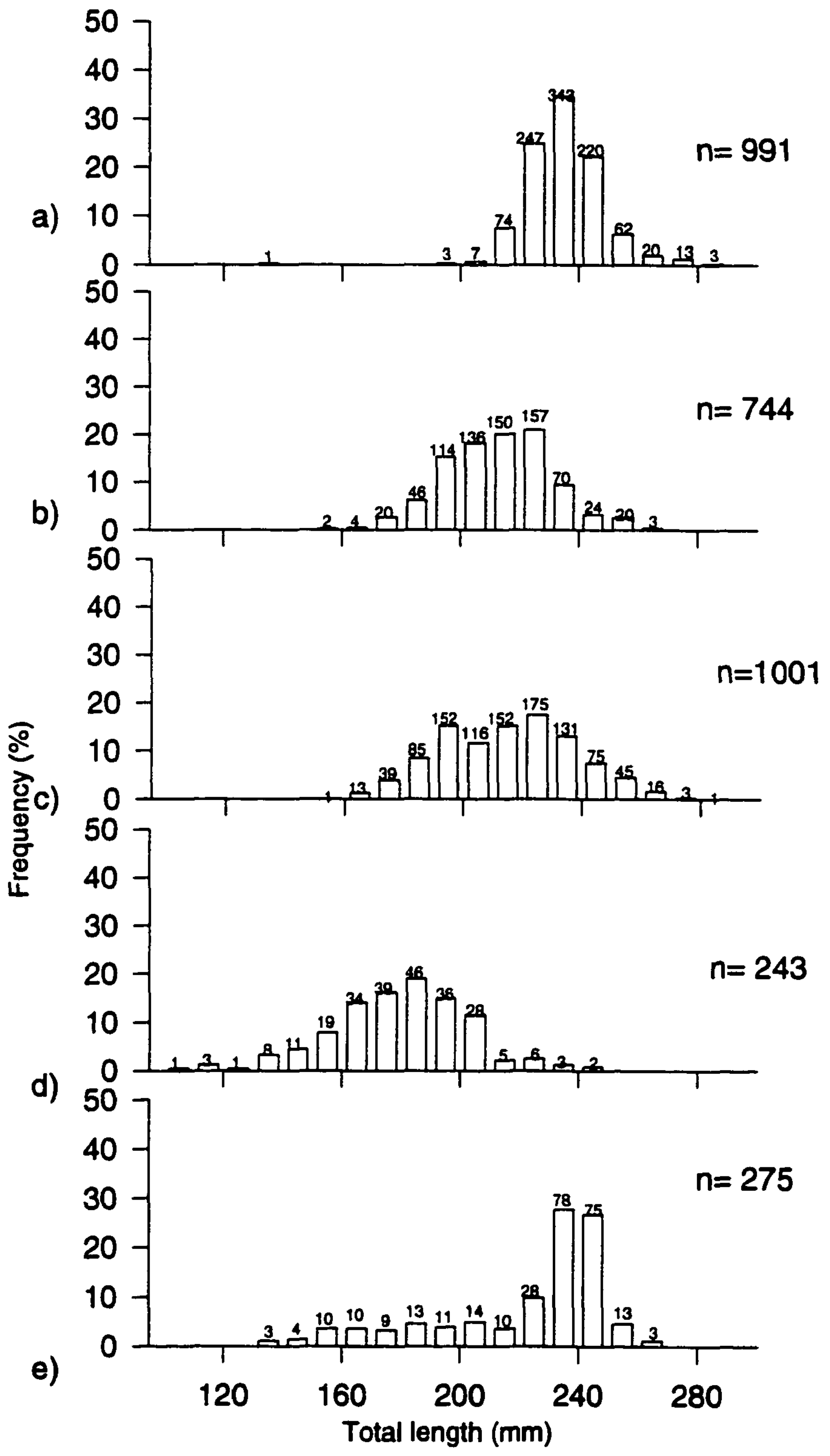


Figure 4

Plots of the length frequency distributions of spot, *Leiostomus xanthurus*, collected in the Chesapeake Bay during 1993-1995 from a) gillnets, b) haul seines, c) pound nets and of spot collected in North Carolina during 1994-1995 from d) trawls and e) sinknets.

the mean age, declined to a minimum in November (mean= 0.6 yr, 50^{th} percentile= 1yr, SE= 0.06, n= 75). Median age remained the same throughout the year, even though mean age dropped, because of the overwhelming number of 1 yr old fish. The drop in mean age in the Fall was the result of recruitment of 0^+ aged (8-10 month old) fish to the gears or the result of 0^+ aged fish attaining sufficient size to be considered marketable and therefore sold, instead of being discarded.

The mean size of spot caught in the Chesapeake Bay generally increased throughout the season (Figure 6 b). Mean size of commercially caught spot was maximum in September (mean= 238.0, SE= 0.6, n= 573) and minimum in May (mean=194.2, SE= 0.8, n= 308).

By Sex

The mean age of spot, from both sexes, caught in all three gears used in the Chesapeake Bay was similar, but the mean female size (TL) and the percentage of females in the total catch were larger than males. Males ranged in age from 0^+ to 3^+ yr (mean=1.01, 50^{th} percentile= 1 yr, SE=0.01, n= 893). Females also ranged in age from 0^+ to 3^+ yr (mean= 1.02, 50^{th} percentile= 1 yr, SE= 0.01, n= 1775). Ages reported here were determined from whole annulus counts. Mean ages between sexes were not significantly different ($P>0.44$). Males ranged in TL from 159 to 263 mm (mean= 216.2, 50^{th} percentile= 218 mm, SE= 0.69,n= 896). Females ranged in TL from 157 to 284 mm (mean= 224.4, 50^{th} percentile= 227 mm, SE= 0.49, n= 1782). Mean size between sexes differed significantly ($P<.0001$). Females were 66.5% of the total number of fish sampled from all gears, and males were 33.5%.

Growth Modeling

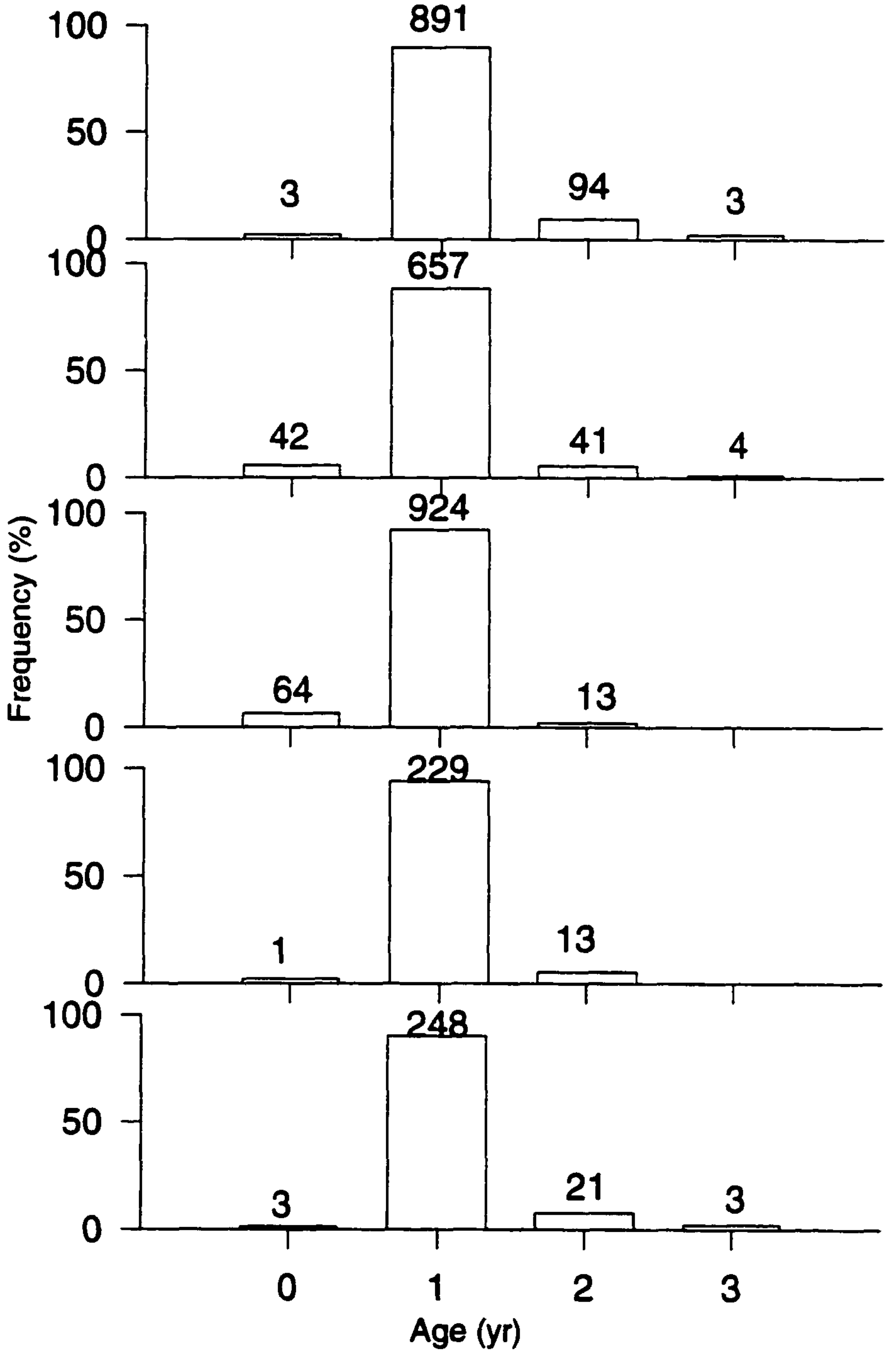


Figure 5
Plots of age frequency distributions of spot, *Leiostomus xanthurus*, collected in the Chesapeake Bay during 1993-1995 from a) gillnets, b) haul seines, c) pound nets and in North Carolina during 1994-1995 from d) trawls and e) sinknets.

A $\log_{10}$ TL- $\log_{10}$ TW relationship was described for male and female spot (Figure 7 a and b). I only used spot collected from the Chesapeake Bay to determine the relationship. No significant difference in the $\log_{10}$ length- $\log_{10}$ weight relationship was found between sexes (ANCOVA P>0.37), so the sexes were pooled. The relationship for the pooled regression is given in Figure 4 (c). The slope of the regression line (b=3.47, SE=.017) was significantly different from 3.0 (p<.001) indicating that growth was allometric. The 95% confidence interval around the slope was 3.42< b <3.52.

The von Bertalanffy growth model was fit to male and female spot (Figure 8 a,b). Observed lengths at age were used because it eliminated the need for the correction of growth past the time of annulus formation. Ages used in the model were based on fractional annulus counts. No significant difference was found between sexes (P=0.14) based on the randomization test, so the sexes were pooled and a combined von Bertalanffy growth curve was fitted. The fit of the pooled von Bertalanffy growth model was good (r^2=0.99) and the relationship is given in Figure 8 (c) and the estimated parameters and their S.E. are given in Table (4).

Spot growth in length is very rapid and the size at age is highly variable (Fig. 8 c). An average of 72% of the cumulative growth of spot occurred within its 1st year, and 86% of the cumulative growth occurred by the end of its second year. Mean observed total lengths of spot are 197, 232, 250 mm for ages 1-3, respectively.

Mortality Estimation

Natural Mortality (M)

Instantaneous natural mortality (M) calculated using Royce's maximum age method (1972) was 0.92, and 0.86 using Hoenig's maximum age method

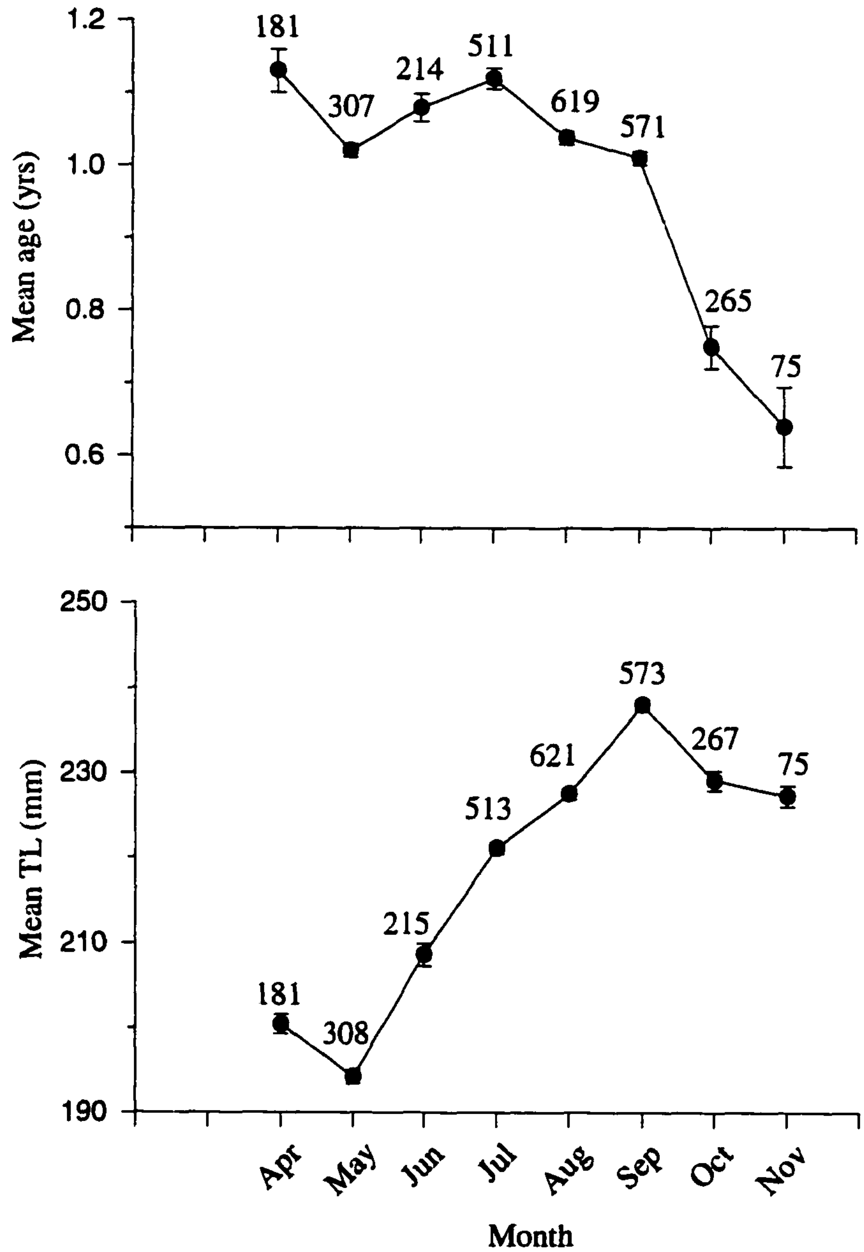


Figure 6
Plots of the a) mean age ± S.E. and of the b) mean TL ± S.E. of spot, *Leiostomus xanthurus*, collected in the Chesapeake Bay from 1993-1995. Numbers above each point represent sample size. All ages were based on whole annulus counts.

(1983). Because M=Z in an unfished population, M=0.92 corresponds to an annualized mortality (A) =0.60, and M=0.86 corresponds to A=0.58. These estimates were based on a maximum age of 5 years, which was reported by DeVries (1982) in North Carolina and from an individual fish I aged as 5 years that was collected the Chesapeake Bay. Since these fish constitute the oldest ages reported, I considered them as the most conservative estimate of the maximum age reached in an unfished stock. The 5 year-old fish I aged was reported to us as having been caught in the lower Chesapeake Bay in 1980 or 1981 and frozen as a trophy specimen until given to me.

Total Mortality (Z)

The estimates of instantaneous total mortality (Z) using maximum age techniques were always higher when Z was calculated with whole annulus counts compared to fractional annulus counts. Instantaneous total mortality (Z), calculated with maximum age methods were estimated using the 99th percentile of the cumulative age distribution. I calculated Z = 1.67 (A= 0.81) and 2.3 (A= 0.90) using Royce's method (1972) and fractional annulus counts and whole annulus counts, respectively. I calculated Z = 1.56 (A= 0.79) and 2.14 (A= 0.88) using Hoenig's method and fractional annulus counts and whole annulus counts, respectively. I also estimated Z=2.75 (A= 0.94) using a catch curve (Figure 9). Only fish that were collected from the gears operating in the Chesapeake Bay commercial fishery were used to estimate Z.

Fishing Mortality (F)

The estimate of F, calculated from the relationship Z=M+F, was largest when Z was calculated using a catch curve and smallest when Z was calculated using maximum age estimates based on fractional annulus counts. Estimates of F were 0.70 and 0.75

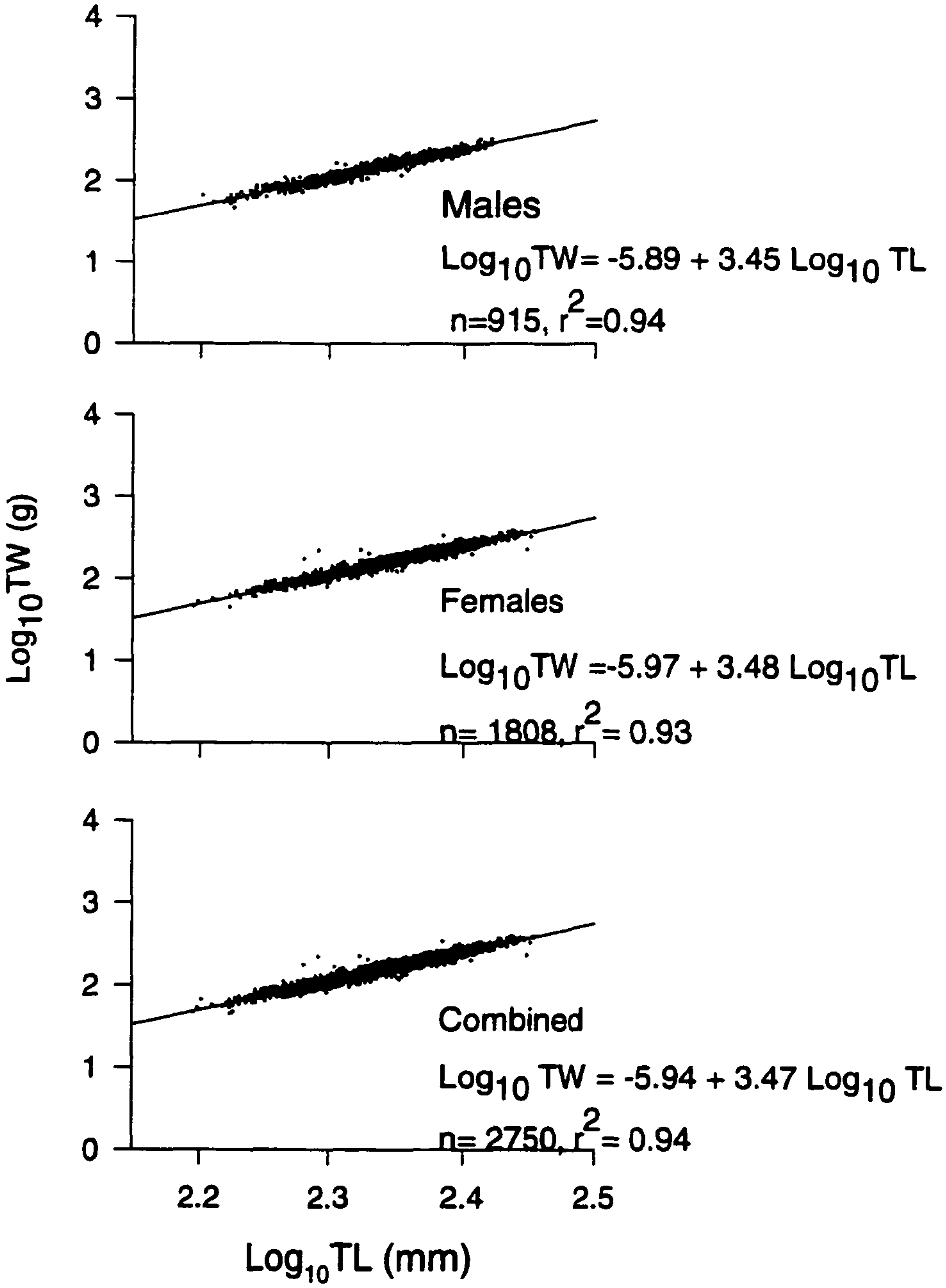


Figure 7
Plots of the log10 tw and log10 tl relationship of a) males, b) females, and c) combined sexes of spot, *Leiostomus xanthurus*, collected in the Chesapeake Bay from 1993-1995.

Table 4

Parameter estimates, standard errors, and 95% confidence intervals for the von Bertalanffy growth model of spot, *Leiostomus xanthurus*, from the Chesapeake Bay region.

Parameter	Estimate	Standard Error	95% Confidence Interval	
			Lower	Upper
L_{∞}	272.7	8.5	256.1	289.4
K	0.6	0.1	0.4	0.8
t_o	-1.1	0.2	-1.5	-0.6

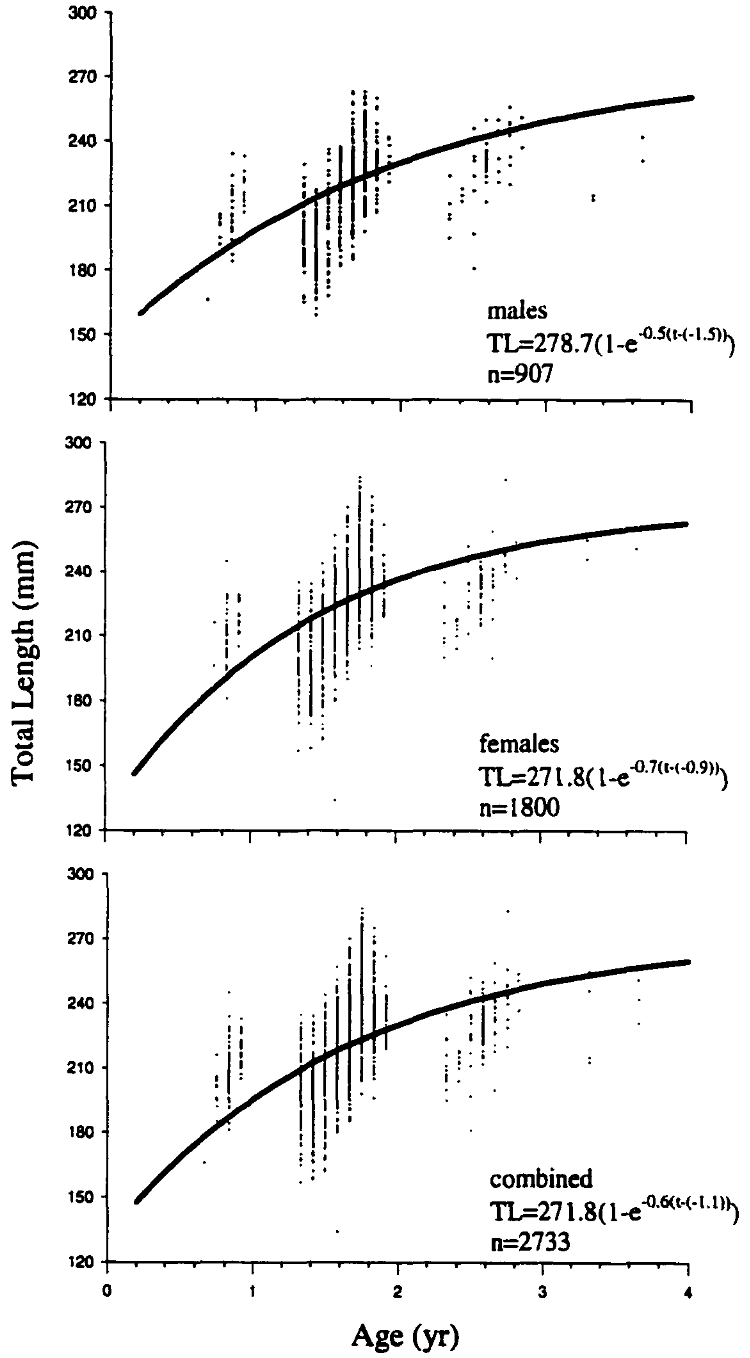


Figure 8
Observed lengths at age and the von Bertalanffy growth model for spot, *Leiostomus xanthurus*, collected in the Chesapeake Bay from 1993-1995, fitted for a) males, b) females, and c) combined sexes.

when Z was calculated from fractional annulus counts, and Z and M were calculated using Hoenig's and Royce's method, respectively. Estimates of F were 1.38 using Royce's method and 1.28 using Hoenigs method, using Z based on whole annulus counts. Estimates of F ranged from 1.83 to 1.89 using Z from the catch curve and estimates of M from Royce's and Hoenig's methods, respectively.

Size and Age Compositions

By Length

Length-frequency distributions (TL) of spot taken by commercial gears in the North Carolina winter fishery were not similar to each other (Figure 4 d and e). Trawls caught a smaller mean and median sized fish (mean= 179.1, 50^{th} percentile= 181 mm, SE=1.5, n=243) than gillnets (mean= 222.3, 50^{th} percentile= 234 mm, SE=1.7, n= 279). The mean size of fish captured in gillnets was smaller in North Carolina than in the Chesapeake Bay. The smallest fish collected from North Carolina was 103 mm and the largest was 263 mm.

By Age

The age composition of the North Carolina winter commercial catch was similar to that of the Chesapeake Bay (Figure 5 d and e). One-year old spot comprised greater than 90% of the total catch by numbers, and fish less than 1 year were less than 2% of the total catch by numbers of both trawls and gillnets. Three year-old spot comprised 0.0% and 1.1% of the total catch by numbers of trawls and gillnets, respectively.

By Sex

The differences between the sexes of fish caught in North Carolina were similar to the differences I found between sexes in the Chesapeake Bay. The mean and median size

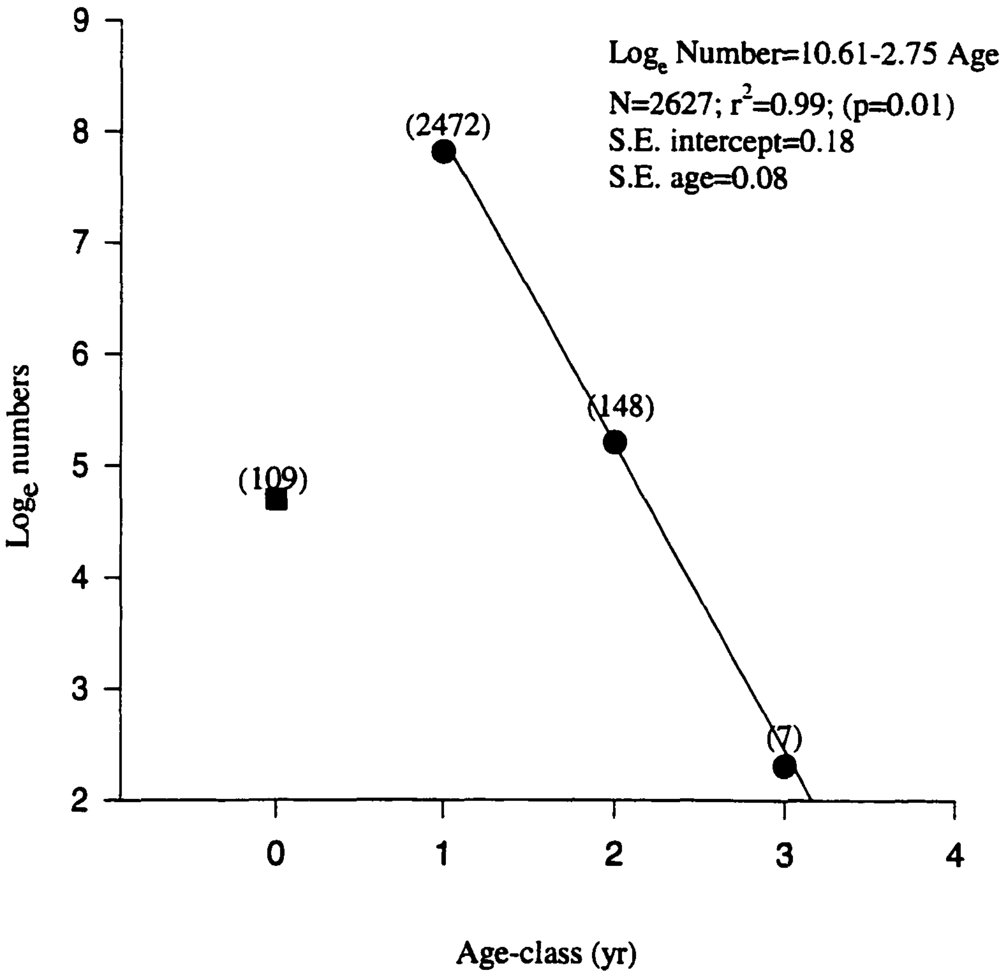


Figure 9

Catch curve for spot, *Leiostomus xanthurus*, collected in the Chesapeake Bay from 1993-1995. The circles correspond to age-classes used in the regression and the squares represent the age-class not used in the regression. The number of fish in each age-class is given above the symbol and the S.E. of the parameter estimates along with the relationship is also given.

of females (mean= 216.0, 50^{th} percentile= 229 mm, SE= 2.1, n= 216) was greater than the mean and median size of males (mean= 208.1, 50^{th} percentile= 207 mm, S.E.= 2.3, n= 181). The mean and median age captured was identical for males (mean=1.1, 50^{th} percentile= 1 yr, S.E.= 0.03, n= 181) and females (mean= 1.1, 50^{th} percentile= 1 yr, S.E.= .02, n= 212). Females comprised a slightly larger percentage of the total numbers of the catch (54.4%) than males (45.6%).

Discussion

The commercial catch of spot in the Chesapeake Bay was comprised almost entirely of a single age-class of fish between 1 and 2 years. The dominance of young fish in the commercial catch from the Chesapeake Bay has been documented since the mid-1950's (Pacheco 1962; Joseph 1972). Our results, however, typically produced a higher percentage of age 1^+ fish and a smaller percentage of 0^+ aged fish than reported in the 1950's. This may be due to the lack of information on discards of unmarketable sized spot caught within the Chesapeake Bay, a difference in gears sampled (Pacheco 1962) or fluctuations in age-class strengths common in short-lived species. Pacheco's (1962) sampling differed from ours in that he only sampled pound nets and experimental trawls, and his aging procedure used scales. Scales taken from spot have been shown to consistently underage fish that are older than 2 years in comparison to otolith thin-sections (Chapter II). which may indicate that older spot were a larger part of the historical catch than previously reported.

We feel the mean age at first capture (t_c), estimated for the Chesapeake Bay, is a good estimate despite the difficulty in obtaining the smallest sized (and therefore possibly youngest), least marketable fish which may be discarded or sold separately from the marketable fish as scrap. Mean age at first capture, calculated as the 50^{th} percentile of the cumulative age distribution instead of the average age, is used in stock assessment models such as Yield-per-Recruit (Beverton and Holt 1957) to estimate at what age a cohort can be considered fully exploited. Because the overwhelming majority of fish I collected from the commercial gears were age 1^+, the discard rate would have to be as large as the catch to alter our estimate of t_c based on ages determined from annulus counts alone. Our estimate is consistent with the t_c value that could be calculated from Pacheco's (1962) published data. However, because of the uncertainty generated by the lack of samples of discarded fish, our estimates should be viewed as an upper bound to t_c for conservative management practices.

I calculated t_c based on 2 different otolith aging methods, using whole as well as using fractional annulus counts. The advantage of using fractional annulus counts to calculate parameter estimates is that for a short-lived species such as spot, 6 months constitutes 1/4 to 1/6 of its current life span of 2-3 years in the Chesapeake Bay. Condensing age categories to year-class ignores the relatively important contributions that a fraction of a year represents in the total lifespan of a spot. Conversely, the disadvantage of using the fraction of the year is that the aging technique assumes that ages can be assigned precisely to the month, which only occurs if the exact birthdate of each fish is known. Spot, like many sciaenids, have a protracted spawning season from 2-5 months. Assigning the correct fraction of a year lived beyond the birthdate for a species with a long spawning season is difficult. A further complication encountered when estimating t_c using fractions of a year is that the number of fish from each month used to estimate the median must be weighted to represent the actual number of fish caught in that month. This requires good estimates of total catch by month, which I did not have. The t_c value determined with fractional annuli counts will always be larger and therefore less conservative than with whole annulus counts. I suggest using the t_c estimate generated from fractional counts with care, even though it may represent a more realistic estimate of the age structure of the catch from a short-lived species than whole annulus counts.

The high variability of length at age makes estimation of fish age based on length alone difficult after only one year of growth. The high variability of size at age, characteristic of fast growing fish, was partially responsible for the relatively wide confidence intervals I estimated around the growth parameters. The variability of size at age is probably not due to aging errors since transversely sectioned otoliths have been shown to be an excellent structure for aging spot (Chapter II). Also, spot in the Chesapeake Bay seldom reach sufficient age to make annulus counts difficult or illegible, which reduces variability due to aging errors. Rapid and early growth along with highly variable size at age is seen in the Atlantic croaker (Barbieri et al. 1994), another relatively short-lived sciaenid found in the Chesapeake Bay as well. Spot growth, however, is unlike the slower more linear growth shown by weakfish (Lowerre-Barbieri 1994), a sciaenid also found in the Chesapeake Bay. The apparent large size at age that spot attain early in life may be due in part to Lee's phenomenon. The faster growing and potentially largest fish at age may show up early in the fishery and the slower growing and smaller at age fish survive to make up the older age-classes (Lee 1912).

The high fishing mortality (F) of spot has likely affected the estimates of L_∞ and K from the von Bertalanffy growth model, relative to a lightly fished or virgin stock. The estimate of asymptotic length was probably an underestimate and the Brody growth coefficient likely an overestimate (Zhao et al. 1997). Any resulting Yield-per-Recruit modeling, therefore should consider that results based on these parameter estimates may represent a best case yield, or an overestimation of the actual yield that is possible, and future changes in fishing may yet affect those estimates.

The estimates of Z, and therefore the resulting F, based on maximum age techniques and the catch curve were different. The only total mortality rate published for Chesapeake Bay spot was an estimate of approximately 80% mortality after the first year based on length composition analysis (Pacheco 1962). This estimate was most similar to the annualized mortality estimates using maximum age methods. Our catch curve estimate of Z was much higher than the estimates obtained from maximum age methods. Typically, catch curves are regressed starting with the age-class after the highest frequency to insure that all age-classes used in the regression have fully recruited to the fishery (Ricker 1975). However, I assumed that all spot had fully recruited to all three gears by April (the month commercial fishing typically begins for spot in the Chesapeake Bay) of their second year, for three reasons. The first reason was that an overwhelming majority (approximately 90%) of the total catch from all gears was age 1^+ fish. The second reason was that minimum size (TL) captured by haul seines and pound nets was smaller than the mean size of 9-12 month old fish, as estimated by the von Bertalanffy growth curve, which indicates that those gears were capable of catching fish smaller than age 1^+. The third reason was that the mean age of all spot caught in April was the same as the other months until the 0^+ age-class fish recruited in the fall and mean age decreased. This trend indicated that by the beginning of the fishing season age 1^+ fish had already fully recruited to the fishery. Thus, I used fish aged as 1^+ in the regression of the catch curve. If I had not used the 1^+ aged fish in our catch curve analysis of mortality, the regression would have been based only on two age-classes. Because of the assumption of full recruitment by April of age 1^+ fish and the limited number of data points (3), I don't have as much confidence in the Z and resulting F estimated with this technique. Estimates from the catch curve however, do provide a useful upper bound of mortality for modeling purposes. As with the estimation of t_c, the values of Z estimated using whole annulus counts are more conservative than those using fractional annulus counts, because the resulting F calculated from the relationship Z=M+F, will always be larger given the same M.

I did not find enough significant differences in parameter estimates between the sexes, and the small differences that exist do not warrant developing separate management strategies for each sex in the Chesapeake Bay. Both the growth form and the age distribution of fish caught in the commercial fishery were nearly identical between the sexes, and only the average TL captured and the percentage of the catch made up by each sex were different. The larger mean and median female TL was due in part to the very largest (> 260mm) fish I collected which were predominantly female. As well, the higher relative percentage of females to males in our samples may not have represented a significant gear selectivity towards females. This is especially true, given the similarity between sexes in the mean size at age estimated by the von Bertalanffy model and that both sexes were captured at very similar small sizes. However, if the difference in the percentage of the catch made up by each sex does represent different vulnerabilities to the gears, the 8mm mean difference and 9mm median difference in mean TL between males and females is probably too small to be effectively managed. This is especially true given that gears are designed to operate within a multi-species fishery with a wide variety of sizes and body shapes. The potential effect that the difference in the percentage of the commercial catch made up by each sex has on recruitment still needs to be investigated, as well as fishery independent sampling along the entire Mid-Atlantic Region to check our estimate of the population sex ratio.

The fishery parameters estimated from spot caught by North Carolina fishermen were consistent with the fishery parameters estimated from spot taken in Virginia which indicate both areas are part of a common stock. Because spot typically spawn south of Cape Hatterus, N. C. and the larvae advect into appropriate nursery areas all along the Mid-Atlantic Coast (Norcross and Bodolus 1991), it is improbable that separate stocks would have formed in areas as close in proximity as Virginia and North Carolina. I only sampled fish from North Carolina during the winter, and our estimates of the fisheries parameters from that area only represented what was caught during that season. Thus, the smaller average size in North Carolina relative to the Chesapeake Bay was probably due to the inclusion of trawl samples, as trawls generally catch smaller fish than the other gears. The winter fishery in North Carolina includes fish which had just turned 1 year of age on January 1st and were therefore smaller than 1^+ aged fish caught in the Chesapeake Bay. The dominance of young fish in the commercial catch has been documented since the 1980's (DeVries 1982; Ross et al. 1986). Because our sampling program could not be structured to get representative samples from North Carolina throughout the year, this paper did not present that information as fully as those of Chesapeake Bay. Instead I used it only to determine if there were obvious dissimilarities in the age and size structure of the catch that would indicate these two areas needed to be treated as separate stocks. Based on the data presented in this paper and a review of the published literature, I recommend that spot should be managed regionally.

CHAPTER IV

YIELD-PER-RECRUIT MODELING AND THE APPLICATION OF THE PRECAUTIONARY APPROACH TO SPOT IN THE CHESAPEAKE BAY REGION, WITH CONSIDERATIONS TO MANAGING THIS SPECIES IN A MULTISPECIES FISHERY

Introduction

Spot (*Leiostomus xanthurus*) are a short-lived Sciaenid species found throughout the South and Mid-Atlantic Region of the Atlantic Coast of the United States. Maximum reported age of spot in the Middle Atlantic Region is 5 years (DeVries 1982; Chapter III), with few fish reaching their 3rd year in the Chesapeake Bay. Spot typically recruit to the Chesapeake Bay from March-May (Cowan and Birdsong 1987; Olney and Boehlert 1988), and leave for warmer waters in the late fall (Norcross and Bodolus 1991). During the late spring, summer, and fall spot are a common component of the commercial catch of Chesapeake Bay. Two additional Sciaenids are also commonly taken along with spot in the catch, Atlantic croaker (*Micropogonias undulatus*) and weakfish (*Cynoscion regalis*). The dockside values of all three species make them among the most valuable commercial finfish landed in the Chesapeake Bay (VMRC Plans and Statistics per. comm.). Spot have been commercially harvested in the Chesapeake Bay since the 1950's. The commercial catch of spot has ranged from 200,000 kg to 4,000,000 kg since that time. Landing from the 1990's, however, have typically ranged between 0.5-2 million kilograms. Gillnets, haul seines, and pound nets land the majority of the spot commercially taken in the Chesapeake Bay. The majority of the catch of spot comes from one age-class, between 1 and 2 yrs (Pacheco 1962; Joseph 1972; and Chapter III), and this trend is reflected in all three of the common commercial gears used in the fishery. Spot are an important part of the recreational fishery as well. Little information however exists on the age structure of the recreational catch.

It is not known if spot are presently overfished in the Chesapeake Bay, because no study has directly investigated the dynamics of this fishery. Overfishing is generally divided into two categories: growth and recruitment overfishing. Growth overfishing thresholds, which can be determined using Yield-per-Recruit modeling, detects if a cohort has been harvested before attaining maximum biomass. The determination of growth overfishing can usually be done rapidly with moderate data requirements. Recruitment overfishing, which is more serious, typically is detected with long-term data collections through stock recruit relationships developed from Virtual Population Analysis. For many stocks, however, those long-term data collections are unavailable. For these stocks, the thresholds of growth overfishing often act as a more conservative substitute for recruitment overfishing, because for many species growth overfishing will occur before recruitment overfishing.

Because intrinsic stock characteristics can vary naturally, targeting harvest levels at maximum sustainable yield (MSY) can lead to detrimental fishing practices (Larkin 1977). For this reason much management, based on yield thresholds set at MSY, has been criticized as unsafe. Conservative management practices should be aimed at setting harvest levels below MSY to account for uncertainties. Early applications of this philosophy included the use of $F_{0.1}$ (Deriso 1987), which set fishing mortality (F) at levels where increases in yield-per-recruit due to small increases in F were 10% of that at the origin (Anthony 1982). Such concepts, however, did not account for the inherent variability in F between years or account for the differences between fish species to resist overfishing. The precautionary approach was developed to address these needs.

The precautionary approach to fisheries management (Garcia 1994) accounts, beforehand, for uncertainties in fishery parameters and for consequences to that fishery if the estimation of those parameters was wrong. The precautionary approach is a concept that can be applied to the ideas of recruitment failure (Garcia 1996) and yield management (Caddy and McGarvey 1996). It involves setting a threshold, which should not be exceeded, and defining safer targets with known probabilities of exceeding the thresholds. It offers decision makers the choice of a series of safer fishing levels, each with an associated probability given the uncertainty in the system of exceeding that threshold.

The objectives of this paper were to determine if spot in the Chesapeake Bay are growth overfished, by using Y/R modeling. I also consider use of the intrinsic stock parameters such as growth and natural mortality, to determine the potential for overfishing spot in the future. The precautionary approach was used to provide safe target levels of instantaneous fishing mortality (F) along with its associated probability, given a degree of uncertainty, of the target F actually exceeding the threshold value of F_{MSY}.

Materials and Methods

A total of 2750 spot were collected in 1993-1995 from commercial fishermen and fish dealers operating within the Chesapeake Bay to estimate the parameters necessary for yield-per-recruit modeling (Chapter III). A Beverton and Holt yield-per-recruit model (Beverton and Holt 1957) was chosen to determine the effects of varying the possible ranges of the extrinsic factors (F and t_c) against possible ranges of the intrinsic factors (M and K). The program BH-4, from the Basic Fisheries Science Programs package (Saila et al. 1988), was used to perform the Y/R simulations.

The Beverton and Holt Y/R model is:

$$Y/R=Fe^{-M(t_c-t_r)}\,W_\infty \Sigma U_n e^{-nk(t_c-t_0)}/F+M+nK$$

where Y/R=yield-per-recruit (g); F=instanteous fishing mortality coefficient; M=instanteous natural mortality coefficient; W_∞=asymptotic weight; U_n=summation parameter; t_c=mean age at first capture; t_r=mean age at recruitment to the fishing area; t_0=hypothetical age when length is zero; K=Brody growth coefficient. Asymptotic weight (W_∞) was calculated from the relationship:

$$W_\infty=aL_\infty^{\ b},$$

where a=intercept, b=the slope of the length-weight relationship (allometery coefficient), and L_∞=asymptotic length (L_∞) from the von Bertalanffy growth model (Von Bertalanffy 1938) performed for Chesapeake Bay spot (Chapter III). The estimates of the parameters I used in modeling and the ranges I modeled across are summarized in Table 5. I generally modeled more scenarios, which were conductive to overfishing (slow growth, low M and younger t_c) than our best estimates, to better understand the possibilities of overfishing.

The proportion of total growth remaining (Pg) after the mean age that spot recruit to the exploited phase of life was calculated as:

$$Pg=(1-l_c/L_\infty)$$

where L_∞, asymptotic length, was obtained from the von Bertalanffy growth curve (Chapter III), and l_c, average length at first capture, which is estimated by converting t_c to length using the von Bertalanffy growth curve. Ages used to assess t_c and l_c were determined from both whole and fractional annulus counts. Ages determined from fractional annulus counts may be more accurate than ages determined from whole annulus counts, but whole annulus counts are a more conservative estimate (Chapter III).

The age of maximum biomass (t_{critic}) for spot was calculated, following Alverson and Carney (1975) and Deriso (1987), as:

$$t_{critic} = t_0 + 1/K \ln (3K/M + 1).$$

The age t_{critic} corresponds to the age when a cohort reaches its maximum biomass in the absence of fishing. The time of t_{critic} is determined by the balance between loses in a cohort's biomass due to natural mortality and increases in cohort biomass due to individual fish growth. In general, when fishing practices (measured by F and t_c) take the majority of the catch well before t_{critic}, a cohort can be considered growth overfished and conversely when fishing practices generally take fish after t_{critc} the cohort is not growth overfished. The maximum yield of a cohort corresponds to the harvest of fish at t_{critic} because harvesting before that age has not allowed enough time for the average fish from a cohort to grow fully, and harvest after that time allows additional cohort losses due to natural mortality that are not compensated by an individual fish's growth. The concept of conservative management, however, restricts fishing to ages on average after t_{critic}.

The application of the precautionary approach dictates that a series of fishing levels (F) be calculated with a known probability of exceeding a threshold level. I followed the procedures outlined by Caddy and McGarvey (1996) in determining an F (F_{NOW}) with a

Table 5

Estimates of parameters, and parameter ranges that were used in the yield-per-recruit modeling of spot, *Leiostomus xanthurus*, in the Chesapeake Bay.

Parameter	Estimate	Range
L_{∞}	272.7	272.7
K	0.6	0.4-0.7
t_o	-1.1	-1.1
t_c	1	0.5-1.5
M	0.86-0.9	0.7-1.0
F	0.7-1.89	0.0-5.0
W_{∞}	324.9	324.9
t_r	0.0	0.0

known probability of exceeding F_{MAX} given the most likely, but conservative scenario of M, K and t_c. The calculation of F_{NOW} was done as follows:

$$F_{NOW}=F_{MSY}/(1+CV_F(t-(a_0+a_1t/(1+b_1t+b_2t^2))))$$

where,

$$t=(\log_e(1/(P(F>FMSY))^2)^{-2}$$

and a_0=2.30753, a_1=0.27061, b_1=0.99229, and b_2=0.04481 (Caddy and McGarvey 1996). F_{MAX} was determined from the particular scenario of M, K, and t_c chosen for the application of the precautionary approach. An estimate of the variability of F, given as the Coefficent of Variation of F (CV_F), was determined by calculating a separate Z using maximum age techniques (Royce 1972; Hoenig 1983) for each year from 1993-1995, and then calculating separate F's based on the relationship Z=M+F for each of those years. Instantaneous natural mortality (M) in each case was assumed to be the M=0.9 (Chapter III).

Results

The results indicated that spot in the Chesapeake Bay were not growth-overfished based on our estimation of current fishing practices. Plots of the curves of Y/R on F (Fig. 10 a, b, c and d) generally indicated that growth-overfishing was possible only when t_c was less than 1 year and when K and M were less than our estimates. The magnitude of the yield-per-recruit in our modeling was influenced more by K and M than by t_c over the ranges modeled (Figure 10). Within each scenario of M and K; t_c was more important than F in determining the potential for growth-overfishing, because maximum yield could only be exceeded at small values of t_c.

The Y/R curves in all scenarios showed rapid increases in yield as F increased, until levels of between F=1 and F=2, for most scenarios of M and K. Yield-per-recruit generally reached an asymptote by F=2.0. This indicates that increases in F, beyond the current F I estimated (between 1.28 and 1.89), will generally not drastically increase the yield-per-recruit. However, decreases in F below 1.0 will typically produce yields much below those of maximum yields for most scenarios.

The maximum yield-per-recruit, estimated for each scenario, based on the modeling ranged from a low of 18.1g (M=1.0, K=0.4, and t_c=1.5) to a high of 73.1g (M=0.7, K=0.7 and t_c=0.75). The harvest of spot at t_c=1.5 generally produced the lowest yield-per-recruit of all the values of t_c modeled in each of the scenarios of M and K, except under scenarios where M and K were lower than our estimates (Table 5). The low Y/R at larger values of t_c can be attributed to the fact by age 1.5 yr much of the biomass of the cohort had already been lost to natural deaths and there had been little additional growth after the first year of life.

Maximum biomass of a spot cohort from the Chesapeake Bay occurs, most likely, by age 1. The values of t_{critic} calculated for all scenarios were generally <1yr (Table 6), but ranged from 1.4 yr in the most conservative scenario (M=0.7 and K=0.4) to 0.5 yr in the least conservative scenario (M=1.0 and K=0.7). Because the age of maximumbiomass occurs early in the life-span of a spot cohort, large increases in F when t_c is larger than 1 year will generally not result in growth overfishing, as can be seen in Figure 10 (a, b, c, and d).

The percentage of growth (Pg), in total length, past the age corresponding to t_c was relatively low despite the early entry of spot into the fishery. The small Pg was the result

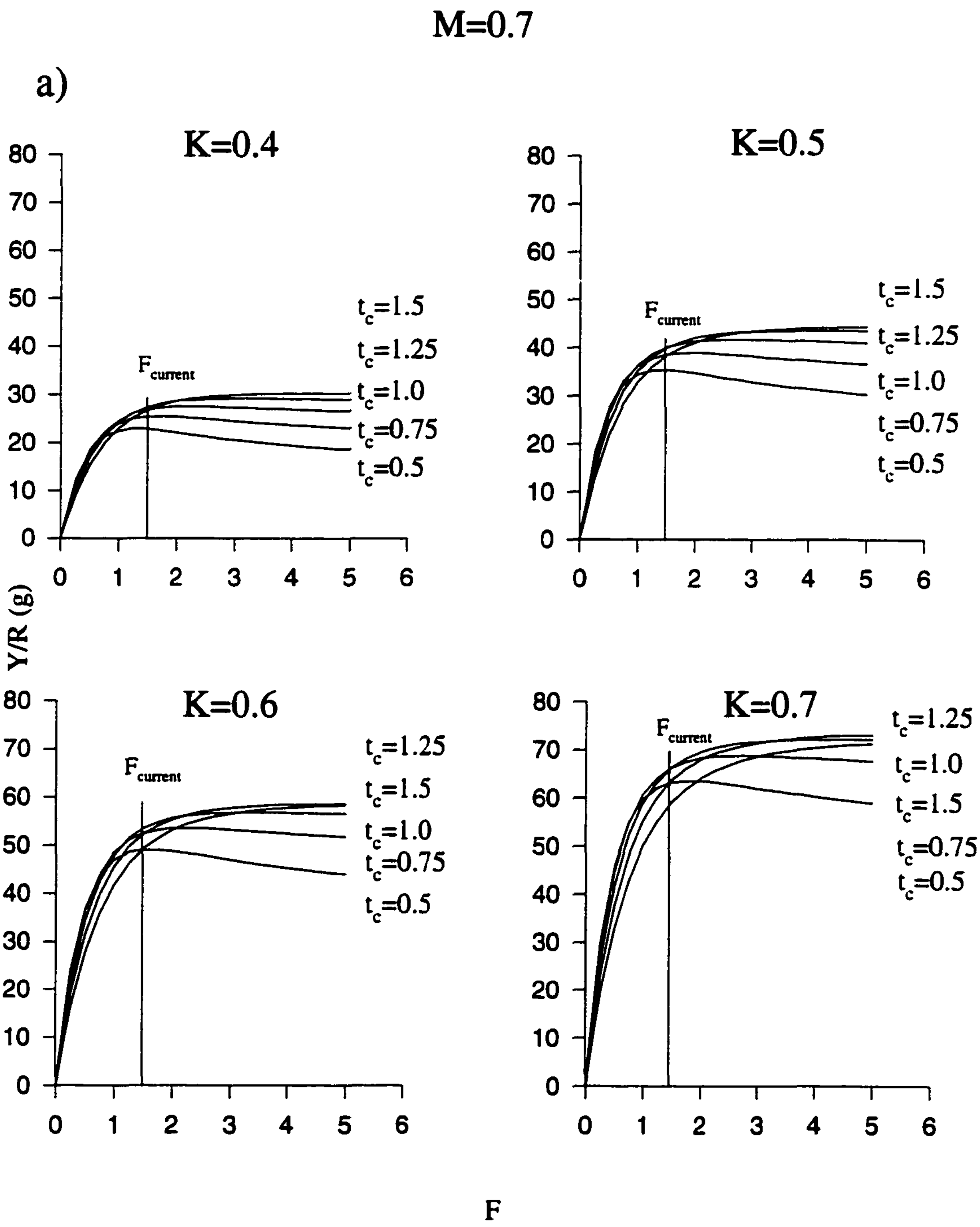
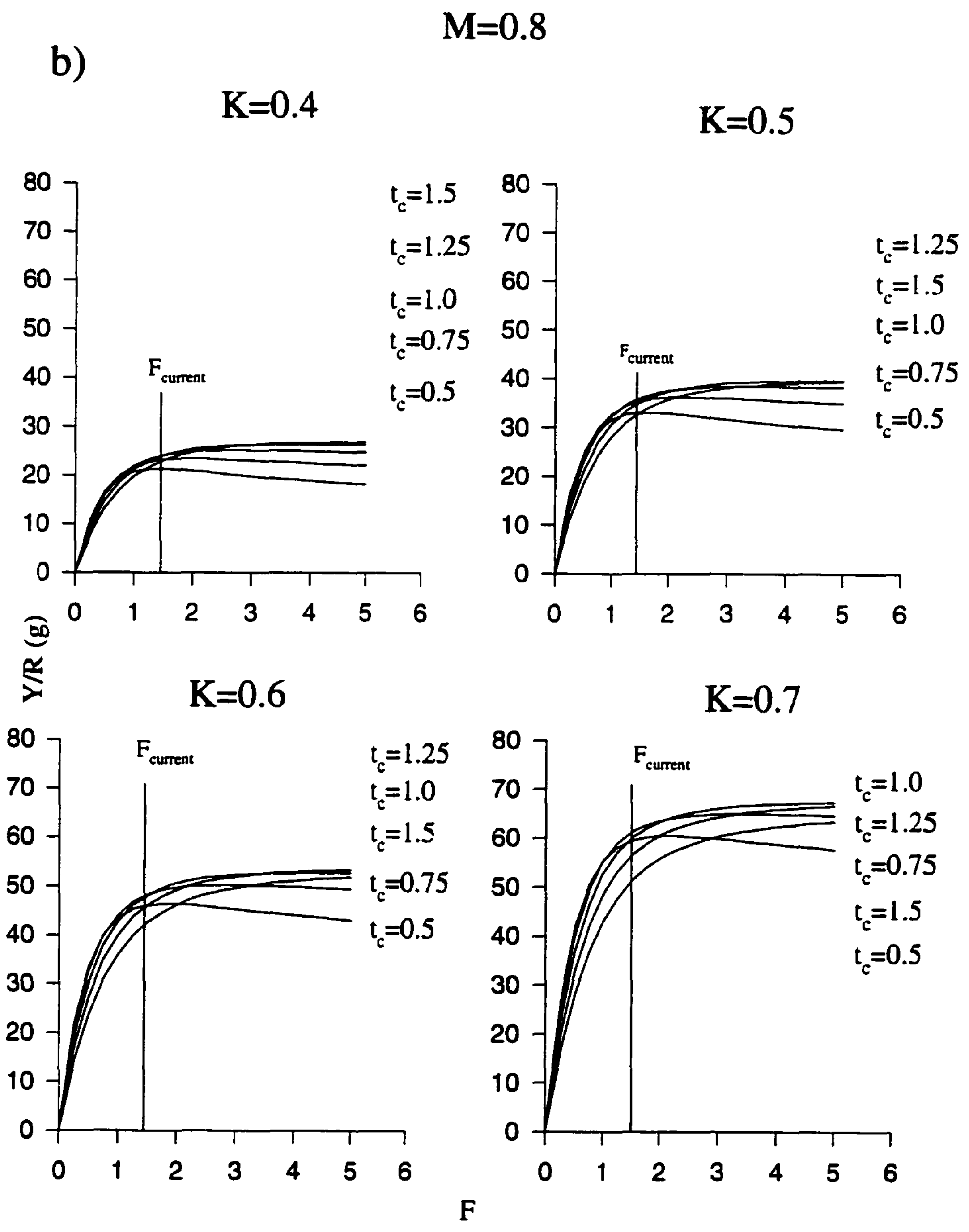
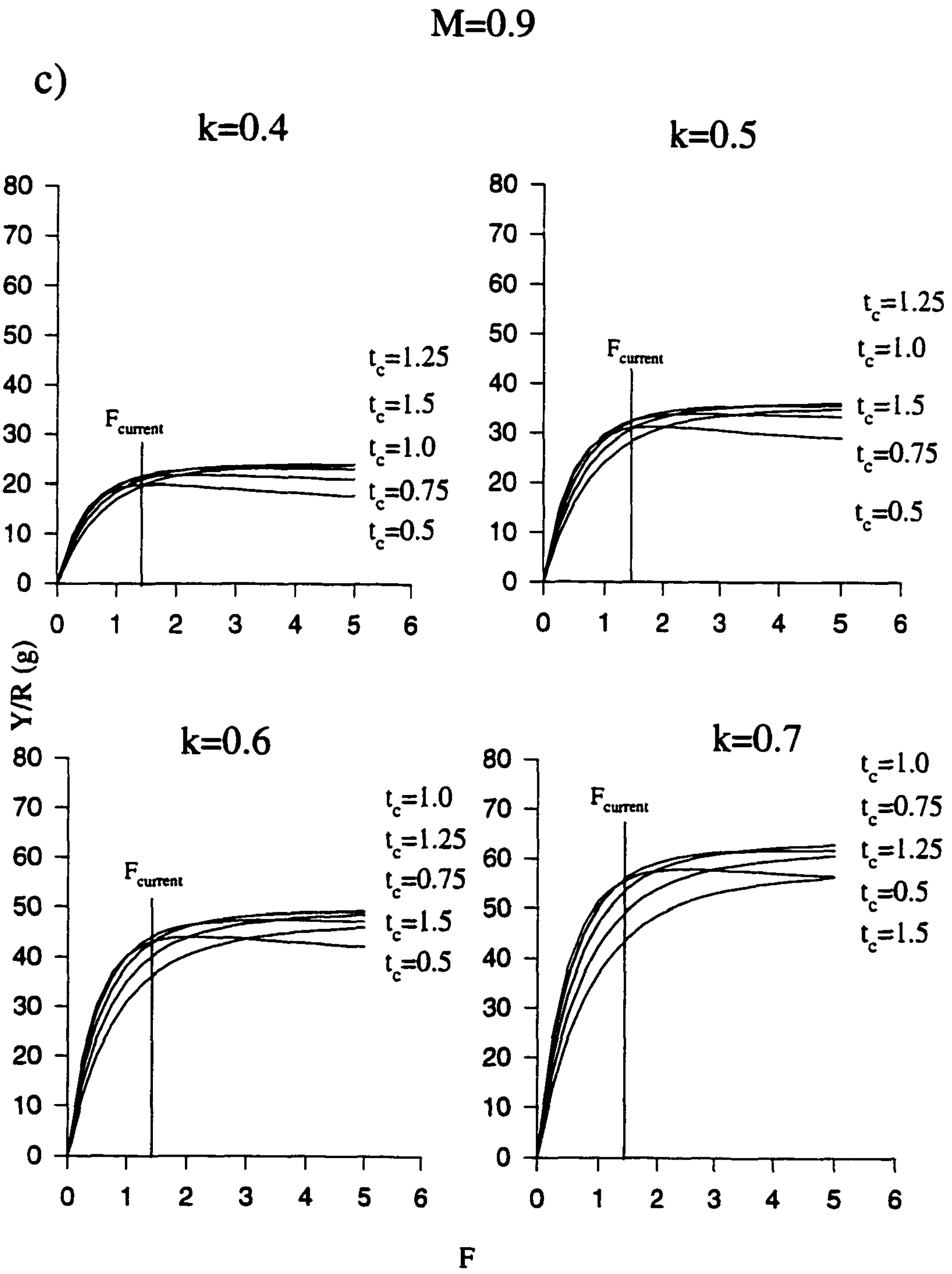
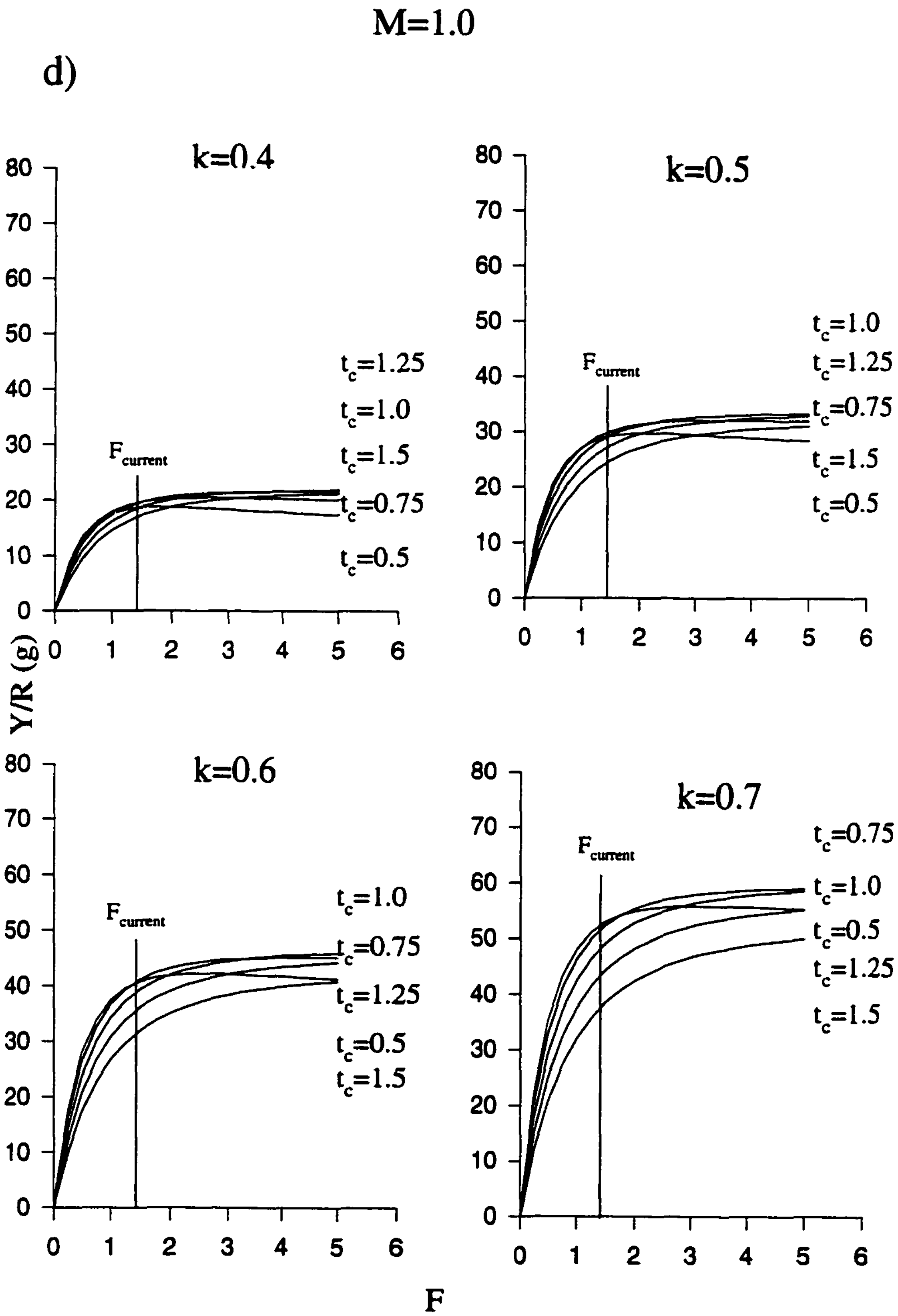


Figure10
Plots of Y/R of spot , *Leiostomus xanthurus*, against F, estimated for tc=0.5-1.5 and M = a) 0.7, b) 0.8, c) 0.9, and d) 1.0.


b)
M=0.8
K=0.4
K=0.5
K=0.6
K=0.7
Y/R (g)
F
F_current
t_c=1.5
t_c=1.25
t_c=1.0
t_c=0.75
t_c=0.5



M=0.9
c)
k=0.4
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6
F_current
t_c=1.25
t_c=1.5
t_c=1.0
t_c=0.75
t_c=0.5
k=0.5
F_current
t_c=1.25
t_c=1.0
t_c=1.5
t_c=0.75
t_c=0.5
Y/R (g)
k=0.6
F_current
t_c=1.0
t_c=1.25
t_c=0.75
t_c=1.5
t_c=0.5
k=0.7
F_current
t_c=1.0
t_c=0.75
t_c=1.25
t_c=0.5
t_c=1.5
F


M=1.0
d)
k=0.4
Fcurrent
tc=1.25
tc=1.0
tc=1.5
tc=0.75
tc=0.5
k=0.5
Fcurrent
tc=1.0
tc=1.25
tc=0.75
tc=1.5
tc=0.5
Y/R (g)
k=0.6
Fcurrent
tc=1.0
tc=0.75
tc=1.25
tc=0.5
tc=1.5
k=0.7
Fcurrent
tc=0.75
tc=1.0
tc=0.5
tc=1.25
tc=1.5
F

of the rapid growth of spot within their first year (Chapter III). When t_c was calculated as 1 yr (based on whole annulus counts) Pg=28.4%, and when t_c was calculated as 1.6 yr (based on fractional annulus counts) Pg=19.8%. It was this early accumulation of mean maximum size coupled with the high M that was responsible for the relatively early t_{critic} in the total lifespan of spot.

The precautionary approach was used with the scenario M=0.7, K=0.5, and t_c=0.75 yr, because in this scenario each parameter was a more conservative estimate (less likely to produce overfishing) than our best estimate. I estimated CV_F as 0.11 and 0.10 using Royce's and Hoenig's methods, respectively. Although determining CV_F in this manner may reflect more the variability of cohort strength than variations in F, I feel that this should produce a larger and therefore more conservative estimate of CV_F. The estimate of CV_F=0.11 was used in the application of the precautionary approach because it will be the more conservative approach. The estimate of F_{MAX} for the scenario chosen was F=4.1. The target F's (F_{NOW}) and their probability of exceeding F_{MAX} are given in Table 7.

The target F's derived from the precautionary approach were greater than the current F I estimated for spot from the Chesapeake Bay (Table 5), despite the estimates of the parameters used in the precautionary approach were more conservative than our actual estimates. Given the variability I estimated in F, there is little chance that the current F exceeds F_{MAX}.

Discussion

Spot from the Chesapeake Bay, as described by our modeling efforts, are relatively

Table 6

The estimated age of maximum biomass (t_{CRITIC}), in years, for spot from each modeling scenario of Instantaneous Natural Mortality rate (M) and growth rate (K). The estimate of t_{CRITIC} for the best estimate of M and K is bolded.

		(M)		
(K)	0.7	0.8	0.9	1.0
0.4	1.4	1.2	1.0	0.9
0.5	1.2	1.0	0.9	0.7
0.6	1.0	0.9	**0.7**	0.6
0.7	0.9	0.7	0.6	0.5

impervious to growth overfishing due to the combination of high natural mortality and fast growth. Unless spot are typically captured at ages that correspond to sizes which are generally considered unmarketable, there is little concern that a cohort can be fished out before attaining maximum biomass. Increases in fishing effort, beyond current levels, however, will generally not increase the yields obtained from this stock, nor will reduction in the ages caught within the fishery. Yield within a given year will most likely be determined by recruitment of a single age-class, since the spot catch comes mainly from a single age-class (Pacheco1962; Joseph 1972; Chapter III).

The yield-per-recruit relations given here are only approximations and are influenced by the allometry of spot growth and the biases in estimating population parameters from heavily fished stocks. Although the allometry of spot growth may affect the absolute estimates of yield it should not greatly affect the relative differences between each yield-per-recruit relationship, since the relative error tends to be much less than the absolute error (Ricker 1975). Our estimates of spot growth (K) may be larger and maximum length (L_∞) may be smaller than for an unfished population; which may make these yield-per-recruit scenarios best case situations (Zhao et al. 1997). Significant changes in the fishing practices in the Chesapeake Bay may make re-estimation of the basic parameters and Y/R models necessary, because the corresponding threshold levels of F may change as well.

As long as t_c remains at or above 1 year, spot can not be growth overfished. Although management decisions cannot directly control the intrinsic stock parameters such as M and K; the management of t_c should be enough to insure that growth overfishing does

Table 7

The target F's (F_{NOW}), and the associated probability of exceeding F_{MAX} calculated for the conservative scenario: M=0.7, K=0.5 and t_c=0.75.

$P(F_{NOW}>F_{MAX})$	F_{NOW}
0.01	3.27
0.05	3.47
0.1	3.59
0.15	3.68
0.2	3.76
0.25	3.82
0.3	3.89
0.35	3.93
0.4	3.99
0.45	4.05
0.5	4.09
0.6	4.21
0.7	4.34
0.8	4.49
0.9	4.72

not occur. Efforts directed at reducing by-catch of spot from other fisheries, as well as management measures such as mesh size restrictions to insure that very small (<195mm) spot, which on average correspond to fish younger than 1 yr, are not captured in the fishery should eliminate the possibility of overfishing. Growth-overfishing thresholds for spot in the Chesapeake Bay may not work as conservative substitutes for recruitment overfishing thresholds. It is possible to take a majority of spot in this fishery before they have reached 1year of age, and still not growth-overfish the Chesapeake Bay stock. Spot have a protracted spawning season, which occurs during late fall and winter. Because December and January are thought to be the principal spawning months for spot, a 0.75 year-old spot would correspond to the fish from the first September after birth. It may therefore be possible to completely deplete a cohort before they can reach the age of their first spawning, but not harvest at a level beyond MSY, according to Y/R theory. A more conservative management philosophy, beyond Y/R, should also be considered. Yield-per-recruit models are only one part of a complete management strategy. Attention to the more serious issues of recruitment overfishing needs to be addressed directly. Wise management strategies use other modeling efforts such as Eggs-per-Recruit (Prager et al. 1987) or Spawning Stock Biomass (Goodyear 1993) coupled with Y/R models to most efficiently, and safely manage exploited stocks.

Although application of the precautionary approach to spot will have little impact on their management, the application of such a conservative approach to other species in the multispecies fishery could significantly affect spot yields. In the Chesapeake Bay, spot are captured along with weakfish and croaker by the same gears. Recent studies have indicated that weakfish have been growth overfished (Lowerri-Barbieri 1994) and croaker are fished near or at MSY (Barbieri 1997). The setting of more conservative target F's for any of these species should consider their impact on the yield of the other two, especially when the precautionary approach is applied to yield-based instead of recruitment-based management. Reductions in F that may be necessary to protect weakfish, which have been shown to be growth overfished but not recruitment overfished, could reduce F on spot to levels of $F<1$ and severely under-utilize the available spot biomass. As long as recruitment of any one species will not be affected, management measures can be aimed at optimizing the yield of all species in aggregate, while providing adequate precautionary protection to the most vulnerable. The biological and economic impacts of management decisions should reflect a systems approach to this multi-species fishery and not just a series of single-species approaches, to better manage the available resources.

CHAPTER V

THE POTENTIAL OF RECRUITMENT OVERFISHING OF SPOT IN THE CHESAPEAKE BAY AND A COMPARISON OF BIOLOGICAL REFERENCE POINTS

Introduction

Spot (Leiostomus xanthurus) are a widely distributed member of the Family Sciaenidae, and an important component of the commercial catch along the middle and lower Atlantic coasts of the United States. The maximum reported lifespan of spot, from the Chesapeake Bay and surrounding region, is 5 years (Devries 1982; Chapter III), but the lifespan of a spot generally does not exceed 2 years in the Chesapeake Bay due to high levels of fishing (Chapter III). Spot, like other Sciaenids family, have relatively high fecundity. Spot fecundity was estimated by Dawson (1958) to be 77,730-83,900 eggs per spawning. Age-specific fecundity, however is not known. Spot spawn off the Continental Shelf, south of Cape Hatteras, North Carolina during winter (Pacheco 1962; Warlen and Chester 1985; Norcross and Bodolus 1991). Young spot are then transported into nursery areas along the South and Mid-Atlantic Coasts throughout the winter and spring (Cowan and Birdsong 1985; Olney and Boehlert 1988), where they reside until fall migrations out of the bays and estuaries.

Spot are part of a multi-species fishery, which captures other species including both weakfish (*Cynoscion regalis*) and croaker (*Micropogonias undulatus*) in addition to spot. The primary gears used in the fishery are pound nets, gillnets, and haul seines (Mercer

1989). The total yield of spot from the commercial operations in the Chesapeake Bay is driven by the harvest of a single year-class. Approximately 90% of the spot taken each year are 1^{+}yr old fish (Chapter III). Spot from the Chesapeake Bay exhibit fast growth, with 72% of the cumulative growth occurring within the first year, and have a high instantaneous natural mortality, (M=0.86-0.92). Spot are also subjected to high fishing pressure, with an estimated instantaneous fishing mortality of between F=0.7-1.9. (Chapter III). Due to their rapid early growth and high mortality, a spot cohort reaches the age of maximum biomass within the first year (Chapter IV). Thus spot are very difficult to growth-overfish.

Growth-overfishing thresholds for spot management, however, may make poor and non-conservative substitutes for recruitment overfishing thresholds, unlike some other species (Vaughn et al. 1996). Early age of maximum biomass of a cohort makes it possible to fully harvest a cohort before it first spawns and yet not growth-overfish the stock. The use of growth overfishing thresholds alone, to manage spot could imperil the recruitment success of this species. Recruitment overfishing potential, a biologically more significant management issue, is generally evaluated based on data intensive methods, such as Virtual Population Analysis (Pope and Shepard 1982). This kind of extensive data set does not yet exist for spot in the Chesapeake Bay region, so the stock-recruit relationship is not known. An alternative approach to gauging the effects of fishing on the recruitment of spot in the Chesapeake Bay needs to be used, such as Spawner Potential Ratios per recruit (Goodyear 1993; Katsukawa 1997).

The objectives of this study were to determine the potential of recruitment overfishing of spot in the Chesapeake Bay at the current level of fishing pressure, and to make recommendations on optimal fishing levels in conjunction with the previously completed yield-per-recruit modeling (Chapter IV). The ages and lengths of maturity were determined for each sex to assay the potential of harvesting spot before their first spawning event. To determine the effects of different levels of fishing on the potential spawning success of spot, a series of Spawning Potential Ratios (SPR) were produced based on spawning stock biomass and mean ovarian weight at each potential spawning event. The SPR's were used to compare the effect of different levels of fishing mortality (F) on the percent of spawning biomass remaining compared with an unfished cohort.

Materials and Methods

A total of 2750 spot were collected in the Chesapeake Bay from 1993-1995, during the months spot were present in the bay (April-November). Spot were bought from commercial fishermen and dealers. Although spot could not be randomly selected from either fishermen or dealers, Chittenden (1989) found that within a box of croaker, which is a closely related species that are caught and processed identically to spot, lengths were representative of those found across boxes. In addition, 418 spot were also collected from commercial gears operating in North Carolina waters during the winter of 1993-1994 (December-March).

Random samples of spot were taken from each box, and total length (TL), total weight (TW), and gonad weight (GW) were measured along with the sex and gonad stage which was determined by visual inspection. Both saggital otoliths and a random sample of all gonads were taken. Gonads were preserved in formalin for 24hrs, washed for 24hrs, and stored in 70% buffered ethanol. Ages were determined from transverse sections of a random choice of left or right sagittal otolith (Piner chapter 2). Ages corresponded to the number of annuli and were based on a January 1st birthdate.

An estimate of the percentage of fish mature at length was determined by calculating the percentage of mature fish in each 10mm length class, then fitting a logistic regression to those percentages. Plots of mean GSI in the same length classes (gonad weight/ gonad free body weight X 100) were used to corroborate those results. An estimate of the percentage of mature fish at each potential spawning season was also determined. Because the spawning season encompasses the January 1st birth date of spot, when spot become the next age-class, the potential spawning event instead of age was used for the calculation of percent maturity. For example, a fish's first November and December along with its second January and February constitute its first potential spawning season. Maturity of fish was based on macroscopic inspection of the gonads, and those results for females was verified with microscopic examination of a random sample of gonads that were prepared histologically. All fish used in the estimation of maturity at both length and age came from fish taken in November-February because those are the principal spawning months of spot, and therefore the number of fish classified as mature but resting should be minimal.

The histological preparation was done by a hospital laboratory. Two 5 um sections were taken from each of the anterior, middle and posterior regions from a random choice of left or right gonad. Gonads were stained with hematoxylin and eosin Y.

To determine the possible effects of fishing on spawning potential, a series of Spawning Potential Ratios (SPR) of a cohort were calculated. The potential ovary mass produced by a cohort under a specific fishing scenario was divided by the potential ovary mass that would be produced in the absence of fishing. For each specific scenario Spawning Potential for a cohort (SP) was calculated as:

$$SP=\Sigma N_t \ M_t GW_t$$

Where, N_t = number of individuals of a cohort (starting with 1000) alive at the mid-point of each potential spawning event (January 1st), M_t = % of females mature at the mid-point of each potential spawning event t, and GW_t = average ovary weight during the spawning event t. For each potential spawning event, an average ovarian weight was calculated from all ovaries determined to be in the most advanced ovarian stage associated with that potential spawning event. The percentage of fish remaining in a cohort was estimated from the basic relationship:

$$N_t=N_o e^{-z}$$

where, N_t = number alive at time t, N_o = number alive initially, and Z = instantaneous total mortality rate. In an unfished stock, Z will equal M, and for each different level of fishing intensity, Z will equal M+F. The SPR values were determined for 5 different scenarios of M: including M=0.7, M=0.8, M=0.9, M=1.0 and M=1.1. The percentage of fish alive at the mid-point of the spawning season (January 1st) was then adjusted by the percentage of fish mature for each spawning event. A series of SPR values were also produced using potential spawning stock biomass in the absence of fishing divided into potential spawning stock biomass under a series of different F's. Average weight of a fish on January 1st (mid-point of spawning season) was estimated from a conversion of length at each age from a von Bertallanfy relationship to weight at length using the previously determined length-weight relationship (Chapter III):

$$w=al^b$$

where, w= total weight, a= intercept of $\log_{10}$ TL-$\log_{10}$ TW relationship, l= total length, and b= slope of the $\log_{10}$ length-$\log_{10}$ weight relationship. The percentage of males in our samples was 33.5% and the percentage of females was 66.5% (Chapter III). These percentages were adjusted by the percentage mature for each potential spawning event to calculate the actual spawning biomass of a cohort at each potential spawning event. The remaining calculations were done using the same methods as described for the mean ovarian weight SPR. A separate SPR was also calculated for M=0.9 (our best estimate of M) and a sex ratio of 1/1 to compare to the resulting SPR curve obtained from a sex ratio commonly assumed for management purposes.

Results

Spot become sexually mature at an early age and at a relatively small size. I estimated that at least 50% of both male and female fish are sexually mature by 190mm(Figure 11), though 50% of females were estimated to be sexual mature at a slightly smaller size (170mm) than the same percentage of males (190mm). These results were corroborated by plots of the mean GSI for each sex against the same 10mm length classes. Mean GSI for both sexes begins to increase dramatically by 190mm (Figure 12) which indicated maturing gonads at approximately these sizes. Fish <170mm have been commonly captured by all three primary commercial gears used in this fishery (Chapter III), indicating that the gears are capable of capturing fish before they reach a size wherein 50% are mature. I estimated, from our samples, that 49% of males and 68% of females are sexually mature at the end of their first year of life (Figure 13), which corresponds to their

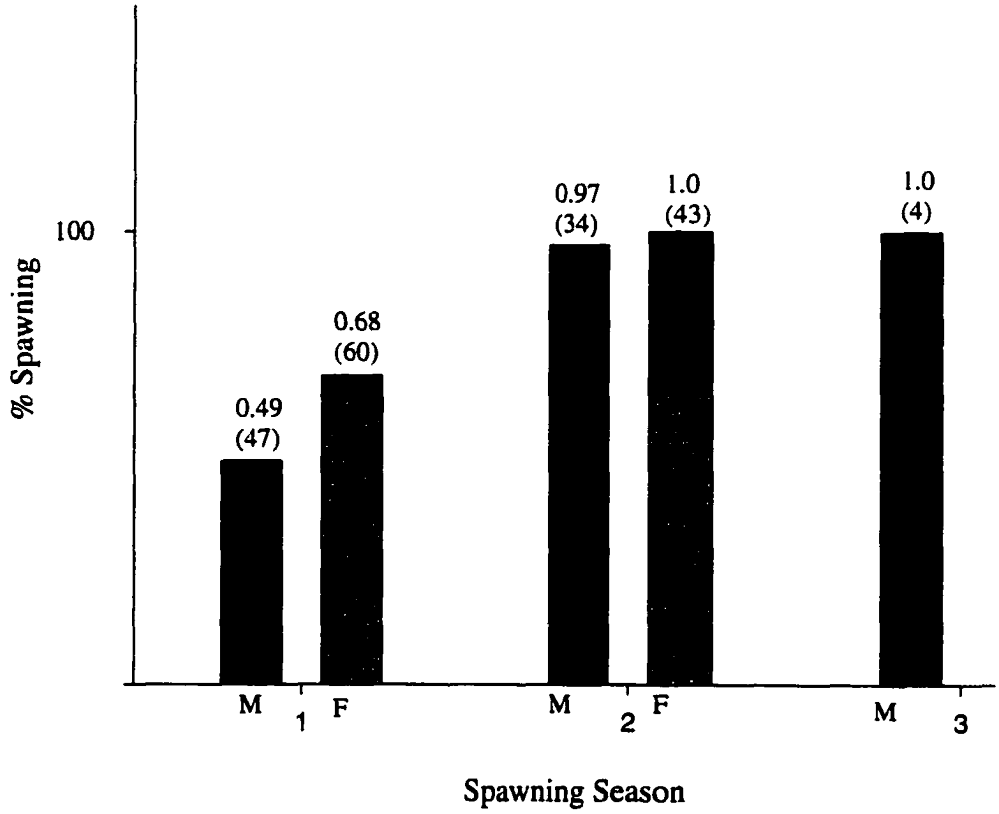


Figure 11
The percentage of male and female spot that are mature during November through February. The first spawning season corresponds to the first winter when the average spot is 11-14 months old. The second spawning season begins 12 months later, and the third 24 months later.

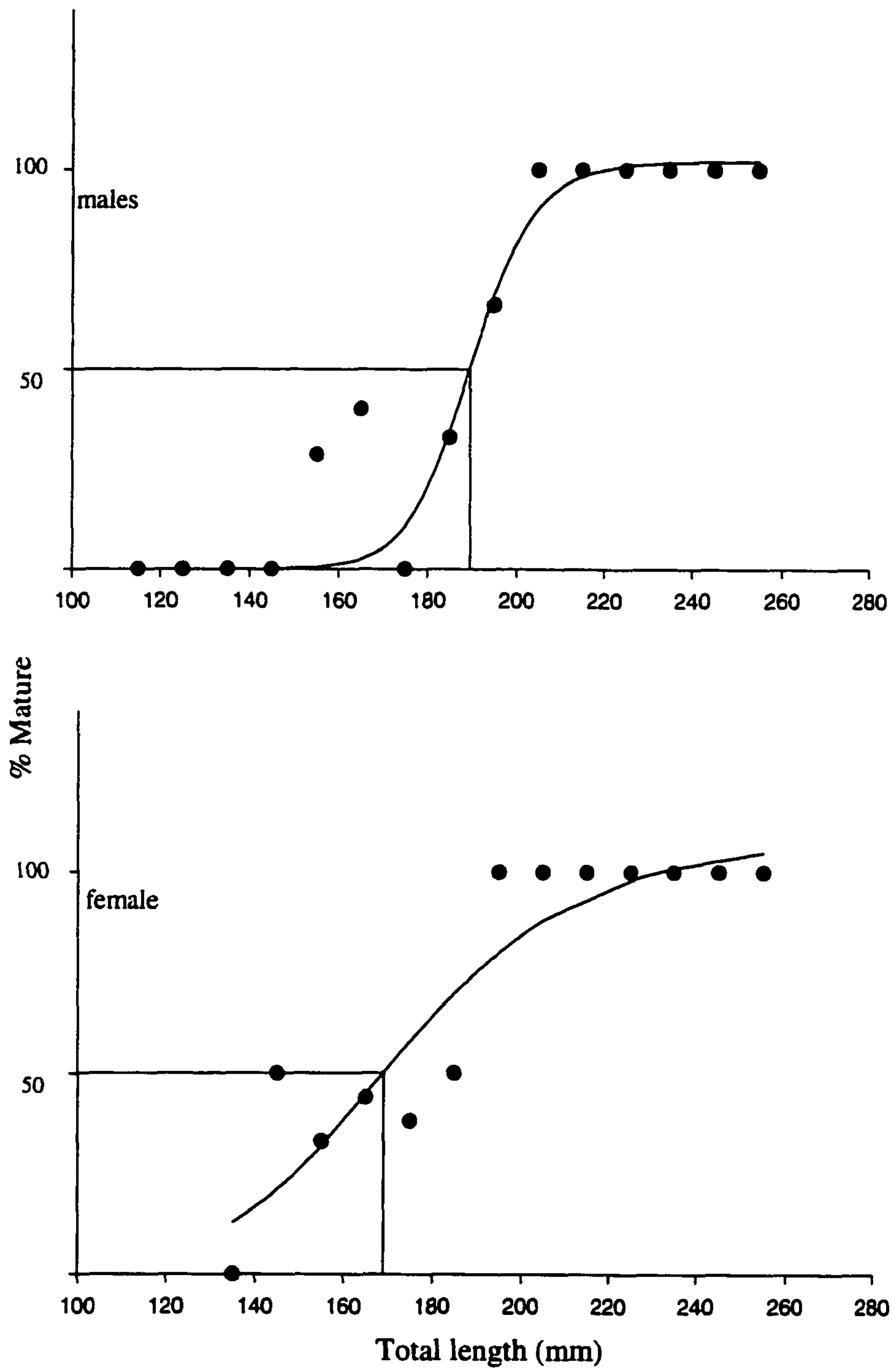


Figure 12

The percentage of male and female spot that are mature in 10 mm increments of total length. Circles represent the percentage mature and the line is a logistic regression fitted to those points.

first potential spawning event. Almost all fish, of both sexes are sexually mature, by the end of their second year. I checked our assignment of mature and immature status for females using microscopic examination of histological slides. In all cases, our microscopic determination of mature/immature assignment corroborated our macroscopic maturity designation from fish taken during the November-February spawning season. For the SPR modeling, I assumed that all fish reaching their third potential spawning season were sexually mature.

Less than 20% of the potential reproductive effort of a cohort is available for spawning; based on our best estimates of F=1.0-1.5 (Chapter III). Both SPR curves

(mean ovary weight and spawning stock biomass) were similar, yielding SPR values which were almost identical for each F. These SPR curves were robust to different levels of M (Figure 14). At levels of fishing of F>0.5, all 5 scenarios based on different M's were close enough to have yielded almost identical SPR values, despite the differences in M. Analysis of the graphs of SPR against F, for our best estimate of M (M=0.9) indicated that at values of F>0.5 the available potential spawning mass (ovaries or stock biomass) was only 40% or less than that of an virgin stock (Figure 15). At levels of F>1.0 the available potential spawning mass of a cohort was less than 20% of that of a virgin stock. The SPR values obtained from the two sex ratios (2/1 and 1/1) were virtually identical when M=0.9 (Figure 15). This result indicated that the effects of the different sex ratios acting through the resulting differences in the percentage mature for each sex had little effect on the shape of the SPR curve.

A plot of the most likely scenario of Y/R (Chapter IV) against the most likely SPR curve indicates that for the stock to have reproductive potential >20%, some losses in

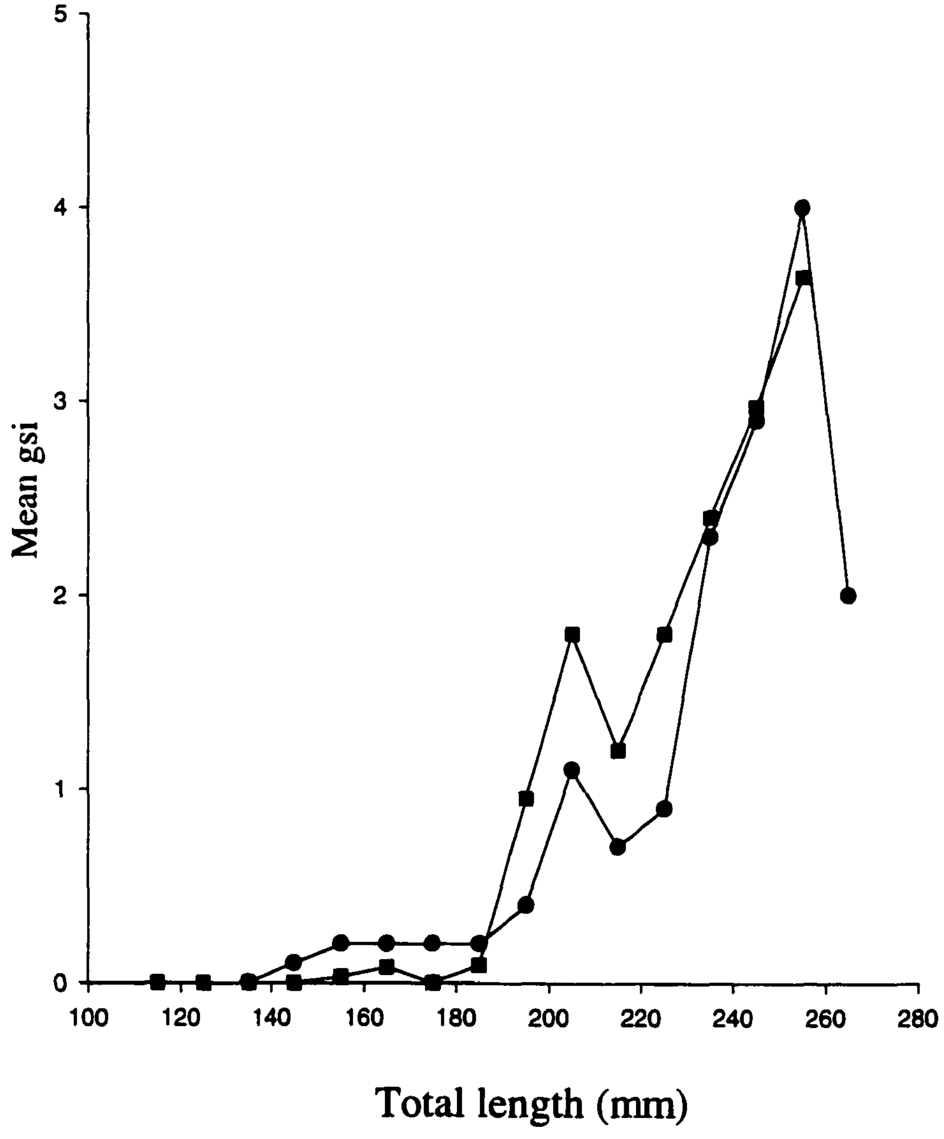


Figure 13
The average GSI of male and female spot taken from the spawning season and divided into 10 mm- increment size-classes. Male GSI is represented by squares and female GSI is represented by circles.

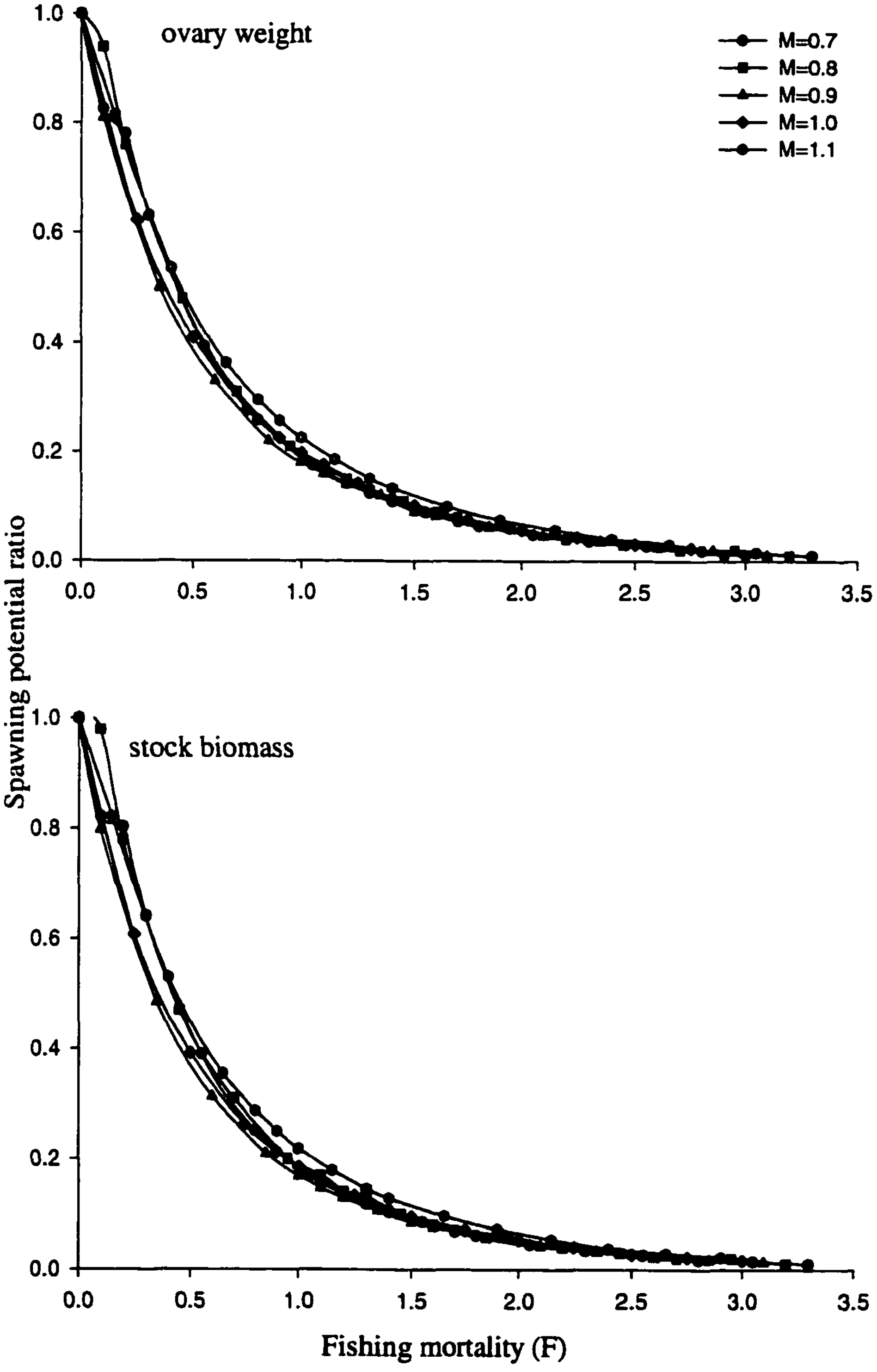


Figure 14

Plots of spawning potential ratio per recruit (SPR) against fishing mortality (F) for 5 different scenarios of natural mortality (M). Separate SPR curves based on mean ovary weight and spawning stock biomass are given.

yield-per-recruit should be expected (Figure 16). Fishing mortality must be reduced to levels F<1 to achieve SPR values equal to or above 20%. At levels of F<1, however, I began to see significant drops in the Y/R for small changes in F. To achieve SPR values of 40% would require Y/R to fall to levels 50% or below of the maximum yield.

Precautionary levels of F based on Y/R models (Chapter IV), will not protect spot from recruitment overfishing and should therefore not be used solely to manage spot in the Chesapeake Bay. The precautionary approach to yield modeling predicts only a 5% chance ($F_{5\%Y/R}$) of exceeding F at maximum yield (F_{MAX}) at a level of F=3.5. The SPR models indicated, that at levels of F>3, less than 5% of the potential spawning biomass or ovarian weight was actually available for spawning. Levels of SPR this low may lead to diminishing stock size. Since $F_{MY}>F_{5\%Y/R}>F_{20\%SPR}$, Y/R modeling should be used to determine the effects of different management strategies on potential yield, but not to protect the stock from recruitment overfishing.

Discussion

Despite the ability of the Chesapeake Bay spot stocks to resist growth overfishing (Chapter IV), due to fast growth and high natural mortality, spot seem vulnerable to recruitment overfishing at the levels of F in the Chesapeake Bay. Target F's set by Y/R modeling will not protect spot from recruitment overfishing. Common fisheries management practices generally set SPR values anywhere from 20-30% (Gabriel et al. 1990; Mace and Sissenwine 1993) to protect recruitment. I have estimated that spot are fished at levels that most likely exceed F=1.0 (Chapter III), indicating that the ratio of actual spawning biomass or ovary weight to potential spawning biomass or ovarian

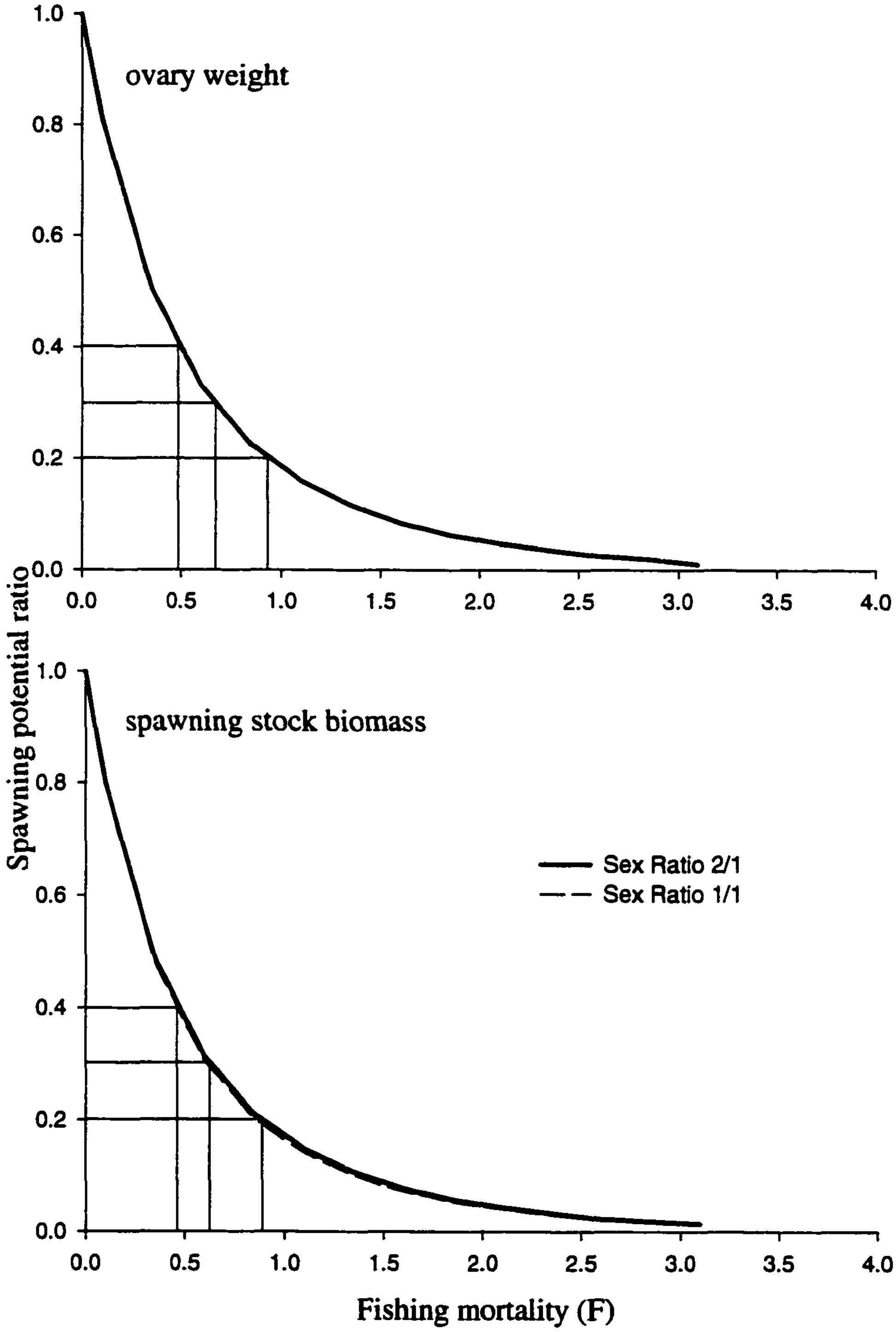


Figure 15

Plots of spawning potential ratio (SPR) per recruit based on our best estimate of natural mortality (M=0.9) plotted against fishing mortality (F). SPR curves based on mean ovary weight and spawning stock biomass are given. Two SPR curves based on spawning stock biomass with different ratios of females to males (1/1 and 2/1) are also given.

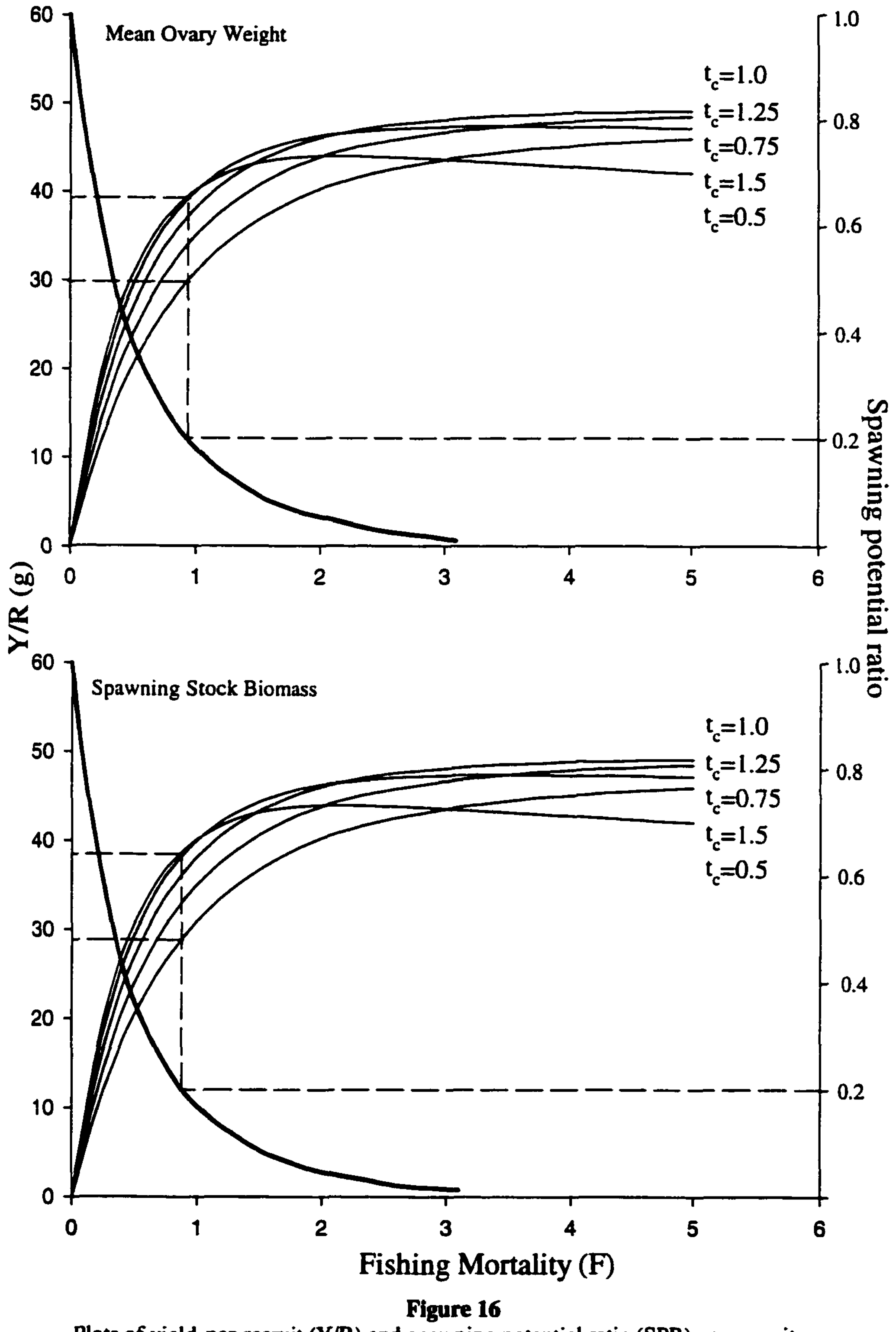


Figure 16

Plots of yield-per-recruit (Y/R) and spawning potential ratio (SPR) per recruit against fishing mortality (F). The Y/R curves were based on natural mortality of M=0.9 and the Brody Growth Coefficient of K=0.6. Two SPR curves were based on M=0.9 and determined from both mean ovary weight and spawning stock biomass.

weight is most likely less than 20%. This result may indicate that spot have been harvested at levels exceeding their replacement capacity or exceeding the reproductive contribution of Chesapeake Bay spot to a coast-wide or Mid-Atlantic stock.

It is not known what SPR values are necessary to perpetuate this stock, given that the underlying Spawner-Recruit relationship is not known. Atlantic menhaden (*Brevoortia tyrannus*), a highly fecund species with high M and spawning strategies similar to spot (Checkley Jr. et al. 1988; Powell 1994), appear to have been perpetuated at SPR<20% (Vaughn 1990). Spot typically spawn on the continental shelf, south of Cape Hatteras, North Carolina during winter. Eggs or larvae must then be transported into the estuaries along the Middle and South Atlantic coasts, which are the nursery areas for larval and juvenile spot. The relative percentage of reproductive effort necessary to perpetuate a stock with this spawning strategy may be different than for a species that spawns near or in the larval nursery area, such as weakfish (Lowerre-Barbieri 1997). Because of the relative uncertainty of the recruitment process of a shelf spawner due to the importance of environmental events, spot may require either a higher or lower SPR value than other species, despite their high fecundity. Because of this uncertainty in the necessary SPR levels, management should be conservative in the levels of F targeted until the underlying stock-recruit relationship is known.

There is always some error in the estimation of parameters used in modeling. It is possible that the percentages mature, at each potential spawning event, were higher than those of the actual stock because of the size selective gears used in the fishery. Thus smaller fish at age, which may not have been mature, were not sampled because they did not show up in the commercial catch. It may also, however, be possible that I underestimated the percent mature at age. This is possible because our samples, during the spawning season, were collected from the Chesapeake Bay or nearshore areas in North Carolina. If spot migration from bays and estuaries is due to spawning, then a higher percentage of fish, remaining in the near-shore areas during or just before the spawning season, may have been sexually immature compared to the total stock. Thus, our samples may have been taken from a subset of the population with a smaller percentage mature at age or length. I should also note that the estimates of the K and L_∞ from the von Bertalanffy growth curve, which were used in converting length into weight, may have been influenced by the heavy fishing pressure. These estimates may not represent length at age for a less heavily fished or virgin stock, and the actual value of K may have been an overestimate, and L_∞ an underestimate (Zhao et al. 1997). I did not have age-specific estimates of mortality, which could better estimate the fraction of a cohort left for each potential spawning event. Spot are a fast-growing and short-lived species (<3yrs) in the Chesapeake Bay, and are taken in the commercial fishery in their first year. It may, therefore, not be that unreasonable to assume constant F across the lifetime of the cohort. I also did not have age-specific fecundity estimates, so mean ovarian weight of the most advanced-staged ovaries, was used instead. While ovarian weight does not necessarily make a good estimate of fecundity, fecundity estimates do not themselves take into account egg size and relative egg viability. Thus, ovary weight may provide a more robust estimator of reproductive investment that includes both numbers and weights of eggs than fish fecundity alone, especially batch fecundity estimates.

We recommend that F on spot be reduced to levels where approximately 20% of the potential reproductive effort of a cohort is available for reproduction. Although spot taken in the Chesapeake Bay are probably part of a larger reproductive population that includes fish from North Carolina, prudent harvest levels would not remove a greater proportion of fish from any single area than are necessary to replenish the stock. Reductions in F, however, should not be so severe as to produce an unnecessary decrease in the Y/R, such as those necessary to produce SPR levels of 40%; a biological target recommended when the underlying Spawner-Recruit relationship is not known (Mace 1994). Potential losses in Y/R from reductions in F<1, however, may be offset by increases in the numbers of recruits associated with increases in SPR levels. Protection of small spot (<190mm) which have not yet reached a size necessary for the majority of fish to mature, may also be beneficial. Both the directed catch of small spot, which are potentially discarded, and the non-directed by-catch of spot needs to be investigated. Little is known, at this time, about the by-catch of spot along the Atlantic Coast and its effects on potential recruitment. Additional research on the non-directed or incidental catch of spot may provide insights into ways to protect this stock without directly reducing yield.

Fishing mortality on spot may have declined since 1996 due to efforts to reduce fishing mortality on weakfish, which have been shown to be growth overfished (Lowerre-Barbieri 1994) in the Chesapeake Bay Region. Spot are part of a multi-species fishery which takes croaker and weakfish in addition to spot. Because of the overfished status of weakfish, attempts have been made to reduce their fishing mortality by 33%. This effort may have reduced the fishing mortality on spot as well. If the recent reduction in F on weakfish has carried over to spot, it should be easily seen in percentage of 2 and 3 year old fish that will be found in the commercial catch, compared to what I reported previously (Chapter III). If it can be shown that fishing levels on spot have been reduced along with those on weakfish, then management measures to reduce F on spot to achieve SPR levels of 20% may not be necessary. A common SPR target level should be adopted for all areas of the Atlantic Coast that contribute to the spawning population so that no single area harvests at levels that must be subsidized by excess spawning stock from other areas.

CHAPTER VI

SUMMARY

1. Transverse sections of the sagittal otolith were determined to be the most appropriate structure, in a comparison with pectoral finray and dorsal spine sections and scales, for ageing spot taken from the Chesapeake Bay. Age assignment using otoliths had higher precision and less bias than those using the other three structures. Through the use of marginal increment analysis, I determined that one annulus is formed in an otolith each year during May-June, which indicates that annuli counts are a good measure of fish age. The timing of annulus formations is the same across all age-classes and cohorts I sampled, which indicates that annuli are a good estimator of age for all cohorts and age-classes that were sampled. A comparison of age assignment of scales versus otoliths indicated that fish age 3 or older may be under-aged using scales instead of otoliths.

2. The commercial catch of spot from the Chesapeake Bay is dominated by fish between 1 and 2 years of age. Approximately 90% of the catch comes from this age class, thus the yield from the commercial catch is driven each year by only one age-class. Spot growth was rapid, with the majority of total length obtained within the first year. Parameter estimates from the von Bertalanffy growth curve were: $K=0.6\ y^{-1}$, $L_{\infty}=272.7$ mm, and $t_0=-1.1$ yr. Instantaneous total mortality (Z) of spot in the Chesapeake Bay was estimated at Z=1.56-2.75. Instantaneous Natural Mortality (M) was estimated to be M=0.86-0.92. Instantaneous fishing mortality (F) was estimated to be F = 0.7-1.89. I estimated the mean age at first capture (t_c) to be t_c=1-1.5 yr. I did not find significant

differences in the growth patterns or fisheries parameters I estimated between males and females to warrant developing separate management strategies for each sex in the Chesapeake Bay.

3. The rapid growth rate and high natural mortality of spot makes this species very resistant to growth overfishing. The age of maximum biomass of a cohort occurs before 1 year of age, and only when fishing typically occurs on fish much younger than 1 year can growth overfishing occur. I estimated the coefficient of variation in F to be 1.1. Given that level of uncertainty, I estimated that the probability of our current estimates of $F > F_{MAX}$ to be less than 5%. Because of the early age of maximum biomass, however, growth-overfishing thresholds do not make conservative estimates of recruitment-overfishing thresholds. Setting target F's based on yield-per-recruit models may make this stock susceptible to recruitment overfishing, even if precautionary methods are used.

4. Although spot are relatively impervious to growth overfishing, there is evidence that the Chesapeake Bay stock was fished at levels that may have exceeded its replacement capability. I estimate that 50% of all spot are sexually mature at around 190 mm in total length. All the major gears used to capture spot are capable of taking fish under 170 mm. The percentage of mature fish for the first potential spawning season was 49% of males and 68% of females. Analysis of spawning potential ratios indicated that at current levels of fishing, less than 20% of the potential spawning biomass is actually available for spawning.

5. Our management recommendations are to lower the fishing mortality to a level that will allow at 20% of the potential spawning stock biomass to be available for spawning. This will entail lowering F to levels at or below F=1. Because of recent

attempts to lower F on weakfish (*Cynoscion regalis*), the lowering of F on spot may already have occurred. The lowering of F will lead to a reduction in yield-per-recruit, but the drop in total yield of the catch, potentially, should be offset by increases in the number of recruits generated. Because of the spawning behavior of spot, this strategy should be employed coast-wide and not just in the Chesapeake Bay. I also recommend that fisheries-independent sampling be done when feasible. All parameters estimated in this study were based on fisheries-dependent sampling. The commercial catch may not be a random sample of the population and any parameters estimated from samples of the commercial catch may therefore be biased. I especially recommend that estimates of the sex ratio and percentages mature at age be checked with fisheries-independent sampling.

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