12-19-1997

Quantitative assessment of fishing mortality for tautog (Tautoga onitis) in Virginia : preliminary report

Geoffrey G. White
Virginia Institute of Marine Science

James E. Kirkley
Virginia Institute of Marine Science

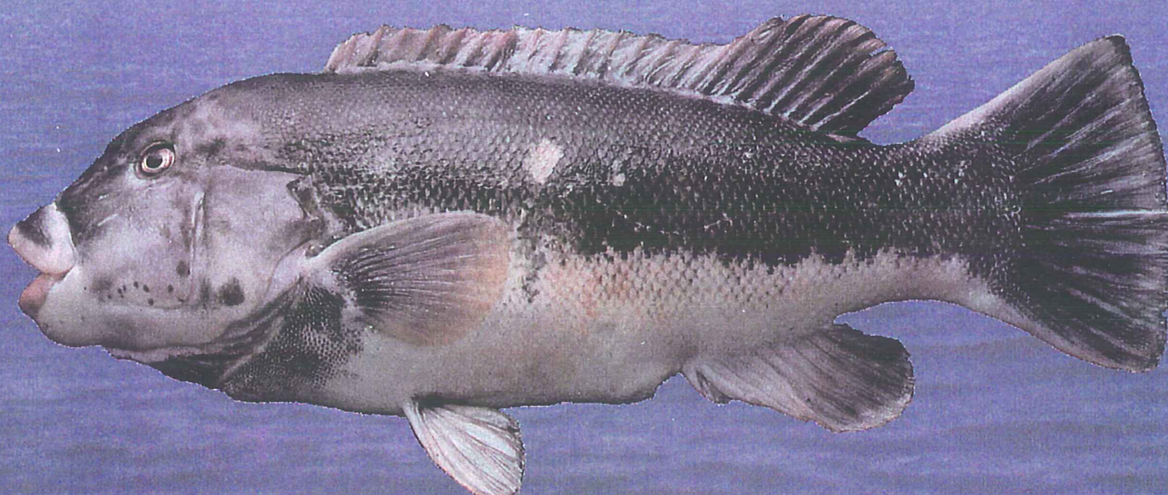
Jon A. Lucy
Virginia Institute of Marine Science

PRELIMINARY REPORT

QUANTITATIVE ASSESSMENT OF FISHING MORTALITY FOR TAUTOG (*Tautoga onitis*) IN VIRGINIA

by

Geoffrey G. White
James E. Kirkley
Jon A. Lucy



Department of Fisheries Science
Department of Marine Advisory Services
Virginia Institute of Marine Science
College of William and Mary
Gloucester Point, VA 23062

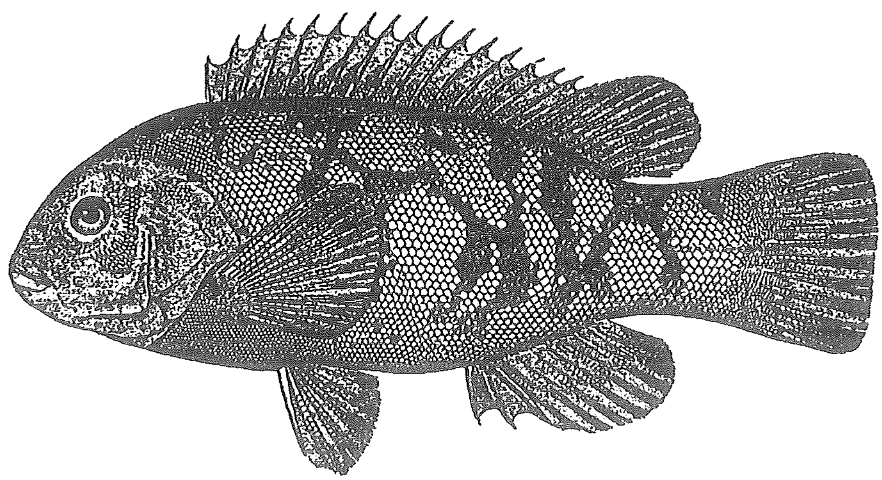
December 19, 1997

PRELIMINARY REPORT

QUANTITATIVE ASSESSMENT OF FISHING MORTALITY FOR TAUTOG (*Tautoga onitis*) IN VIRGINIA

by

Geoffrey G. White
James E. Kirkley
Jon A. Lucy



Funded by Contract No. RF-96-11 from the
Virginia Marine Recreational Advisory Board,
Virginia Marine Resources Commission

Acknowledgments

We would like to thank all of the fishermen who volunteered their time, data, and fish carcasses to the project. A special thanks is extended to Joe Clark and Chester Stultz, who not only helped with data collection, but shared many insights into the tautog fishery, their help and perspective is appreciated. Four local fishing clubs were also helpful in providing a forum to announce and explain the project, collect data, and distribute results. Those four clubs are the Peninsula Saltwater Sport Fisherman's Association, the Portsmouth Angler's Club, the Tidewater Angler's Club, and the Virginia Beach Angler's Club.

Data was provided by Tom Munroe (Hostetter and Munroe, 1993) and Geoff White (White et al. 1996) for development of age-length keys. Tag release and recapture data was provided by the American Littoral Society and the Virginia Game Fish Tagging Program. Tautog citation data was provided by the Virginia Saltwater FishingTournament.

We also appreciate the help of the VIMS trawl survey for saving tautog for us and providing lab space for fish work-up. Mike Arendt spent many hours processing opercle bones for which we are grateful. Thank you also to Diana Taylor, Susan Stein, and the VIMS Publications Department for their help with cover design and layout. Many thanks to Najih Lazar of ASMFC for his cooperation, help, insight into data analysis, and review of a preliminary form of this report.

This project is funded by contract No. RF-96-11 from the Virginia Marine Recreational Fishing Advisory Board, Virginia Marine Resources Commission.

Table of Contents

Acknowledgments i

Table of Contents ii

List of Tables iii

List of Figures iv

1.0 History and Relevance 1

2.0 Data Collection 4

3.0 Analysis of Length Frequency by season and area 5

4.0 Development of Proportional age-length keys 7

5.0 Mortality Estimates 9

5.1 Natural Mortality 9

5.2 Fishing Mortality (catch curve) 9

Catch curve estimates (25% release mortality) 9

Catch curve estimates (10% release mortality) 9

Other methods used to estimate of F 14

6.0 Management considerations 14

7.0 Tables 16

8.0 Figures 28

9.0 Literature cited 49

10.0 Appendices . . . .

A. Sensitivity of F estimates to changes in catch at age matrix 51

B. Letter from Jon Lucy regarding release mortality 52

C. Letter from Najih Lazar regarding this project 53

D. Management limits tables 14+15 from tautog FMP 54

List of Tables

Table Number	Title	Page
2.1	Fishing locations sampled 1 April 1996 to 30 June 1997 by area	17
2.2	Summary of tautog sampling results by season, all areas combined	18
2.3	Sampling protocol and actual collection results by season and area	19
4.1	Proportional Age-Length key for Virginia tautog collected 1979-1985	20
4.2	Proportional Age-Length key for Virginia tautog collected 1994-1995	21
4.3	Proportional Age-Length key for Virginia tautog collected 1996	22
4.4	Proportional Age-Length key for Virginia tautog collected 1994-1996	23
5.1	Estimate of natural mortality for tautog in Virginia using Pauly (1980) method	24
5.2.1	Catch at age matrix for unweighted MRFSS, 25% release mortality	25
5.2.2	Catch at age matrix for unweighted MRFSS, 10% release mortality	26
5.2.3	Tautog tag-recapture data, 1995-1997	27

List of Figures

Figure Number	Title	Page
	I	
I.1	Historical recreational landings by ASMFC management zones	29
I.2	Historical commercial landings by ASMFC management zones	30
I.3	Frequency of tautog citations (≥9 lbs) 1975-1996	31
I.4	Recreational and commercial landings of tautog in Virginia	32
	III	
III.1	Length frequency of tautog sampled from Virginia's recreational fishermen in 1996. This study and MRFSS data	33
III.2	Length frequency of tautog sampled from 1 April 1996 to 30 June 1997	34
III.3	Length frequency for the fall 1996 season	35
III.4	Length frequency for the winter 1996-1997 season	36
III.5	Length frequency for the spring 1997 season	37
	IV	
IV.1	Virginia tautog mean length, standard deviation, and size range at age for specimens collected 1979-1985	38
IV.2	Virginia tautog mean length, standard deviation, and size range at age for specimens collected 1994-1995	39
IV.3	Virginia tautog mean length, standard deviation, and size range at age for specimens collected 1996	40
IV.4	Virginia tautog mean length, standard deviation, and size range at age for specimens collected 1994-1996	41

List of Figures (cont.)

Figure Number	Title	Page
	V	
V.1	Summary of Catch Curve Results: unweighted MRFSS, 25% release mortality	42
V.2	Summary of Catch Curve Results: weighted MRFSS, 25% release mortality	43
V.3	Summary of Catch Curve Results: MRFSS + Other data, 25% release mortality	44
V.4	Summary of Catch Curve Results: unweighted MRFSS, 10% release mortality	45
V.5	Summary of Catch Curve Results: weighted MRFSS, 10% release mortality	46
V.6	Summary of Catch Curve Results: MRFSS + Other data, 10% release mortality	47
V.7	Comparison of all Catch Curve Results	48

Quantitative Assessment of Fishing Mortality
for tautog, *Tautoga onitis*, in Virginia

1.0 History and Relevance

Tautog (*Tautoga onitis*) have become a popular food and sport fish from Massachusetts to Virginia over the past ten years. Tautog are a long lived (30 years), late maturing (3-4 years), slow growing species. Although the maximum age recorded in Virginia is 31 years, recent studies have found that over 95% of the population is less than 12 years old (Hostetter and Munroe, 1993; White et al., 1996). Adult tautog inhabit hard bottom wreck and reef environments, which are limited in Virginia's waters and are easily located and re-located by fishermen. Tautog are known to migrate inshore-offshore in New England waters, with minimal movement of adults in the north-south direction (Cooper, 1966; Lynch, 1991). However, tautog movements are less well documented in Virginia waters (Bain and Lucy, 1996, 1997, unpublished 1997 data). The combination of slow growth, late maturity, limited habitat, and increased popularity among fishermen makes tautog stocks vulnerable to overfishing.

In April 1996 the Atlantic States Marine Fisheries Commission (ASMFC) passed a fisheries management plan (FMP) for tautog governing tautog fishing regulations from Massachusetts to North Carolina. Within the coastwide management area, the tautog resource was split into two management zones by ASMFC; a northern zone (MA, RI, CT, NY, NJ) and a southern zone (DE, MD, VA, NC). The primary goal of the FMP is to reduce the fishing mortality rate (F) to a target rate of F=0.24 as of April 1998, and F=0.15 as of April 2000 by implementing minimum size and daily catch per person (bag limit) regulations. The FMP requires all states to enforce a minimum size limit of 13 inches as of April 1997, and 14 inches as of April 1998.

Bag limits for recreational and commercial fishermen are often set by measuring the difference between the current fishing mortality rate (F) and the target level of F, and enacting appropriate limits to reach that target. At the time of the FMP development, the only available estimate of F was developed from data in the northern management zone where fishing mortality is estimated at F=0.58. There was no estimate of fishing mortality in the tautog's southern range (DE, MD, VA, NC). Therefore states were given until April 1998 to assess local fishing mortality rates or utilize the coastwide estimate of F=0.58 (ASMFC tautog FMP Addendum 1, 1997). At that time states must implement appropriate management to reach the target fishing mortality of F=0.24.

Since adult tautog do not exhibit significant north-south coastal migrations (Cooper, 1966; Olla et al., 1974; Briggs, 1977), regional stocks are not subjected to fishing pressure by user groups in multiple states. This makes tautog an extraordinary fish for smaller scale management regimes. Therefore, regulations in Virginia will have a clear impact on Virginia's local tautog resource. Based on differences in habitat availability, duration and scope of historical fisheries, fishing gear, and basic comparisons of size and age of landed fish, the fishing mortality rate in Virginia is most likely less than the coastwide estimate of F=0.58 based on data from northern states. A potential consequence of imposing blanket, coastwide regulations in Virginia is that overly restrictive catch limits would be imposed upon the Virginia fishery.

Although growth and reproduction patterns may not be significantly different between northern and southern regions (Hostetter and Munroe 1993, White et al. 1996), tautog resources in northern and southern management zones have been subjected to different fishing pressure, and therefore may have different stock characteristics. Data from the Marine Recreational Fisheries Statistics Survey (MRFSS) indicate that recreational fishermen in the northern management zone landed between 2.5 and 12.6 times the number of fish landed in the southern management zone between 1981 and 1992 (Figure I.1). After 1993, recreational landings in the northern zone have decreased dramatically concurrent with stringent management regulations while landings south of Delaware Bay remained relatively stable with no change in management regulations. For example, Rhode Island enacted a 16 inch minimum size limit in 1994 while Virginia had no minimum size at that time. Differences in commercial landings between northern and southern management zones are more extreme than the recreational landings. Commercial landings increased in the northern zone from 1981 (329,000 lbs) to 1987 (1,150,100 lbs), and have fallen since 1991 concurrent with more stringent regulations (Figure I.2). At the same time, commercial landings in the southern zone were less than 3.5 percent of northern landings between 1982 and 1993. Southern zone commercial landings have increased somewhat since mandatory reporting was enacted by VMRC in 1993, reaching maximum landings of 35,965 lbs in 1995. Meanwhile, tight quotas in the northern zone have reduced commercial landings to roughly 200,000 lbs in 1996. Figures I.1 and I.2 illustrate that while northern states increased the exploitation of tautog in the mid 1980's and experienced reduced landings since 1990, the southern states have maintained a lower and more steady exploitation. Thus it is reasonable to expect that the fishing mortality rate estimated in northern states would be higher than in the southern zone. Further evidence that a healthy size/age structure exists in the southern zone tautog population is indicated by the landing of the world record tautog (24 lbs) caught offshore of Virginia's coastline in 1987, a 32 year old fish (19 lbs) landed in February 1995, a 30 year old (18 lbs) landed in February 1996, and over 100 tautog ≥9 lbs landed annually since 1981 (Figure I.3). Data on tautog ≥9 lbs was collected by the Virginia Salt Water Fishing Tournament, which awards a citation to recreational anglers landing tautog ≥9 lbs. This data does not include tautog ≥9 lbs landed by recreational spear fishing or commercial hook and line fishing.

Another objective of the ASMFC tautog FMP is to maintain the historical allocation between recreational and commercial fisheries of 90:10 percent (ASMFC 1996). In Virginia, comparison between recreational landings (MRFSS) and commercial landings (NMFS) indicate the fishery is over 95% recreational for the years 1981 through 1996 (Figure I.4). Reported commercial landings have increased since the Virginia Marine Resources Commission (VMRC) began mandatory commercial reporting in 1993. Although the entire increase cannot be attributed to the change in reporting, it may account for a portion of the increase. Since the validity of both recreational and commercial landings data are commonly questioned, we calculated an extreme example to compare recreational and commercial catch proportions. In 1996, if Virginia recreational landings were in half, and commercial landings were doubled, the fishery would still be 87% recreational. Thus even as reported commercial landings have increased, the historical catch ratio between Virginia's recreational and commercial fisheries has remained within ASMFC guidelines.

In response to a request by the VMRC, we have developed a limited resource assessment to help Virginia comply with ASMFC management goals in 1998. The objectives of this research are to: (1) assess length frequency distribution by spatial and temporal groupings with special reference to inshore vs. offshore and major fishing periods (e.g., fall, winter, spring); (2) obtain information necessary to develop proportional age-length keys for tautog landed in Virginia; (3) assess fishing mortality based on catch-curve analysis; and (4) explore other methods of estimating fishing mortality with limited data.

2.0 Data Collection

The tautog fishery in Virginia occurs over many months (September through June), and areas (mouth of Rappahannock River to 40 miles offshore), and is complicated by differential size and age fish per season and area. To adequately estimate mortality of tautog based on fishery dependent data, samples must be taken from each season and area. The tautog fishery in Virginia has three periods of fishing effort defined as follows: (1) fall (1 September - 30 November), (2) winter (1 December - 31 March), and (3) spring (1 April - 30 June). The three primary fishing areas are defined as: 1.) Chesapeake Bay from Gwynn's Island to the Chesapeake Bay Bridge Tunnel (CBBT), 2.) CBBT to three miles offshore (state line), and 3.) three to fifteen miles offshore. Areas have been selected to illustrate the importance of state versus federal waters, with a special emphasis on the CBBT due to its importance to this study regarding fishing pressure, and providing habitat. For this report, inshore is defined as state territorial waters (areas 1+2) and offshore is defined as the United States exclusive economic zone (EEZ, 3-200 miles offshore). In general, the fall and spring seasons are characterized by high landings of small to medium size fish from inshore areas, while the winter season is characterized by landings of larger fish from offshore areas.

Tautog were sampled between 1 April 1996 and 31 December 1997. The results included in this report focus on collections between 1 April 1996 and 30 June 1997. Tautog length data and age samples were obtained from 23 recreational and 11 commercial fishermen using hook and line gear at 22 locations (Table 1.1). Length and sex data were recorded for 2,719 landed and 556 released tautog. Opercle bones were removed from 906 tautog for age determination. Data collected within each fishing season is summarized in Table 1.2 by number of trips, number of fish landed, number of fish released, sex ratio and age samples. Table 1.3 depicts our sampling protocol and a record of actual collections. During the fall 1996 season, we met and exceeded collection goals inshore. However, we could not attain our sample goal of 175 fish from offshore areas, as offshore water temperature did not decline until December. This caused the fishing effort to remain focused inshore significantly longer than during 1993-1995, the years upon which our protocol was based. We were able to exceed all collection goals during the winter 1996-1997 fishery. In the spring 1997 fishery, we did not meet collection goals within the Chesapeake Bay for opercle or length data and exceeded collection goals around the Chesapeake Bay Bridge Tunnel. We met our goal of age samples, but not length samples, from offshore areas in the spring 1997 fishery. We attribute the lower sample size in the spring season to two factors, lower fishing pressure during the spawning season and decreased participation in this study from anglers.

3.0 Analysis of length frequency by season and area

The tautog FMP indicates that data is lacking for recreational and commercial length frequencies in Virginia. Prior to 1994, the only annual analysis of length frequency was the MRFSS survey, which underestimates the Virginia fishery by not sampling in January and February, since tautog are landed in Virginia during that time. In addition to continued MRFSS sampling, recreational and commercial length frequency data for 1994 and 1995 were collected by White et al. (1996) and for this project for 1996. The length data collected from recreational fishermen in 1996 supports and extends the data collected by MRFSS. The 381 tautog sampled display a more normal size distribution than the 127 fish measured by MRFSS sampling (Figure III.1). A broad look at our sampling reveals three important aspects of the tautog fishery in Virginia: 1) the overall size range and length frequency of landed and released tautog in the Virginia fishery; 2) variation in fishing effort between areas as the seasons progress; and 3) the effect of enforcing size limits on landings.

Between 1 April 1996 and 30 June 1997 we collected length data for 2,719 landed and 556 released tautog from both recreational and commercial fisheries (Figure III.2). Tautog were landed from 9 to 28 inches (229-735 mm), with maximum landings in the 14 inch (355-381 mm) length class, while tautog between 5 and 23 inches (127-584 mm) were released, with the majority of releases under 14 inches (355-381 mm). The existence of 1996 landings in the 20-28 inch classes (508-735 mm) indicates a relatively healthy size structure (Figure III.2). However, citation data suggests that either fishing pressure or abundance of large tautog has declined, evidenced by lower number of citations (fish > 9 lbs) awarded from 1987 to 1991, and again since 1995 (Figure I.3).

An interesting facet of the Virginia tautog fishery is that there is a viable fishing season throughout the winter if bottom water temperatures in the lower Chesapeake Bay and/or offshore areas do not decline below 48-50°F (9-10°C). Length frequencies were analyzed by season (fall, winter, spring) and area (inshore, offshore). Our results support fishermen's reports that fall and spring seasons consist of smaller (12-18 inches, 305-482 mm) tautog from inshore areas while the winter fishery lands larger (13-26 inches, 330-685 mm) fish from inshore and offshore areas. Landings during the fall 1996 season were concentrated between the 12 and 17 inch size classes (305-457 mm), with only 4% of the samples from offshore waters (Figure III.3). Although the fishery was focused inshore due to warmer water temperatures and fish availability, the few fish landed from offshore areas were larger in size (15-25 inches, 381-660 mm) but were caught late in the season as the water temperature decreased.

Avid tautog fishermen know that tautog activity, and therefore catchability, varies with water temperature. Olla et al. (1974) found that tautog enter a winter torpor, or hibernation state, when water temperatures decline to 40-51 °F (2.0-4.8 °C). In many years, water temperatures at the mouth of the Chesapeake Bay and/or offshore waters of Virginia remain above 41 °F (5 °C), and tautog maintain activity throughout the winter. Tautog landings in the winter 1996-1997 fishery ranged from 13 to 26 inches (330-685 mm) (Figure III.4). The higher proportion of landings from offshore areas during the winter fishery (33%) represents the availability of tautog to Virginia anglers throughout the year. A more detailed look at the data reveals that most of the inshore samples were from December and March, while most of the offshore samples were landed in January and February. This pattern in landings is indicative of offshore bottom water temperatures warm enough to maintain tautog activity throughout the winter.

The spring 1997 fishery also landed mostly small fish (12 to 18 inches, 305-482 mm) from inshore areas, with only 17% landed in offshore waters (Figure III.5). Again, as the season progressed, water temperatures increased and the fishery became more focused on inshore areas. The shift to the inshore fishery is probably a function of access to fishing locations by small boats, and for many, the first fishing opportunity of the year. VMRC enacted a 13 inch minimum size on May 1, 1997, thus allowing a comparison between the fall 1996 unregulated season and the spring 1997 season with the 13 inch minimum size. During a period of no limits (fall 1996) that the mode of landed fish was 14 inches. However, after the 13 inch size limit was enforced, the mode decreased to 13 inch fish. Thus it appears that fishermen, or at least those volunteering data, were self regulating at 13-14 inches already and landed more fish near the limit once a limit was set. However, the minimum size did cause a decrease in the number of landed fish under the 13 inch size limit, and the increase of the minimum size to 14 inches in April 1998 should shift the mode of landed fish above 14 inches again.

4.0 Development of Proportional Age-length Keys

Proportional age-length keys (ALK) are the critical link between collection of length data from a fishery and conversion to an age-frequency for input into fish stock assessments. Fortunately, there have been two prior studies of tautog in Virginia, and both Hostetter and Munroe (1993) and White et al. (1996) aged all specimens by opercle bones. Raw age data from both Tom Munroe and Geoff White were converted to the ASMFC accepted birthdate convention of 1 January (Tautog Aging Workshop, 1995). Therefore we were able to develop two age-length keys with tautog data previously collected in Virginia waters. The first ALK was developed for the years 1979-1985 with data from Hostetter and Munroe (1993, Table 3.1), and the second was developed for the years 1994-1995 with data from White et al. (1996, Table 3.2). The two ALKs were used to convert historical length frequencies from the MRFSS database to age frequencies to develop catch at age matrices (see section 5.0).

During this study we collected and aged 502 tautog opercle bones in 1996 to develop a third age-length key (Table 3.3). Our collections more closely resemble the length frequency proportions of landed fish than equal samples per length class, as it is difficult to obtain samples at the tails of the size distribution. Although age-length keys are ideally taken from a single year and applied only to that year, the slow growth and overlapping lengths at age of tautog result in the need to combine years with the goal of reducing the overall variance of mean length at age. Figure III.1 graphs the mean, range, and standard deviation of length at age for tautog collected from 1979 to 1985 (Hostetter and Munroe, 1993). Note that the standard deviations become larger for fish greater than age 12, as 95% of their samples were age 12 or less. Figure III.2 graphs the same information for White et al. (1996) and shows similar growth patterns. However, the lower sample size for 1996 (n=502) resulted in increasing standard deviations with age, and single points for ages 12, 15, 16, and 30 years (Figure III.3). Therefore we combined the White et al. (1996) age length key with the 1996 age length key to increase the sample size and thereby reduce variance, providing a more precise conversion from length to age (Table 3.4). Mean length, range, and standard deviations for the combined key in Figure III.4 also show a closer fit to the general Von Bertalannfy growth curve.

Thus it appears that two age-length keys can be appropriately used on tautog length frequency data from 1981 to 1996. Hostetter and Munroe data can be more accurately applied to length frequency data from 1981 to 1990, while the White et al (1996) key combined with this project's 1996 key can be applied to length frequency data from 1991 to 1996. However, it should be noted that both of these keys have a minimum number of fish sampled at ages 15 and 16. This feature of the keys is most likely a random occurrence due to the high overlap of lengths at that age, and low sample sizes in those length intervals. The low point at ages 15 or 16 will result in an artificially low value for landings in the catch at age matrix at that point. Therefore catch curve regressions were performed on data to age 18. An analysis of the sensitivity of mortality estimates to changes in the catch at age matrix (Appendix A) shows that fishing mortality estimates are robust to changes in the catch at age matrix, thus the low point at ages 15-16 may be insignificant when performing catch curve regressions including data to age 18.

5.0 Mortality Estimates

Natural Mortality

The ASMFC tautog FMP assumes natural mortality (M) to be M=0.15. We tested this assumption using the methods of Pauly (1980) and Hoenig (1983) and found M=0.15 to be an appropriate level. The Pauly (1980) method resulted in an average natural mortality of M=0.113 for the years 1985-1996 (Table 4.1). Similarly, when Hoenig's equation for fish, cetaceans, and molluscs was applied to the maximum age fish in Virginia, 32 years, we estimated total mortality (Z) such that Z=M=0.145. Thus these two 'ballpark' estimates of M resulted in values that support the ASMFC assumed level of M=0.15. It is interesting to note that when we used age 12 as a maximum age in Hoenig's equation, based on the fact that 95% of our samples were age 12 or less, the total mortality was estimated at Z=0.368, corresponding to a first approximation of fishing mortality (F) in this area of F=0.218 (Z-M=F).

Fishing Mortality

The primary goal of the tautog FMP is to reduce fishing mortality to F=0.24 in 1998, with further reduction to F=0.15 in the year 2000. To effectively manage toward that goal, VMRC must first know the current fishing mortality rate. Without access to long time series of data necessary for a virtual population analysis (VPA), we have proceeded with estimation of fishing mortality with catch curve methodology on several sources and combinations of data.

Catch Curve estimates (25% release mortality)

The first step to estimating fishing mortality via a catch curve is the development of an annual catch at age matrix. We obtained the raw unweighted length frequencies from 1985 to 1996 for tautog from the MRFSS intercept survey conducted in Virginia. Thus, the unweighted data is the intercept data not weighted by the MRFSS telephone survey. The unweighted length frequency was applied to the total recreational landings (Type A catch = fish landed and kept) in Virginia for those years, resulting in an estimate of the number of fish landed within each length interval. The MRFSS B2 fish (estimate of the number of tautog released alive) was distributed by the length frequency of released fish from the American Littoral Society, and a 25% hook release mortality rate was applied in accordance with the tautog FMP. The Type A landings were added to the B2 mortalities to give us total landings by length interval for each year. Length frequencies were then passed through age-length keys by date. The Hostetter and Munroe (1993) key was used for 1985-1990, and the White et al. (1996) key was used for 1991-1996. The catch at age matrix (Table 5.1) became the starting point for a typical horizontal catch curve analysis (Ricker, 1975; Vetter, 1988) which uses a linear regression to estimate total mortality (Z). For each year, data between the shaded blocks were used in the regression analysis to estimate Z. Natural mortality (M=0.15) was subtracted from Z to get fishing mortality (F).

The unweighted MRFSS data set provides the longest time series to analyze the tautog fishery in Virginia on a historical basis (Figure V.1). Fishing mortality varies between F=0.116 and F=0.430, with a 12 year average of F=0.244. Two years stand out as peaks in the estimates of F, 1989 (F=0.430) and 1994 (F=0.388). The horizontal catch curve for a single year (ex. 1996) yields an estimate of Z which is an average mortality rate over all age classes included in the analysis. In this case, the 1996 catch curve regression includes 14 age classes of tautog. Thus a single year estimate of mortality actually impacts the tautog resource for many years. Therefore we averaged the past three estimates to incorporate recent trends and impacts to the fishery. The average estimate of F for 1994 to 1996 with the unweighted MRFSS data is F=0.335.

To determine if the MRFSS length frequency data weighted by its telephone survey caused a different estimate of F, we calculated the catch at age matrix for the years 1991-1996 from the weighted MRFSS data. The weighted and unweighted data sets resulted in identical estimates of F for 1991, 1995, and 1996, but much higher estimates of F from the weighted data for 1992-1994 (Figure V.2). The three year average estimate of F from 1994 to 1996 was F=0.391. Thus the weighted data gives a slightly higher estimate of F than the unweighted data (F=0.335). However, the six year trend was similar to that in the unweighted data, and the unweighted data not only has a longer time series, but recreational length frequency observations can be added to it to increase sample size, and thus more accurately reflect the length frequency of the landings.

Recent efforts to collect data on the tautog fishery in Virginia have resulted in better characterization of the length frequency of landed fish, as well as the length frequency of released fish. Samples of recreational landings in 1994 and 1995 by White et al. (1996) and in 1996 by this project were added to the MRFSS length frequency of Type A catch. This increased the sample size of length data from n=204 to n=285 in 1994, from n=246 to n=386 in 1995, and from n=127 to n=508 in 1996. Tautog tag release data from the Virginia Game Fish Tagging Program for 1995 and 1996 (Bain and Lucy, 1996, 1997) was also used to supplement the American Littoral Society tagging data for the length frequency of released fish, increasing the sample sizes from n=57 to n=258 in 1995, and from n=54 to n=442 in 1996. Finally, the combined age-length key for 1994-1996 (Table 3.4) was used to calculate the catch at age matrix.

Figure V.3 displays the catch curve results for what we consider the best available data for the years 1994 to 1996. Using the 25% hook release mortality specified in the tautog FMP, the three year average is F=0.309. These estimates are slightly lower than either the unweighted or weighted MRFSS data set alone.

Thus far, all estimates of fishing mortality in this report have been focused solely on the recreational fishery. This is justified as comparison of MRFSS recreational data and NMFS commercial data show that the Virginia fishery is over 95% recreational. Since we have collected length frequency data from commercial as well as recreational fishermen, a final catch curve analysis was done solely on the data collected by this project in 1996 from recreational and commercial fishermen. This data was not expanded by total catch estimates by MRFSS or NMFS. The single year catch at age matrix resulted in a value of F=0.290, similar to the unweighted MRFSS estimate for 1996 of F=0.280.

To summarize the results of the four data sets used to estimate F using a 25% hook release mortality and linear regression catch curves, all estimates show fishing mortality in Virginia is significantly lower than the coastwide average of F=0.58. Further, all data sets result in similar average estimates of F for the period 1994-1996, between 0.306 and 0.391 (F=0.335 unweighted MRFSS, F=0.391 weighted MRFSS, F=0.306 MRFSS with supplemental data).

<u>10 Percent Hook Release Mortality</u>

The tautog FMP uses a hook release mortality of 25% in fishing mortality estimates. However, based on conversations with fishermen and scientific evidence, the release mortality is significantly lower than 25%. Simpson (1996) concluded that the recreational fishery in Connecticut had a discard mortality was 5% or less (n=240). In Virginia, two studies have estimated hook release mortality at 7.7% in one of three trials (1 mortality from 13 fish; Lucy, 1995), and approximately 2% (four mortalities from 170 fish, Appendix B). Thus it appears that the best current data supports the use of a release mortality less than 25%. A value of 10% would be considered conservative, meaning that it is slightly higher than available estimates to account for factors such as deeper water or higher temperatures, which typically increase the hook release mortality value. Therefore we tested the hypothesis that lowering the hook release mortality value will have no effect on estimates of fishing mortality (F).

To determine if the use of a lower hook release mortality had an effect on the final fishing mortality estimate, we ran the same analysis on the data series used for the 25% calculations above, with the only change being the use of a 10% release mortality. Our results show that the estimates of F for tautog in Virginia are robust to changes in release mortality. While the change in hook release mortality rate from 25% to 10% caused all points in the catch at age matrix to move 'down' with lower release mortality, the slope of the regression (estimate of Z) did not change significantly. Figure V.4 displays results for unweighted MRFSS at 10% release mortality, figure V.5 displays results for the weighted MRFSS at 10% release mortality, and figure V.5 shows the F estimates for the best available data using the 10% release mortality.

For comparative purposes, all estimates of F from catch curve analyses are shown in figure V.7. All values represent the average fishing mortality for all age classes within that year. A point estimate for such a long lived fish would not adequately protect the species from overfishing, as it may take the resource many years to replenish the biomass lost to a single year of high fishing mortality. Therefore we have averaged the last 3 years of estimates from each data set. As seen in figure V.7, the use of 10% or 25% hook release mortality result in non-significant changes in the calculation of F. However, note that all six average estimates of F are in the range of .31-.39. These values are far below the coastwide average of F=0.58 listed in the tautog FMP.

In summary, changing the value of hook release mortality in the management plan would provide many benefits. Although our current calculations show no significant difference in F caused by the value of release mortality, as size limits increase and bag limits are enforced, we expect more fish to be released. Thus the value of release mortality may have a larger impact on stock assessments as size limits increase and bag limits decrease. Furthermore, the use of 10% hook release mortality may increase credibility with the fishing community by using appropriate and available data.

Other methods used to estimate F

Data from the Virginia Game Fish Tagging program (Table 5.2.3) was used to estimate F for tautog in 1995 and 1996 assuming a wide variety of tag induced mortality and tag loss rates (Lazar, Appendix C). Tag data estimates of F ranged from F=0.2-0.3 in 1995 and F=0.25-0.37 in 1996. These estimates support estimates obtained from catch curve analysis.

In addition to traditional catch curve methodology, which utilize a linear regression on the log of catch versus age, we performed nonlinear estimates of F on the catch at age matrix (Appendix A). The nonlinear estimates result in significantly lower estimates of Z, and therefore F (Appendix A). However, to conform with the methodologies used by ASMFC, our suggested management regulations are based on the linear estimates of fishing mortality.

6.0 Management Considerations

Current average estimates of F:		**Date range**
MRFSS unweighted 25% data set:	F = 0.34	1994-1996
MRFSS unweighted 10% RM:	F = 0.35	1994-1996
MRFSS weighted 25% RM:	F = 0.39	1994-1996
MRFSS weighted 10% RM:	F = 0.38	1994-1996
MRFSS + other data, 25% RM:	F = 0.31	1994-1996
MRFSS + other data, 10% RM:	F = 0.31	1994-1996
This project collections , 25%:	F = .29	1996
This project collections 10%:	F = .29	1996

Resultant Management options (to reach F = 0.24) supported by these estimates, calculated from table 14 and table 15 in the tautog FMP (Appendix D):

Options for weighted MRFSS data, F = 0.39: (38.5% reduction required to reach F=0.24)

A) 6 fish per person per day, no closed season (36% reduction)
B) 9 fish per person per day, close May and June (38.5% reduction)
C) 10 fish per person per day, close May and June (36% reduction)

Options for unweighted MRFSS data, F = 0.35: (31% reduction required to reach F=0.24)

D) 7 fish per person per day, no closed season (32% reduction)
E) 10 fish per person per day, close May and June (36% reduction)
F) 12 fish per person per day, close May and June (32% reduction)

Options for best available data, F = 0.31: (23% reduction required to reach F=0.24)

G) 10 fish per person per day, no closed season (23% reduction)

Options for 1996 project collections, F = 0.29: (20% reduction required to reach F=0.24):

H) 11 fish per person per day, no closed season (20% reduction)

As a general rule, we support management options that include spawning protection in the form of closed season from 1 May to 30 June. Closed seasons have been supported by conversations with recreational and commercial fishermen in the tidewater area, provided that the season is closed to everyone. Although the tautog spawning season begins in April, few species are available for fishermen to target, thus closing the tautog season in April could deny individuals the opportunity to fish. Current regulations open a striped bass season on 1 May, thus closing the tautog season 1 May does not deny any individual the opportunity to go fishing. Further, water temperatures are typically warm enough in May for other species to enter the Chesapeake Bay, allowing angling opportunities for various target species.

Although all data supports a fishing mortality level in Virginia of between F=0.29 and F=0.39, two data sets have the most merit for use in setting management regulations; the unweighted MRFSS data and the MRFSS + supplemental data set. The unweighted MRFSS data provides the longest time series and reveals trends in the fishery, resulting in a three year average for 1994 to 1996 of F=0.35 using both 10% and 25% release mortality. The preferred management option for the unweighted MRFSS data is option F, 12 fish per person per day, close May and June. The MRFSS + supplemental data includes the most recent data, has increased sample sizes for all length frequency needs, and utilizes the most current age-length key. Thus the MRFSS + supplemental data represents the best available data, estimating an average of F=0.31, resulting in a management option of 10 fish per person per day, no closed season.

Tables

Table 2.1: Fishing locations sampled from 1 April 1996 to 30 June 1997 by area. CBBT = Chesapeake Bay Bridge Tunnel (Rt. 13).

Inside CBBT	CBBT to 3 miles offshore	Greater than 3 miles offshore
Back River Reef	Anglo-African Wreck	Chesapeake Light Tower
Chub Rock	Cape Henry Wreck	The Dry Dock
Fort Wool	CBBT	Hanks Wreck
Gwynn's Island		Kinston Wreck
Hampton Bridge Tunnel		Powell Wreck
York River		Santori Wreck
York Spit Light		Triangle Wrecks
36A bouy		3-10 miles offshore
		11-20 miles offshore
		21-30 miles offshore
		31-40 miles offshore

Table 2.2: Summary of tautog sampling results by season. All areas combined.

	Fall 1996	**Winter 96 - 97**	**Spring 1997**	**Total**
# trips sampled	58	57	61	176
# measured	1370	1025	809	3204
# landed	1128	876	645	2649
# released	242	149	164	555
Sex ratio (F:M)	1.36:1	1.15:1	.97:1	1.18:1
# opercle bones collected	399	225	282	906

Table 2.3: Representation of sampling protocol and actual collection results for quantification of tautog fishing mortality in Virginia. Chesapeake Bay Bridge Tunnel = CBBT. Numbers in **bold** represent numbers of fish collected for age and length, plus the number of fish for which length only was recorded.

Proposed Sampling Protocol

Area	Fall 1996	Winter 1996-1997	Spring 1997	Fall 1997
Inside CBBT	75 + 100		75 + 100	75 + 100
CBBT to 3 miles offshore	75 + 100	25 + 100	75 + 100	75 + 100
Greater than 3 miles offshore	75 + 100	75 + 100	75 + 100	75 + 100

Actual Collection Results

Area	Fall 1996	Winter 1996-1997	Spring 1997	Fall 1997
Inside CBBT	207 + 225	2 + 110	39 + 16	
CBBT to 3 miles offshore	162 + 733	83 + 443	149 + 490	
Greater than 3 miles offshore	30 + 13	140 + 256	94 + 21	

Percent of fish at each Age

Inch class	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1																																
2	100																															
3	100																															
4	100																															
5	50	50																														
6	50	50																														
7		100																														
8	42.9	50.0	7.1																													
9	25.7	31.4	34.3	5.7	2.9																											
10	6.7	24.4	40.0	24.4	4.4																											
11		4.0	28.0	44.0	14.0	6.0	4.0																									
12		9.6	23.1	23.1	25.0	17.3	0.0	1.9																								
13		4.5	10.4	20.9	26.9	20.9	10.4	3.0	3.0																							
14				13.8	25.9	13.8	25.9	15.5	5.2																							
15			2.0	4.0	10.0	22.0	26.0	20.0	12.0	4.0																						
16					2.5	12.5	25.0	22.5	32.5	2.5	2.5																					
17				2.1	2.1	4.3	17.0	27.7	21.3	12.8	6.4	4.3	2.1																			
18						2.3	9.1	20.5	31.8	15.9	11.4	6.8	0.0	2.3																		
19					2.6	0.0	10.5	7.9	15.8	26.3	18.4	10.5	2.6	0.0	2.6	0.0	2.6															
20							2.5	10.0	7.5	25.0	25.0	12.5	15.0	2.5																		
21								3.4	24.1	10.3	6.9	10.3	13.8	6.9	0.0	6.9	3.4	6.9	0.0	3.4	3.4											
22									5.3	10.5	10.5	26.3	21.1	5.3	1.0	5.3	10.5															
23										5.0	15.0	25.0	20.0	10.0	0.0	10.0	0.0	5.0	5.0	0.0	5.0											
24									5.3	5.3	10.5	21.1	5.3	5.3	0.0	0.0	10.5	10.5	10.5	5.3	0.0	10.5										
25												20.0	0.0	20.0	0.0	0.0	0.0	20.0	20.0	0.0	20.0											
26																		20.0	40.0	0.0	0.0	0.0	0.0	20.0	0.0	20.0						
27																																
28																																
29																		100														
30																		100														

Table 4.1: Proportional age-length key for tautog collected 8/79 - 8/85 by percent of fish at each age. Inch class 1 = 1.00-1.99. Data source: Hostetter and Munroe (1993), total n = 696.

Percent of fish at each Age

Inch class	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1																																
2																																
3																																
4																																
5	60	40																														
6	30	67	3.0																													
7	17	72	11.1																													
8		18.8	68.8	12.5																												
9		7.7	50.0	38.5	3.8																											
10		2.3	29.5	59.1	9.1																											
11		2.9	22.9	51.4	18.6	4.3																										
12			8.7	19.4	54.4	14.6	2.9																									
13			1.0	11.5	41.7	36.5	8.3	1.0																								
14				3.3	22.8	41.3	25.0	6.5	0.0	0.0	1.1																					
15					11.4	27.8	49.4	7.6	3.8																							
16						10.4	41.6	33.8	10.4	3.9																						
17						13.8	15.0	31.3	27.5	10.0	2.5																					
18						3.6	10.7	26.8	42.9	12.5	3.6																					
19						2.8	2.8	27.8	22.2	25.0	11.1	5.6	2.8																			
20								6.7	33.3	33.3	16.7	6.7	3.3																			
21								6.9	6.9	10.3	10.3	27.6	24.1	13.8																		
22											23.1	15.4	38.5	7.7	0.0	7.7	0.0	0.0	0.0	7.7												
23											17.6	11.8	35.3	11.8	11.8	0.0	5.9	5.9														
24													22.2	44.4	22.2	0.0	11.1															
25												12.5	0.0	12.5	12.5	12.5	12.5	0.0	12.5	12.5	0.0	0.0	0.0	12.5								
26												33.3	0.0	33.3	0.0	0.0	0.0	0.0	33.3													
27																	100															
28																																
29																																100
30																																

Table 4.2: Proportional age-length key for tautog collected 4/94 - 8/96 by percent of fish at each age. Inch class 1 = 1.00-1.99. Data source: White (1996), total n = 942.

Percent of fish at each Age

Inch class	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1																																
2																																
3																																
4																																
5																																
6																																
7																																
8																																
9			100																													
10		25.0	75.0																													
11			53.1	37.5	9.4																											
12			17.6	50.6	25.9	4.7	1.2																									
13			0.0	37.6	44.0	12.8	5.5																									
14				9.1	41.6	35.1	9.1	5.2																								
15				1.4	23.9	33.8	29.6	7.0	1.4	1.4	1.4																					
16					2.6	21.1	39.5	21.1	7.9	5.3	2.6																					
17					10.3	24.1	31.0	13.8	10.3	6.9	3.4																					
18					5.3	10.5	21.1	26.3	26.3	5.3	0.0	0.0	0.0	0.0	0.0	0.0	5.3															
19					7.1	7.1	14.3	28.6	21.4	21.4																						
20									16.7	50.0	0.0	0.0	16.7	16.7																		
21									50.0	0.0	0.0	50.0																				
22									33.3	0.0	50.0	0.0	16.7																			
23													33.3	0.0	33.3	0.0	33.3															
24														100																		
25														33.3	0.0	33.3	33.3															
26																																
27																														100		
28																																
29																																
30																																

Table 4.3: Proportional age-length key for tautog collected 4/96 - 12/96 by percent of fish at each age. Inch class 1 = 1.00-1.99. Data source: Current study, total n = 502.

Percent of fish at each Age

Inch class	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1																																
2																																
3																																
4																																
5	60	40																														
6	30	67	3.0																													
7	17	72	11.1																													
8		18.8	68.8	12.5																												
9		7.4	51.9	37.0	3.7																											
10		4.2	33.3	54.2	8.3																											
11		2.0	32.4	47.1	15.7	2.9																										
12			12.8	33.5	41.5	10.1	2.1																									
13			0.5	25.4	42.9	23.9	6.8	0.5																								
14				5.9	31.4	38.5	17.8	5.9	0.0	0.0	0.6																					
15				0.7	17.3	30.7	40.0	7.3	2.7	0.7	0.7																					
16				0.0	0.9	13.9	40.9	29.6	9.6	4.3	0.9																					
17					2.8	16.5	19.3	26.6	22.9	9.2	2.8																					
18					1.3	5.3	13.3	26.7	38.7	10.7	2.7	0.0	0.0	0.0	0.0	0.0	1.3															
19					2.0	4.0	6.0	28.0	22.0	24.0	8.0	4.0	2.0																			
20								5.6	30.6	36.1	13.9	5.6	5.6	2.8																		
21								6.5	9.7	9.7	9.7	29.0	22.6	12.9																		
22									10.5	0.0	31.6	10.5	31.6	5.3	0.0	5.3	0.0	0.0	0.0	5.3												
23											15.0	10.0	35.0	10.0	15.0	0.0	10.0	5.0														
24													18.2	54.5	18.2	0.0	9.1															
25												9.1	0.0	18.2	9.1	18.2	18.2	0.0	9.1	9.1	0.0	0.0	0.0	9.1								
26												33.3	0.0	33.3	0.0	0.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0								
27																	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0		
28																																
29																																100
30																																

Table 4.4: Proportional age-length key for tautog collected 4/94 - 12/96 by percent of fish at each age. Inch class 1 = 1.00-1.99. Data source: White (1996) and Current study, total n = 1,444.

Table 5.1: Estimate of natural mortality (M) for tautog using Pauly (1980) method. $L\infty$ and K values from Hostetter and Munroe (1993) for 1985-1990 and White et al. (1996) for 1991-1996. Temperature data at CB7.4 from EPA Bay Monitoring Data, and data at CBBT from National Data Bouy Center.

Published equation: $\text{Log}_{10} M = (-0.0066) - (0.279 * \text{Log}_{10} L\infty)) + (\text{Log}_{10} K) + (0.4634 * \text{Log}_{10} T)$

Year	L∞	K	Avg T @ CB7.4	Avg T @ CBBT	M
1985	742	0.085	15.8		0.112
1986	742	0.085	14.8		0.108
1987	742	0.085	14.8		0.108
1988	742	0.085	15.1		0.109
1989	742	0.085	15.3		0.110
1990	742	0.085	17.3		0.116
1991	792	0.093	17.2		0.121
1992	792	0.093	15.1		0.114
1993	792	0.093	15.0	15.0	0.113
1994	792	0.093		15.1	0.114
1995	792	0.093		16.0	0.117
1996	792	0.093		14.5	0.112
mean			15.6	15.1	0.113

Table 5.2.1: Catch at age matrix for release mortality of 25%

data = A+B1 = MRFSS unweighted length frequencies per year, expanded by MRFSS annual est of A+B1 landings in VA

B2 = (American Littoral society length freq, expanded by MRFSS B2 annual est for VA) * (25% release mortality)

(A+B1)+B2 = Total catch at length matrix for VA

Catch at length converted to catch at age by H+M 1993 ALK for 1985-1990, and by GGW 1996 ALK for 1991-1996

Regressions of LN(catch at age) done to calculate Z, then F

Age																			calc	"actual"	
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19+	tot/yr	catch/yr	error
1985	1674	4015	7038	7825	10179	12230	16205	13495	14408	4054	2750	2264	1377	882	198	287	403	634	1106	101024	101024	0
1986	8174	25580	47581	54814	44898	33635	27632	21876	21246	9718	7447	6316	3203	2195	244	598	1012	3922	12807	332898	332898	0
1987	2698	8623	15711	20530	21973	16383	13451	9803	8352	4727	3847	3971	2062	1214	239	601	663	897	1845	137591	137591	0
1988	974	12179	32290	47247	49852	44494	46388	43744	40526	22854	15186	11747	5848	4413	525	651	851	3485	6318	389570	389570	0
1989	5515	14835	23534	29964	33939	38493	48290	39871	37426	9720	5481	2696	1368	521	153	213	308	262	448	293037	293037	0
1990	8208	13335	18009	15360	13416	10166	12472	10900	10935	6152	4529	2994	1583	599	211	186	556	421	789	130822	130822	0
1991	963	5039	14739	23849	26442	29982	30651	15348	10632	5479	5306	4658	7659	6183	2918	1064	1721	466	3158	196256	196256	0
1992	123	1654	10210	21147	23241	20350	16719	7836	4595	2394	1658	1085	1935	1289	587	81	293	102	81	115379	115379	0
1993	222	3663	20406	35762	58394	54294	47600	26339	16495	7049	8470	6118	14574	10441	5883	1691	4376	1043	3604	326425	326425	0
1994	1408	3113	16349	28436	39813	39204	38539	28651	23481	12610	5683	3314	3181	1509	386	87	193	67	87	246112	246112	0
1995	78	1704	14842	31044	43729	36293	36887	28168	20909	10195	4838	2209	3219	1509	627	465	370	54	693	237832	237832	0
1996	0	2448	18832	31606	39403	36263	28930	24319	20444	11505	6421	3408	5184	2662	994	444	497	120	444	233925	233925	0

ln of catch at age matrix above

Age																			
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19+
1985	7.423	8.298	8.859	8.965	9.228	9.412	9.693	9.510	9.576	8.308	7.919	7.725	7.228	6.782	5.289	5.658	6.000	6.452	7.008
1986	9.009	10.150	10.770	10.912	10.712	10.423	10.227	9.993	9.964	9.182	8.916	8.751	8.072	7.694	5.499	6.394	6.919	8.274	9.458
1987	7.900	9.062	9.662	9.930	9.998	9.704	9.507	9.190	9.030	8.461	8.255	8.287	7.632	7.102	5.477	6.398	6.497	6.799	7.520
1988	6.881	9.407	10.382	10.763	10.817	10.703	10.745	10.686	10.610	10.037	9.628	9.371	8.674	8.392	6.263	6.479	6.746	8.156	8.751
1989	8.615	9.605	10.066	10.308	10.432	10.558	10.785	10.593	10.530	9.182	8.609	7.900	7.221	6.255	5.027	5.361	5.731	5.569	6.105
1990	9.013	9.498	9.799	9.640	9.504	9.227	9.431	9.297	9.300	8.725	8.418	8.004	7.367	6.396	5.354	5.226	6.320	6.042	6.671
1991	6.870	8.525	9.598	10.080	10.183	10.308	10.330	9.639	9.272	8.609	8.577	8.446	8.944	8.730	7.979	6.970	7.451	6.143	8.058
1992	4.815	7.411	9.231	9.959	10.054	9.921	9.724	8.966	8.433	7.781	7.413	6.990	7.568	7.161	6.374	4.389	5.681	4.620	4.389
1993	5.401	8.206	9.924	10.485	10.975	10.902	10.771	10.179	9.711	8.861	9.044	8.719	9.587	9.254	8.680	7.433	8.384	6.950	8.190
1994	7.250	8.043	9.702	10.255	10.592	10.577	10.559	10.263	10.064	9.442	8.645	8.106	8.065	7.319	5.956	4.470	5.263	4.202	4.470
1995	4.363	7.440	9.605	10.343	10.686	10.499	10.516	10.246	9.948	9.230	8.484	7.700	8.077	7.319	6.441	6.142	5.915	3.983	6.541
1996		7.803	9.843	10.361	10.582	10.499	10.273	10.099	9.925	9.351	8.767	8.134	8.553	7.887	6.902	6.095	6.209	4.785	6.095

Table 5.2.2: Catch at age matrix for release mortality of 10%

data = A+B1 = MRFSS unweighted length frequencies per year, expanded by MRFSS annual est of A+B1 landings in VA

B2 = (American Littoral society length freq, expanded by MRFSS B2 annual est for VA) * (10% release mortality)

(A+B1)+B2 = Total catch at length matrix for VA

Catch at length converted to catch at age by H+M 1993 ALK for 1985-1990, and by GGW 1996 ALK for 1991-1996

Regressions of LN(catch at age) done to calculate Z, then F

Year	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19+	calc tot/yr	"actual" catch/yr	error
1985	1586	3712	6359	7026	9416	11561	15556	12964	13967	3834	2601	2189	1323	875	191	287	396	634	1106	95584	95584	0
1986	8077	25247	46833	53932	44057	32898	26916	21291	20761	9475	7282	6234	3143	2188	236	598	1004	3922	12807	326902	326902	0
1987	2593	8262	14902	19577	21063	15586	12677	9170	7827	4464	3669	3883	1998	1206	231	601	655	897	1845	131106	131106	0
1988	767	11469	30699	45373	48064	42926	44867	42500	39494	22337	14836	11573	5722	4397	508	651	834	3485	6318	376820	376820	0
1989	5431	14550	22894	29209	33218	37862	47677	39370	37011	9512	5340	2626	1317	514	146	213	302	262	448	287901	287901	0
1990	8050	12842	17052	13957	11855	8733	10798	9569	9672	5738	4273	2835	1490	575	195	171	528	412	781	119528	119528	0
1991	963	4928	13817	21955	23318	26442	27463	13398	9525	4962	5076	4535	7521	6143	2918	1050	1721	466	3144	179343	179343	0
1992	49	1079	8455	18684	21573	19359	16128	7691	4466	2309	1586	1054	1885	1280	587	72	293	102	72	106723	106723	0
1993	89	2630	17249	31333	55394	52512	46538	26078	16262	6896	8342	6060	14484	10426	5883	1676	4376	1043	3588	310860	310860	0
1994	1381	2798	14551	25458	37823	38271	38101	28560	23443	12602	5677	3314	3181	1509	386	87	193	67	87	237489	237489	0
1995	31	1227	12776	28085	41969	35697	36756	28153	20909	10195	4837	2209	3219	1509	627	465	370	54	693	229781	229781	0
1996	0	2346	17772	29480	37199	34947	27816	23316	19620	11130	6160	3286	4939	2607	971	413	485	108	413	223007	223007	0

ln of catch at age matrix above

Year	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19+
1985	7.369	8.219	8.758	8.857	9.150	9.355	9.652	9.470	9.544	8.252	7.864	7.691	7.188	6.775	5.252	5.658	5.982	6.452	7.008
1986	8.997	10.136	10.754	10.895	10.693	10.401	10.200	9.966	9.941	9.156	8.893	8.738	8.053	7.691	5.466	6.394	6.912	8.274	9.458
1987	7.861	9.019	9.609	9.882	9.955	9.654	9.448	9.124	8.965	8.404	8.208	8.264	7.600	7.095	5.441	6.398	6.484	6.799	7.520
1988	6.643	9.347	10.332	10.723	10.780	10.667	10.711	10.657	10.584	10.014	9.605	9.356	8.652	8.389	6.231	6.479	6.726	8.156	8.751
1989	8.600	9.585	10.039	10.282	10.411	10.542	10.772	10.581	10.519	9.160	8.583	7.873	7.183	6.243	4.982	5.361	5.709	5.569	6.105
1990	8.993	9.460	9.744	9.544	9.381	9.075	9.287	9.166	9.177	8.655	8.360	7.950	7.307	6.355	5.273	5.142	6.270	6.022	6.660
1991	6.870	8.503	9.534	9.997	10.057	10.183	10.221	9.503	9.162	8.510	8.532	8.419	8.925	8.723	7.979	6.956	7.451	6.143	8.053
1992	3.898	6.984	9.042	9.835	9.979	9.871	9.688	8.948	8.404	7.745	7.369	6.960	7.541	7.155	6.374	4.278	5.681	4.620	4.278
1993	4.485	7.875	9.755	10.352	10.922	10.869	10.748	10.169	9.697	8.839	9.029	8.709	9.581	9.252	8.680	7.424	8.384	6.950	8.185
1994	7.231	7.937	9.585	10.145	10.541	10.552	10.548	10.260	10.062	9.442	8.644	8.106	8.065	7.319	5.956	4.470	5.263	4.202	4.470
1995	3.446	7.113	9.455	10.243	10.645	10.483	10.512	10.245	9.948	9.230	8.484	7.700	8.077	7.319	6.441	6.142	5.915	3.983	6.541
1996		7.761	9.785	10.291	10.524	10.462	10.233	10.057	9.884	9.317	8.726	8.097	8.505	7.866	6.878	6.023	6.185	4.681	6.023

Table 5.2.3: Tautog tag-recapture data for 1995-1997. (Virginia Game Fish Tagging Program)

		Tag Recaptures			
Year	**# tagged**	**1995**	**1996**	**1997**	**R**
1995	247	28	7	3	38
1996	457		66	18	84
1997	487			27	27
		28	73	48	

Figures

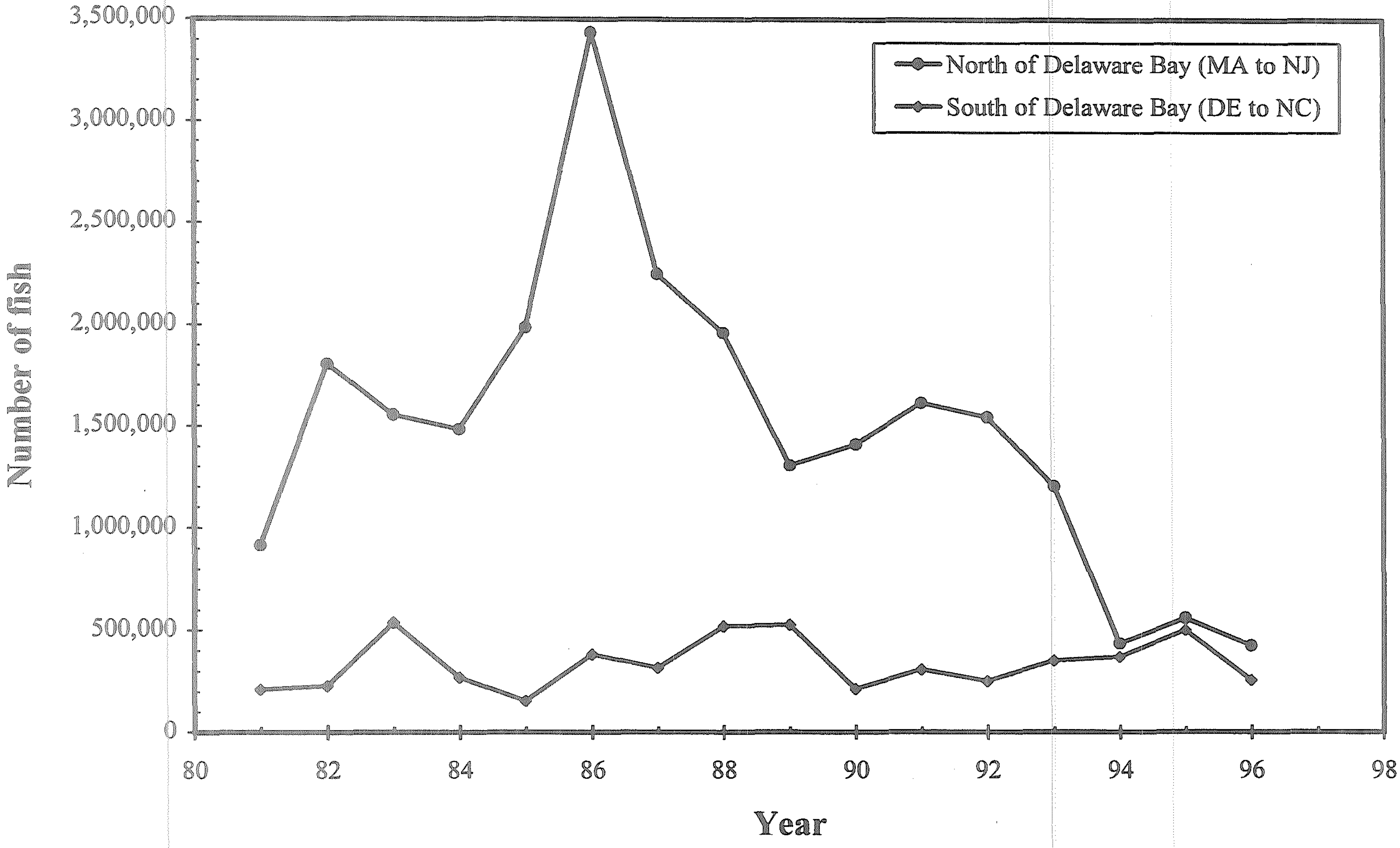


Figure I.1: Historical recreational landings by ASMFC management zones. Data source: MRFSS web page.

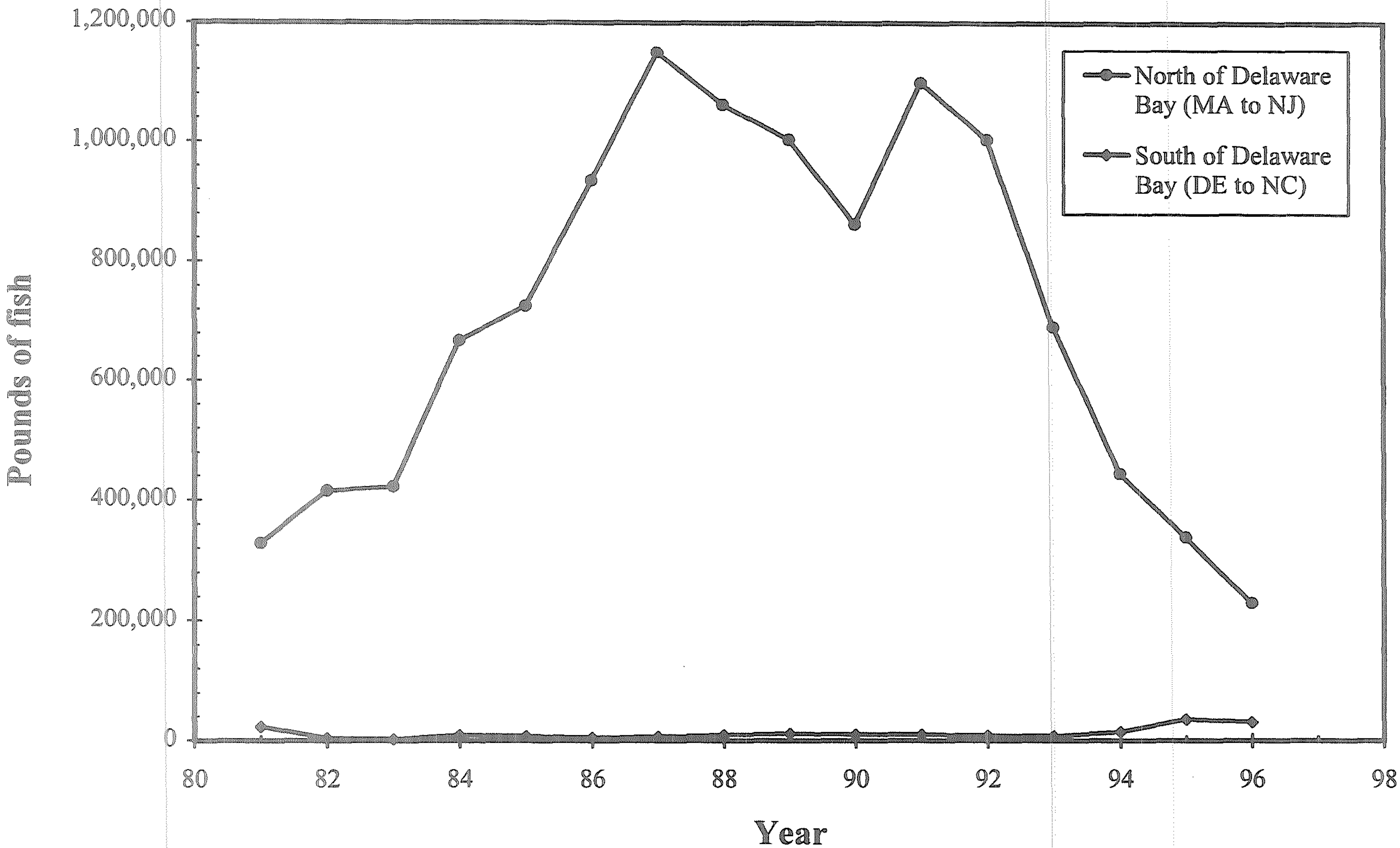


Figure I.2: Historical commercial landings by ASMFC management zone. Data source: NMFS web page.

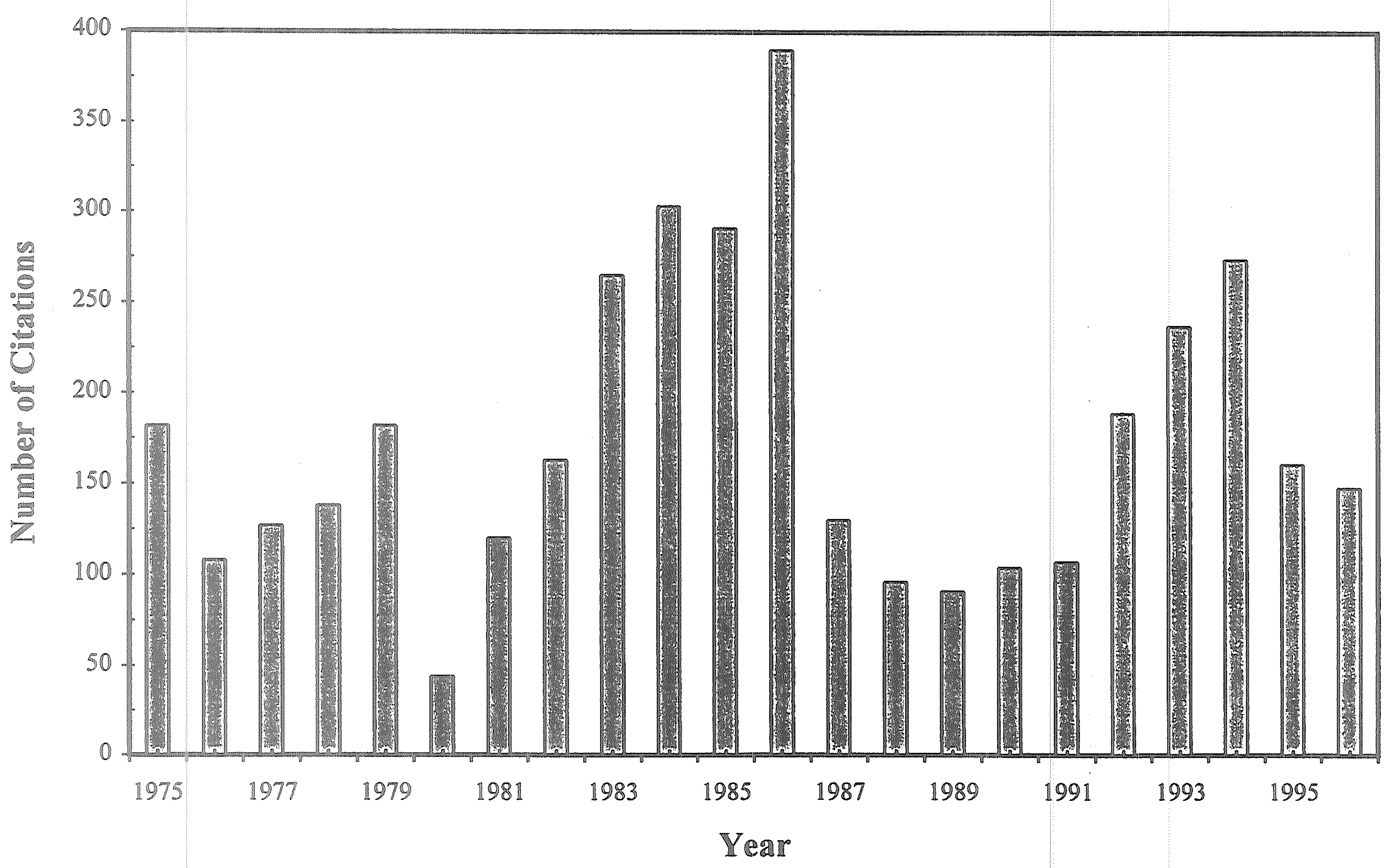


Figure I.3: Number of citation tautog (>9 lbs) landed by recreational fishermen. Data source: Virginia Saltwater Fishing Tournament. Web page http://www.state.va.us/mrc/tautog4.htm

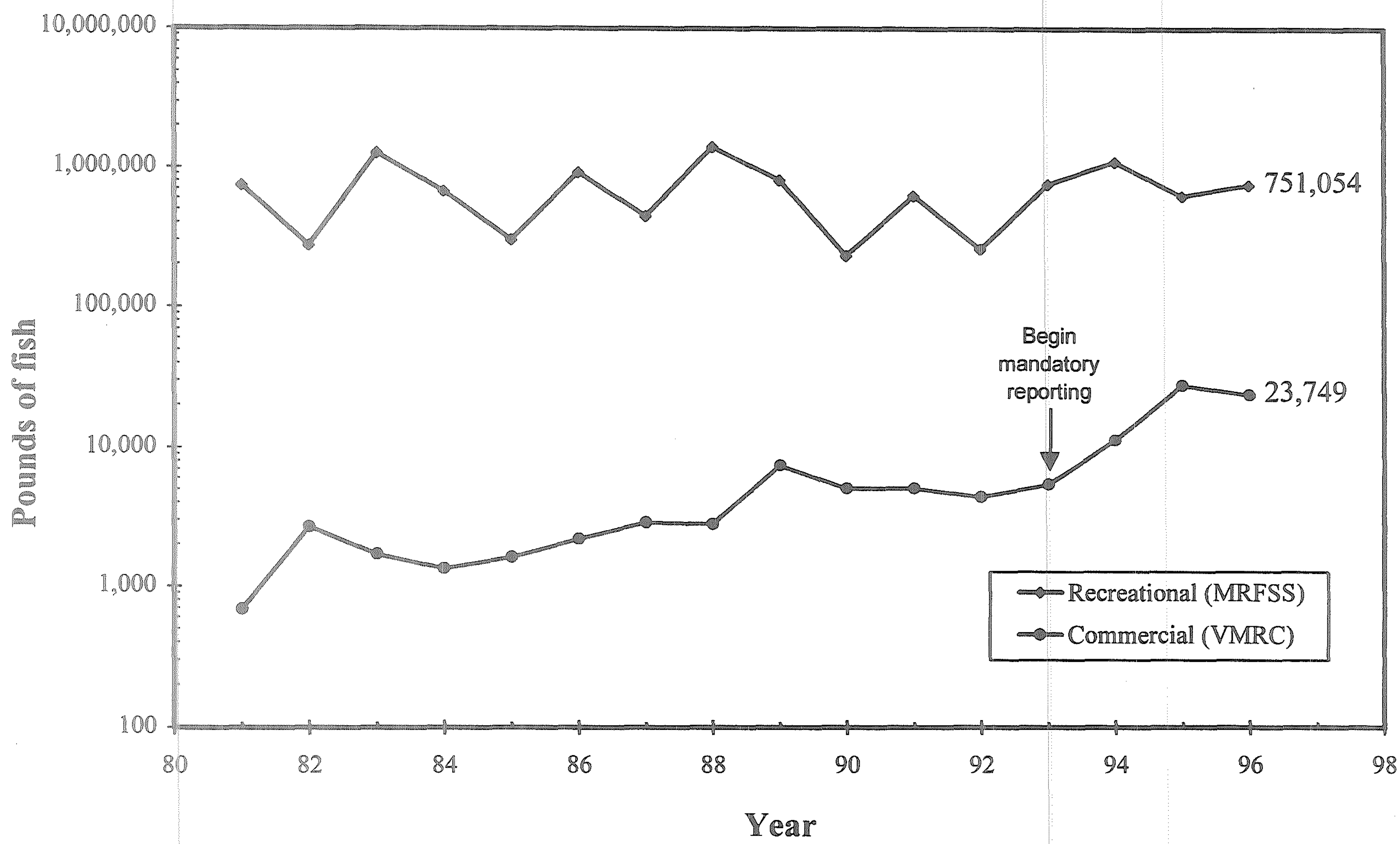


Figure 1.4: Recreational and commercial landings of tautog in Virginia. Data sources: MRFSS web page, VMRC landing stats.

Figure III.1: Length Frequency of tautog sampled from Virginia's recreational fishermen in 1996. Landed fish only, MRFSS data from intercept survey.

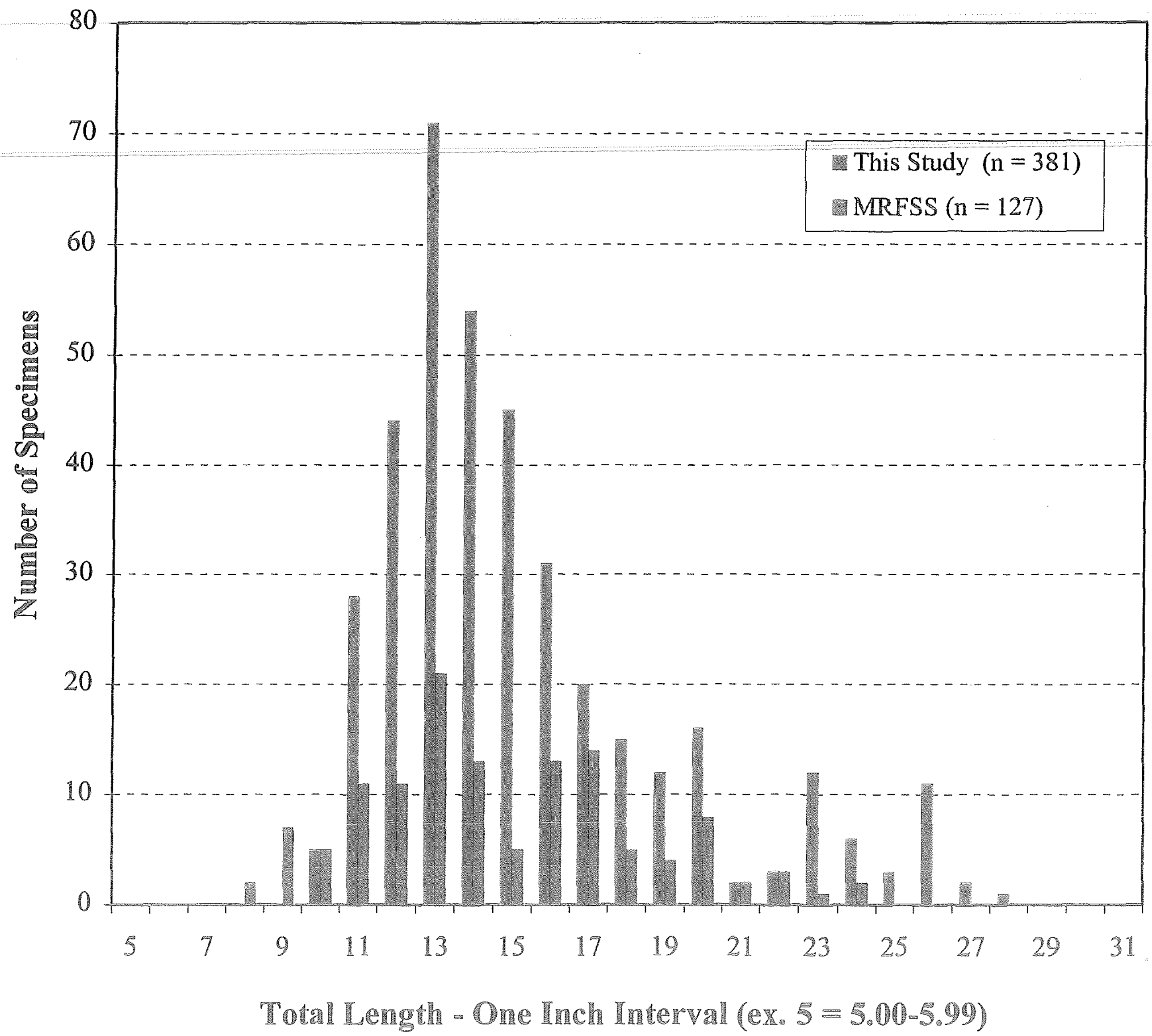


Figure III.1: Length Frequency of tautog sampled from Virginia's recreational fishermen in 1996. Landed fish only, MRFSS data from intercept survey.

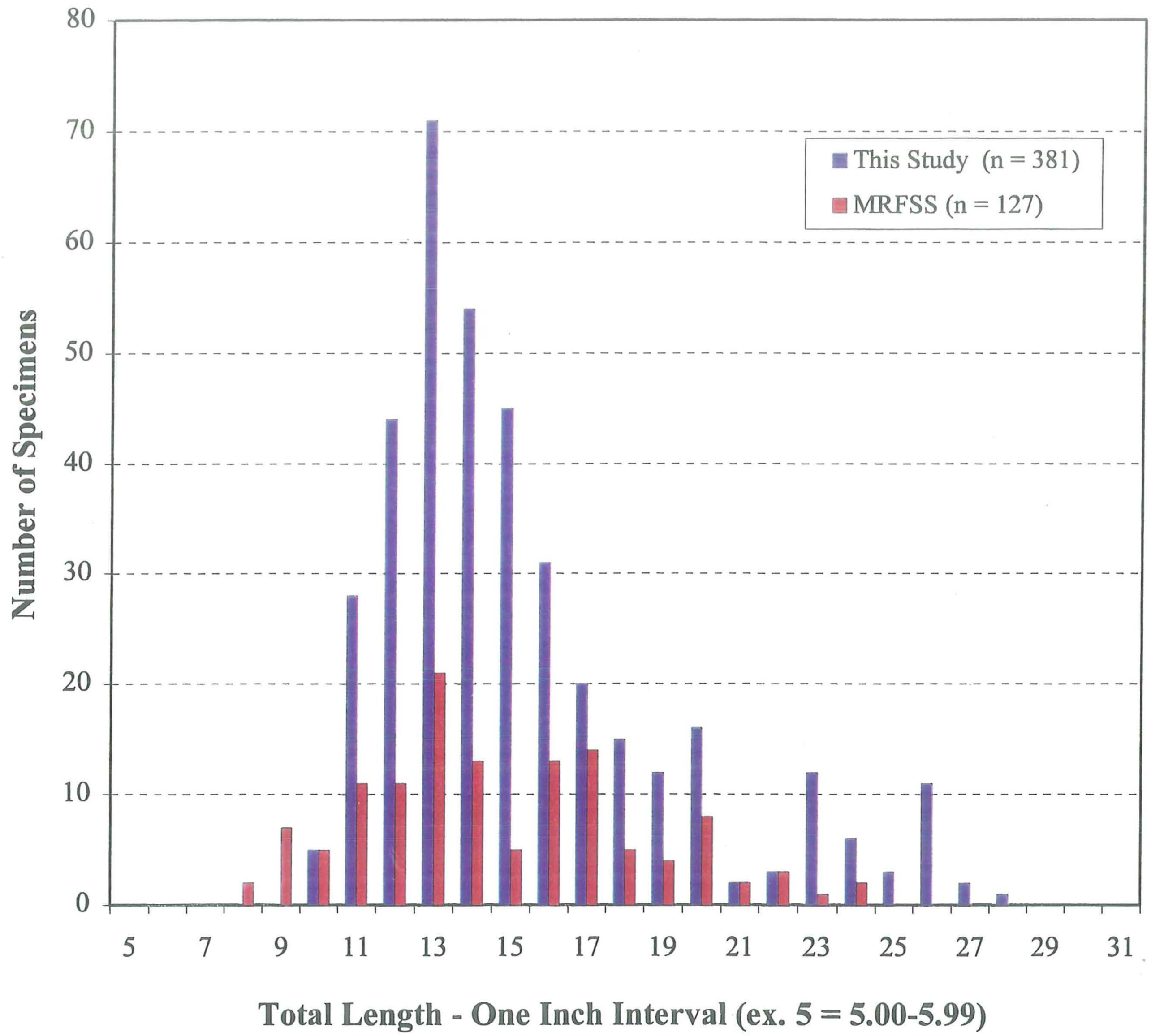


Figure III.2: Length Frequency of tautog sampled from 1 April 1996 to 30 June 1997. Includes fish landed and released alive.

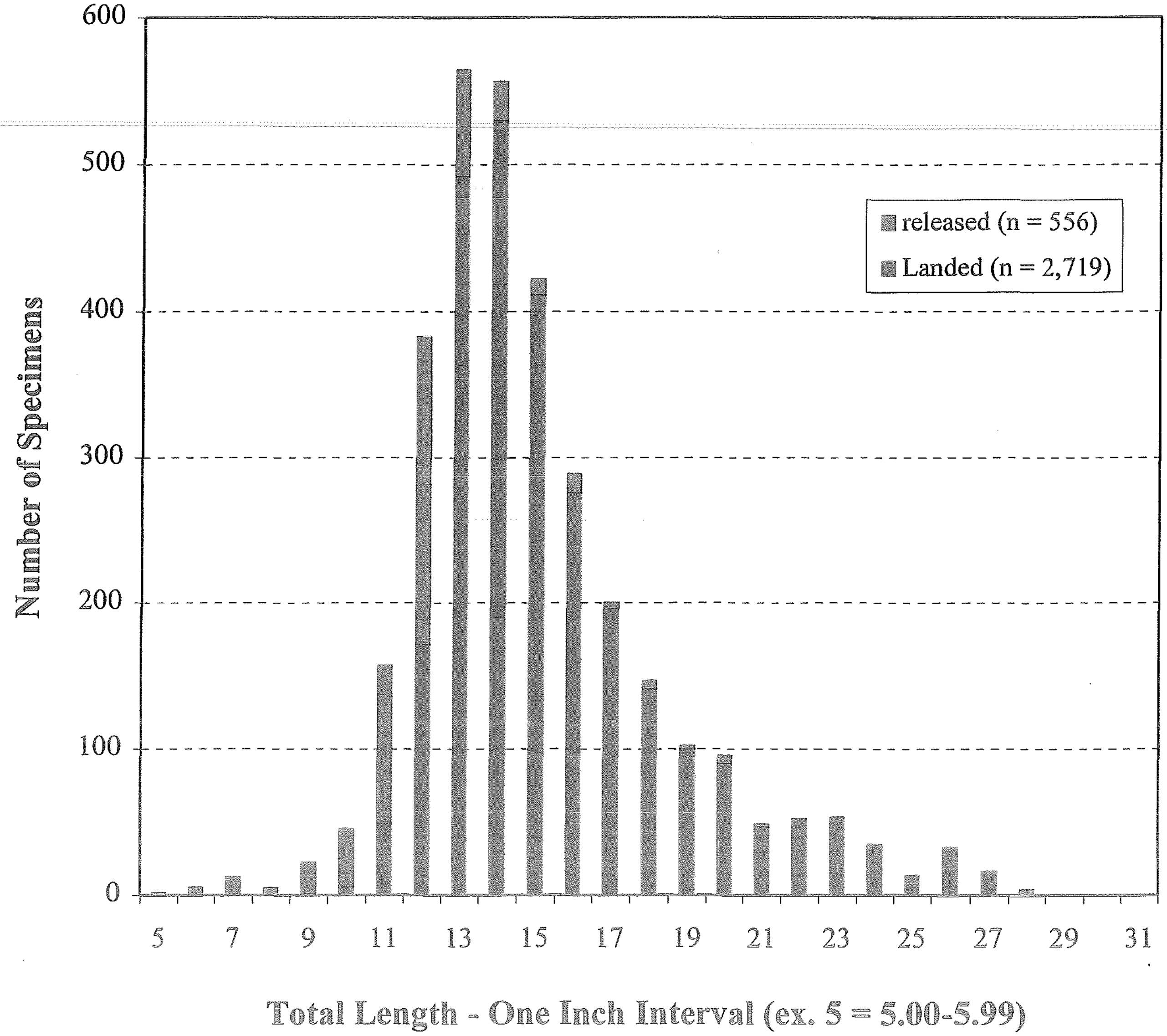


Figure III.2: Length Frequency of tautog sampled from 1 April 1996 to 30 June 1997. Includes fish landed and released alive.

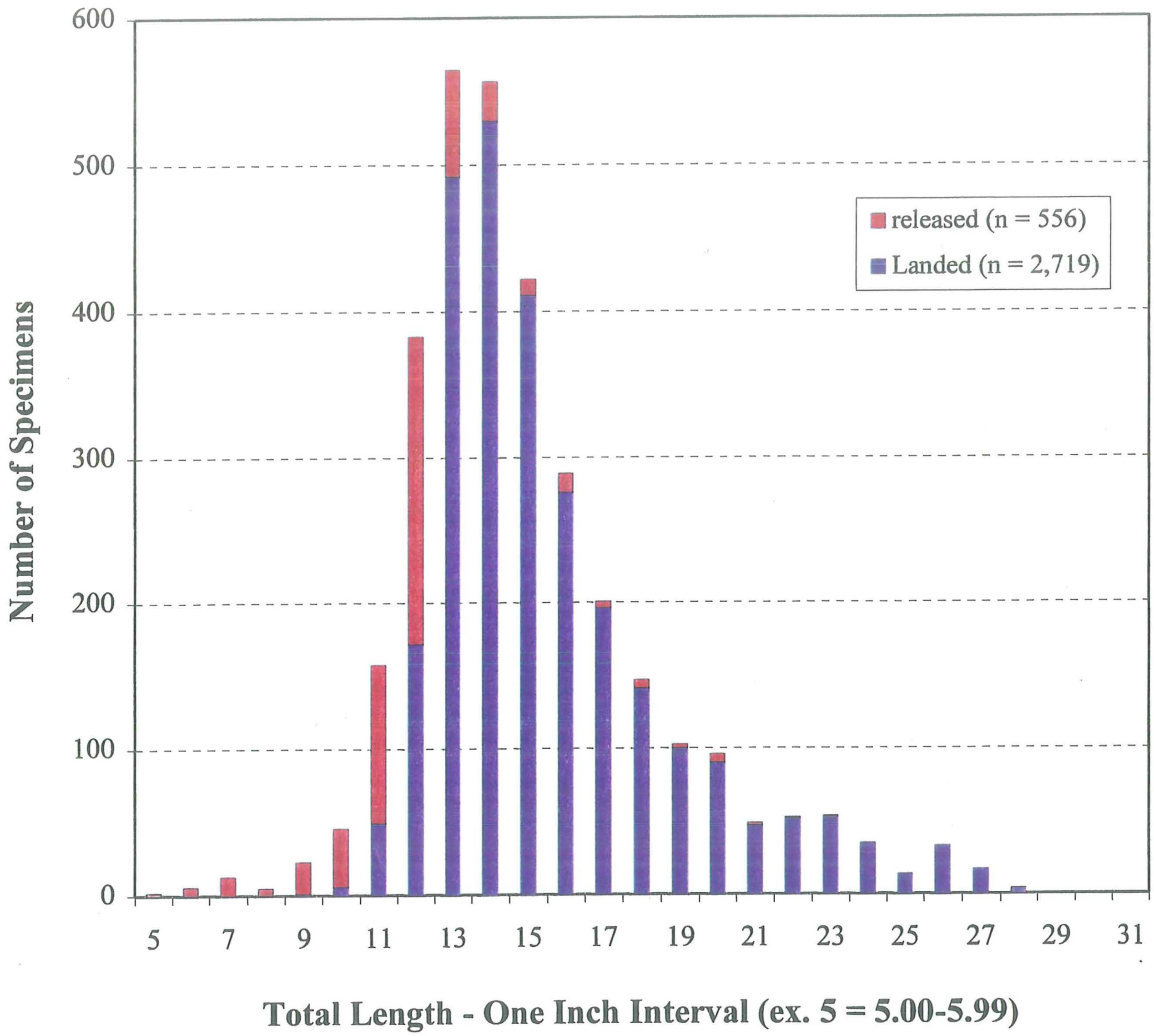


Figure III.3: Tautog length frequency for the fall 1996 season (1 September - 31 November).

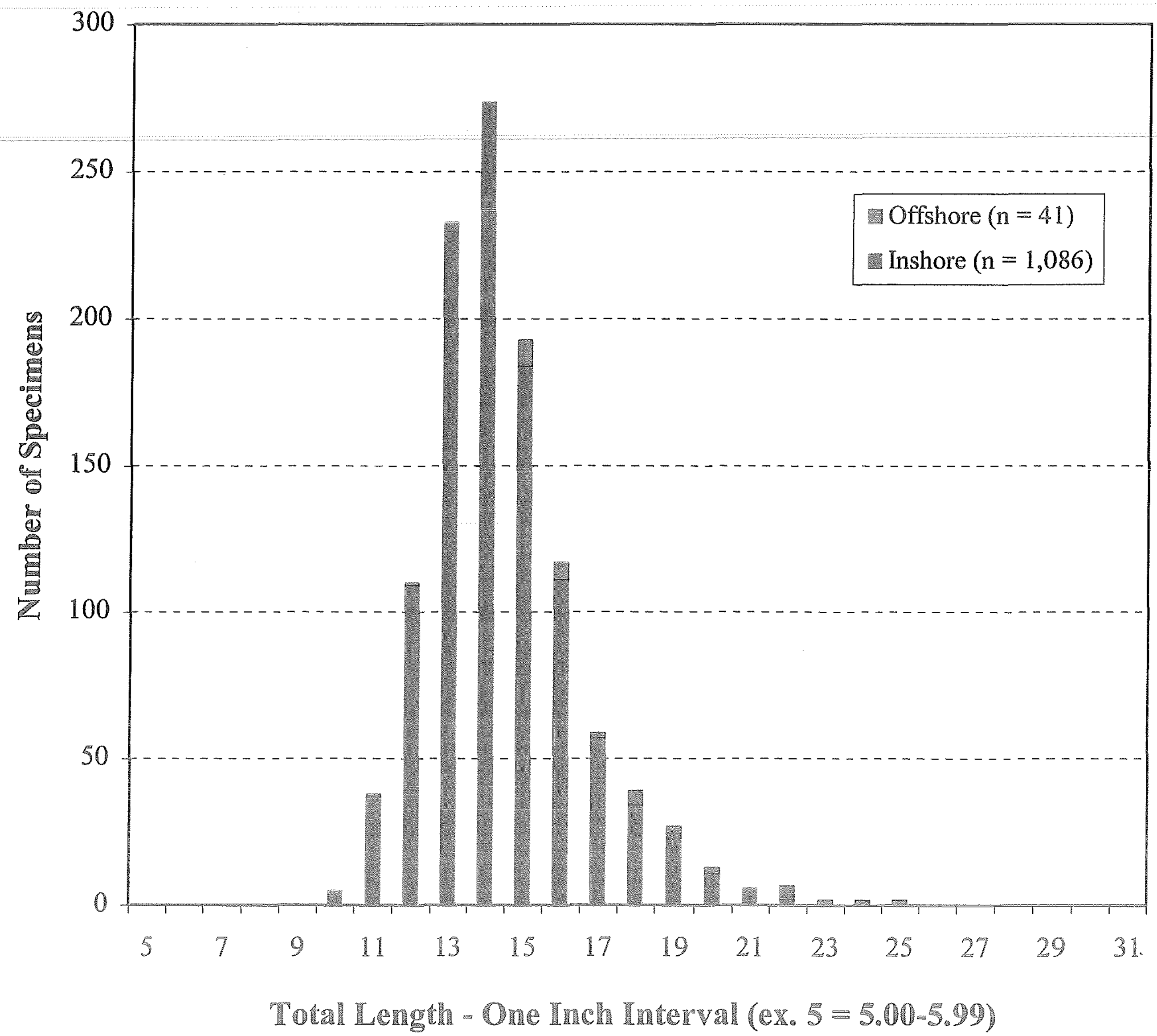


Figure III.3: Tautog length frequency for the fall 1996 season (1 September - 31 November).

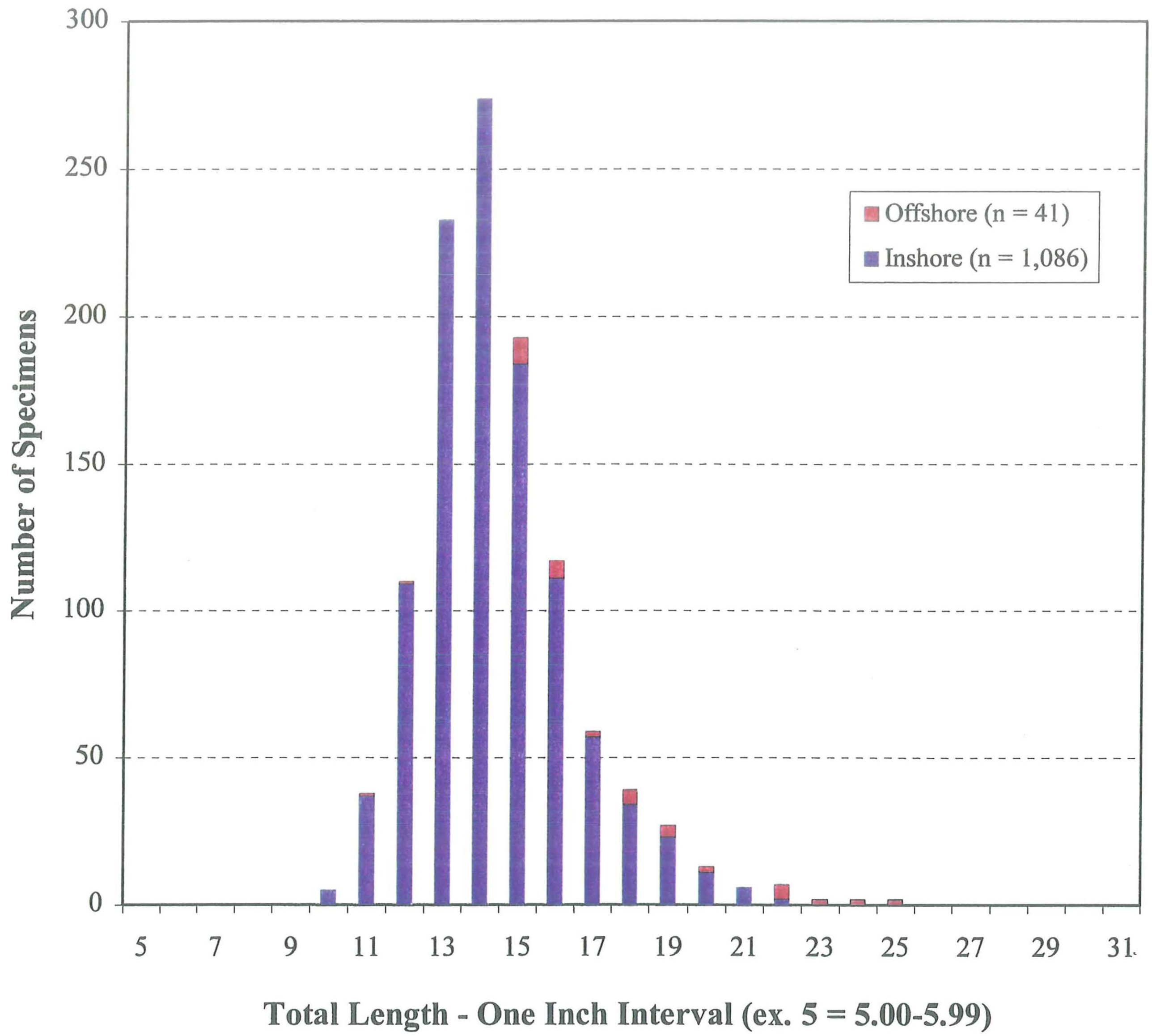


Figure III.4: Tautog length frequency for the Winter 1996 - 1997 season (1 December 1996 - 31 March 1997).

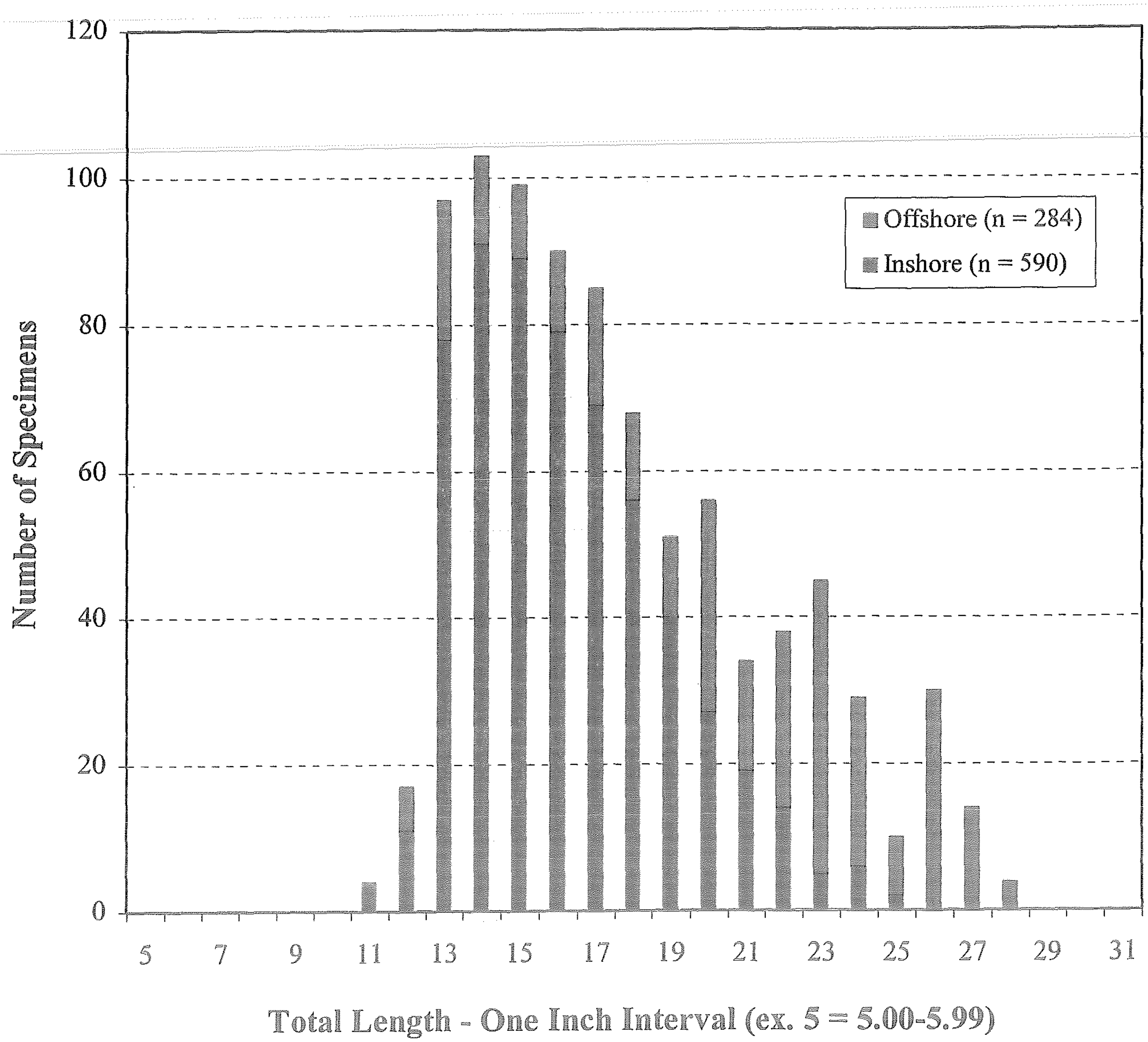


Figure III.4: Tautog length frequency for the Winter 1996 - 1997 season (1 December 1996 - 31 March 1997).

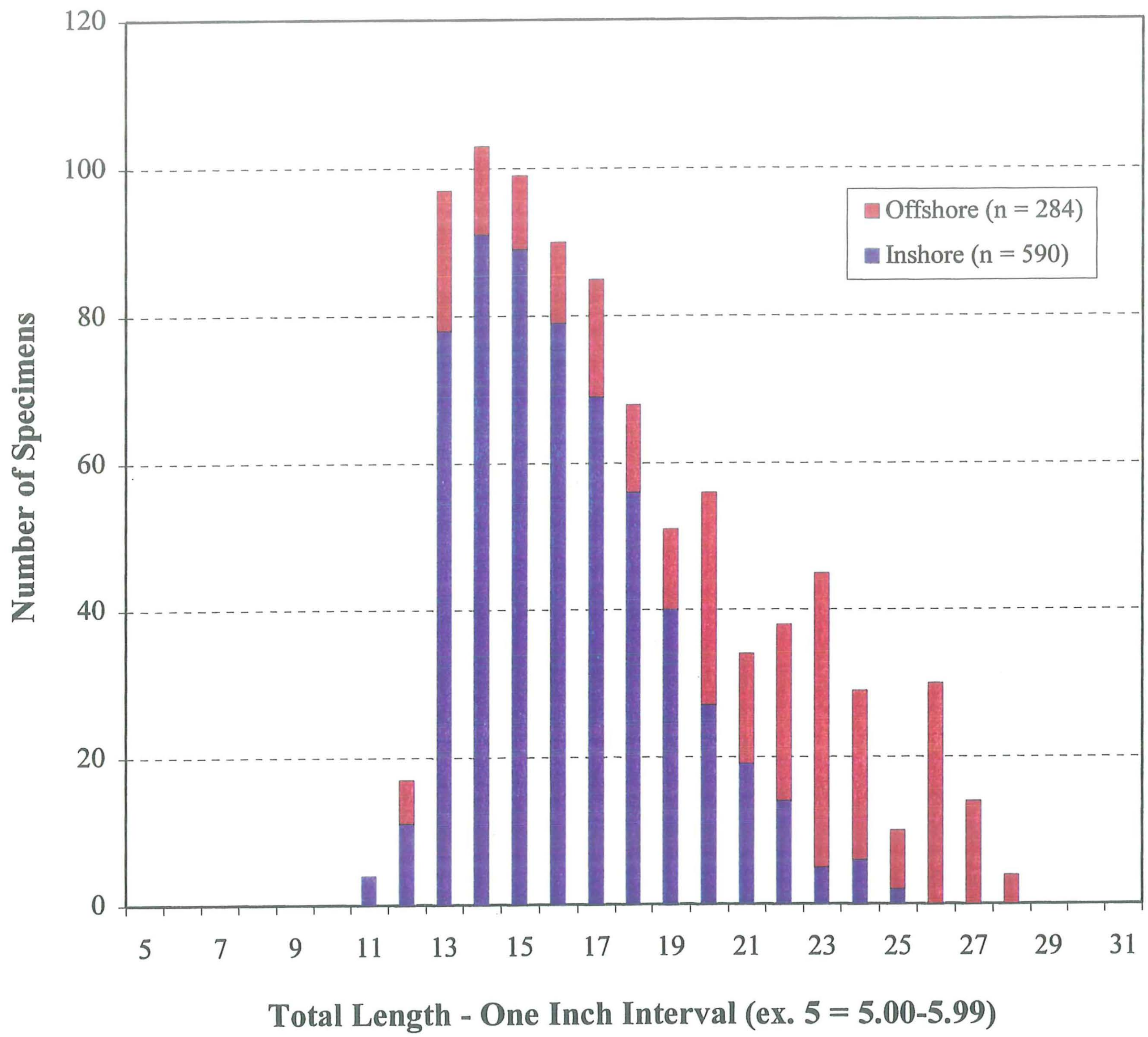


Figure III.5: Tautog length frequency for the spring 1997 season (1 April - 30 June).

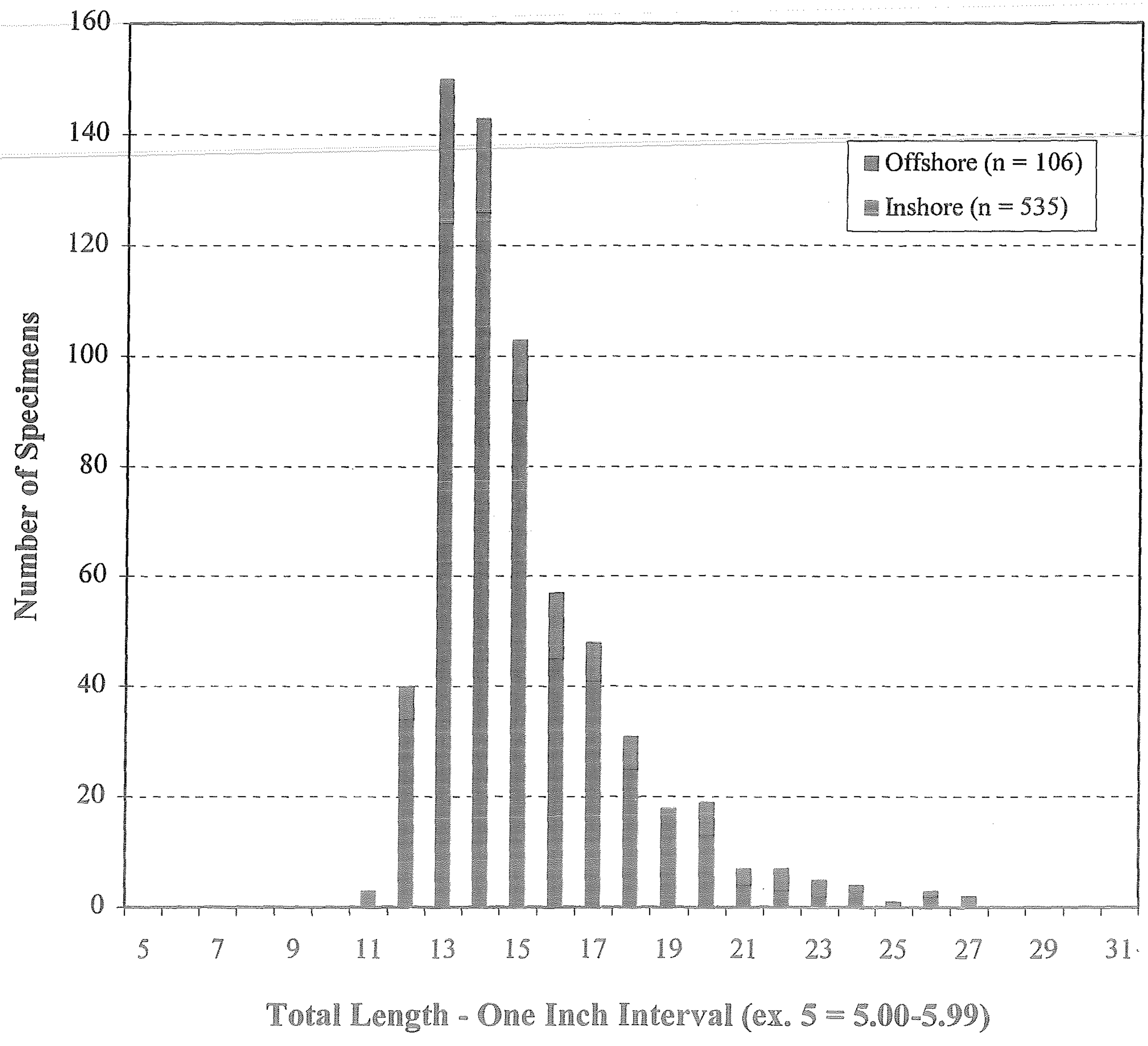
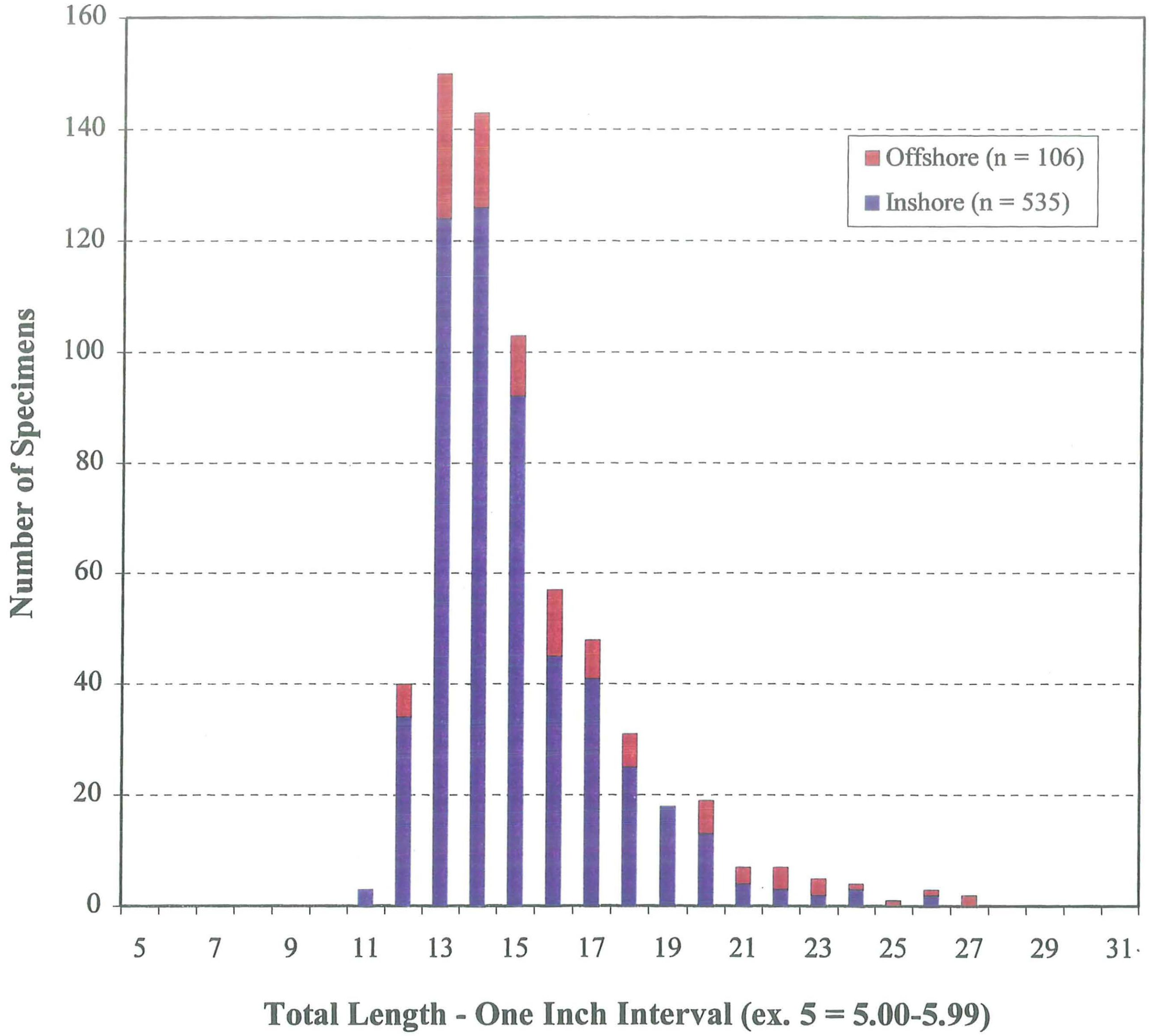


Figure III.5: Tautog length frequency for the spring 1997 season (1 April - 30 June).



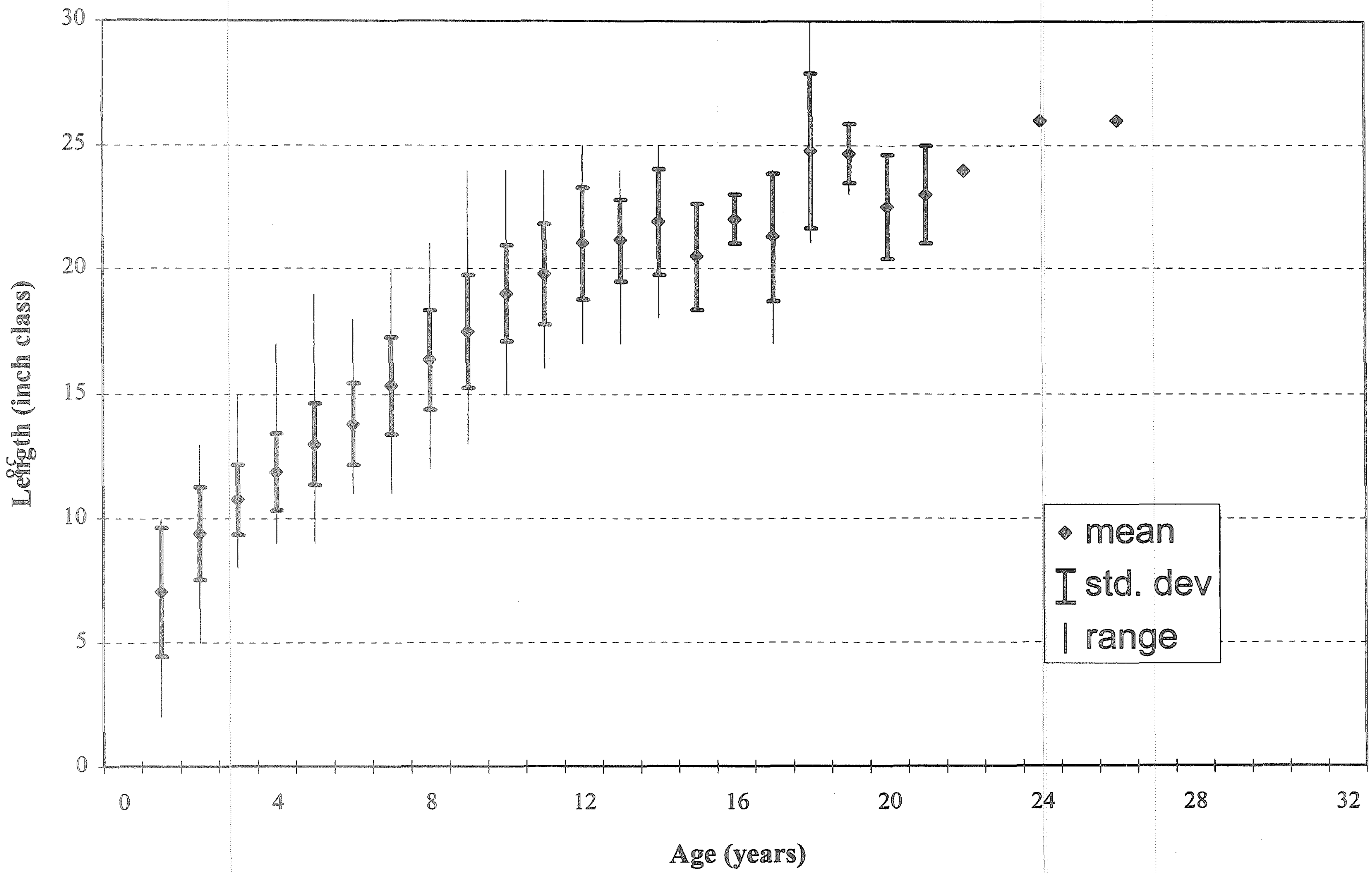


Figure IV.1: Virginia tautog mean length, standard deviation, and size range at age for specimens collected 1979 - 1985. Data source: Hostetter and Munroe (1993), total n = 696.

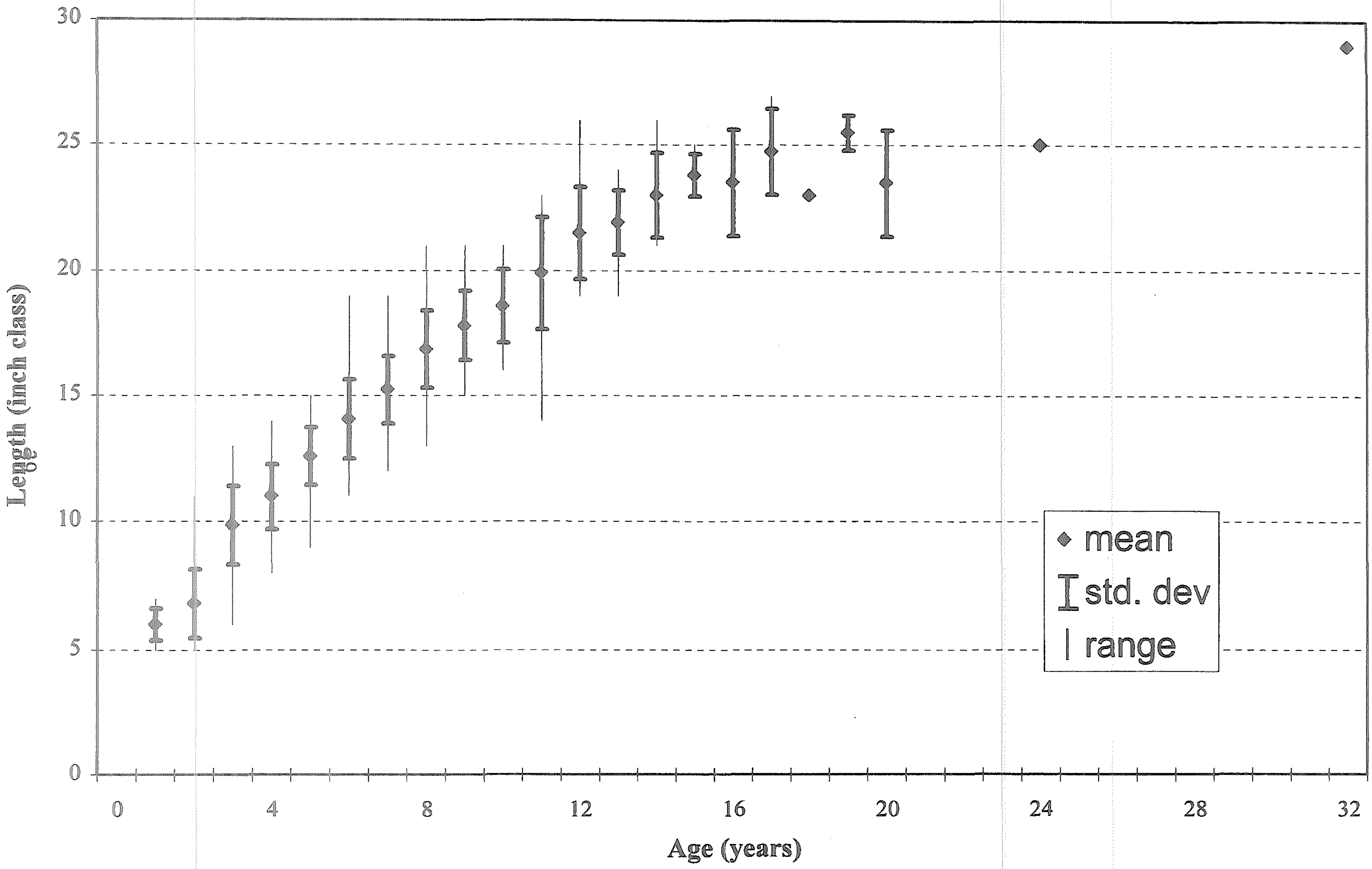


Figure IV.2: Virginia tautog mean length, standard deviation, and size range at age for specimens collected 1994 - 1995. Data source: White (1996), total n = 942.

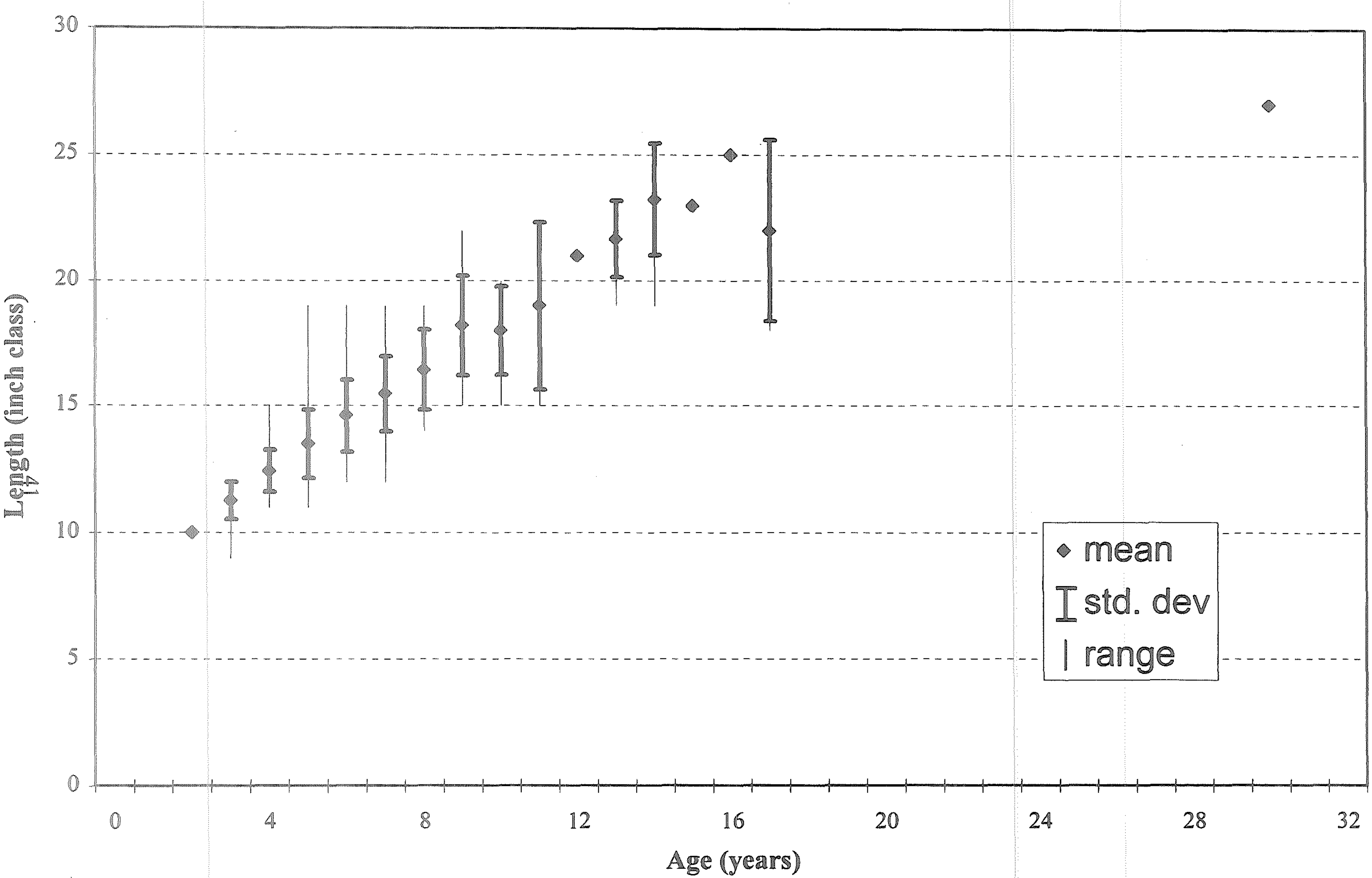


Figure IV.3: Virginia tautog mean length, standard deviation, and size range at age for specimens collected 1996 - 1996. Data source: Current study, total n = 502.

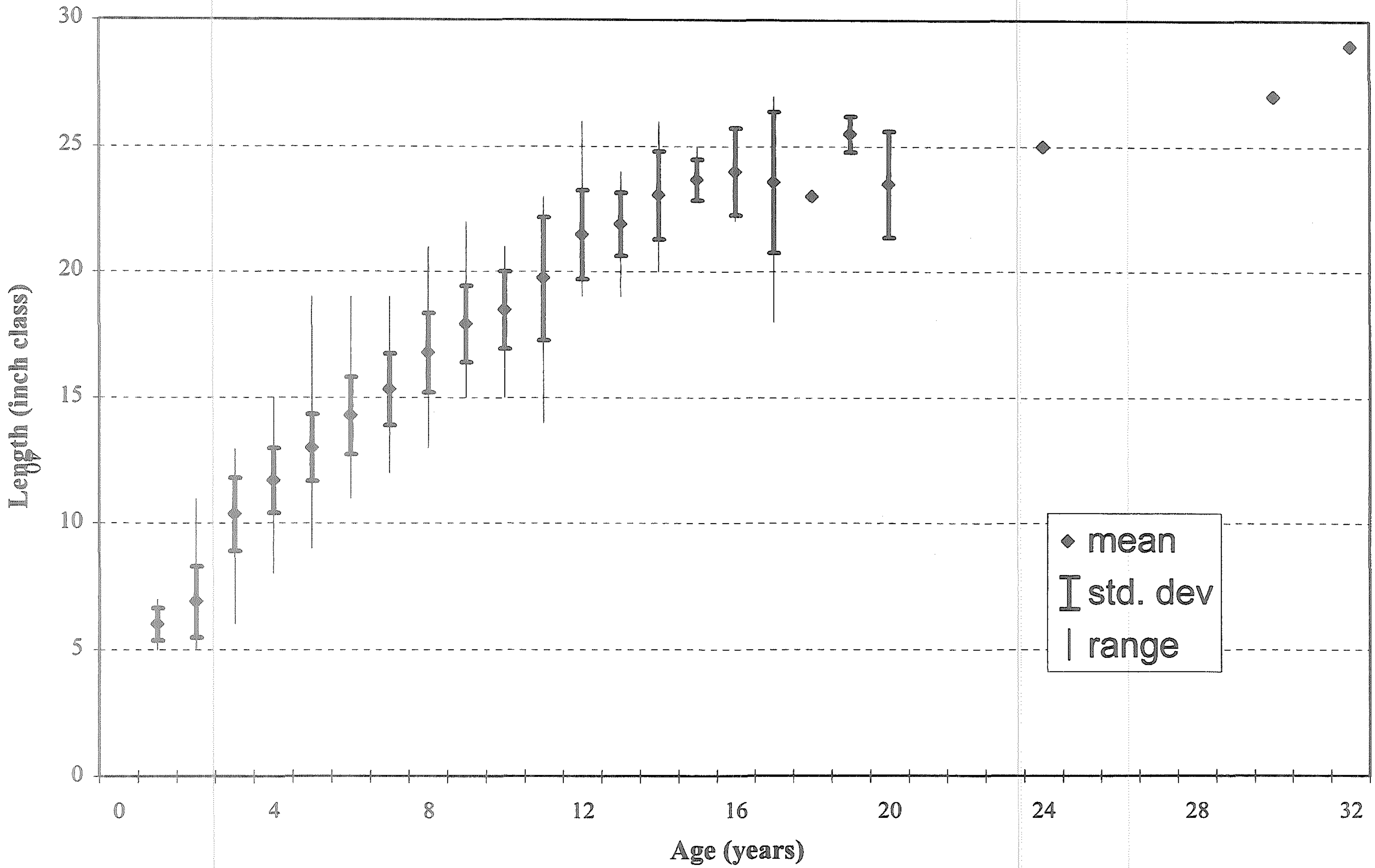


Figure IV.4: Virginia tautog mean length, standard deviation, and size range at age for specimens collected 1994 - 1996. Data source: White (1996) and current study, total n = 1,444.

Summary of single year estimates of F (avg F per year over all age classes)

Year	Z	Std error	Adj R sq	Assumed M	F est
1985	0.3974	0.0506	0.8463	0.15	0.247
1986	0.3264	0.0473	0.7689	0.15	0.176
1987	0.3141	0.0338	0.8678	0.15	0.164
1988	0.3580	0.0511	0.7875	0.15	0.208
1989	0.5798	0.0543	0.9112	0.15	0.430
1990	0.3184	0.0345	0.8487	0.15	0.168
1991	0.2939	0.0406	0.8236	0.15	0.144
1992	0.4195	0.0349	0.9167	0.15	0.270
1993	0.2659	0.0346	0.8173	0.15	0.116
1994	0.5382	0.0418	0.9270	0.15	0.388
1995	0.4856	0.0328	0.9439	0.15	0.336
1996	0.4302	0.0308	0.9373	0.15	0.280

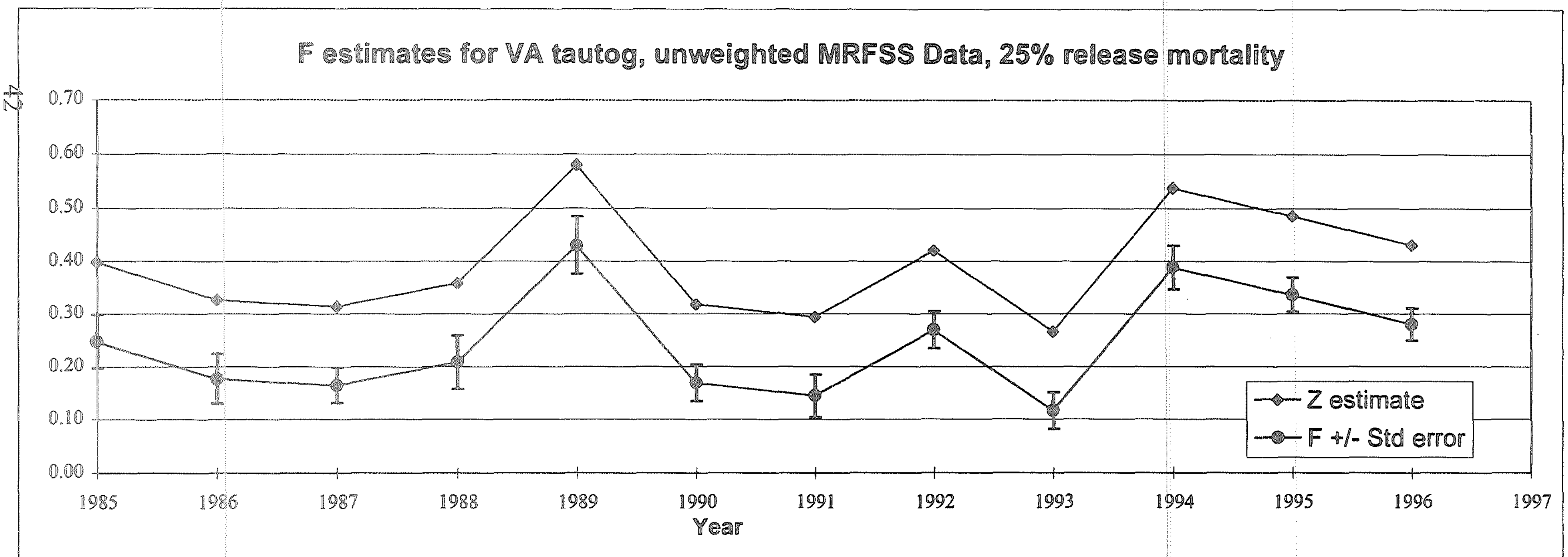


Figure V.1: Summary of Catch Curve Results: unweighted MRFSS, 25% release mortality.

Summary of single year estimates of F (avg F per year over all age classes)

Year	Z	Std error	Adj R sq	Assumed M	F est
1985					
1986					
1987					
1988					
1989					
1990					
1991	0.2939	0.0406	0.8236	0.15	0.144
1992	0.4672	0.0333	0.9332	0.15	0.317
1993	0.4276	0.0449	0.8734	0.15	0.278
1994	0.7040	0.0534	0.9350	0.15	0.554
1995	0.4880	0.0426	0.9098	0.15	0.338
1996	0.4302	0.0308	0.9373	0.15	0.280

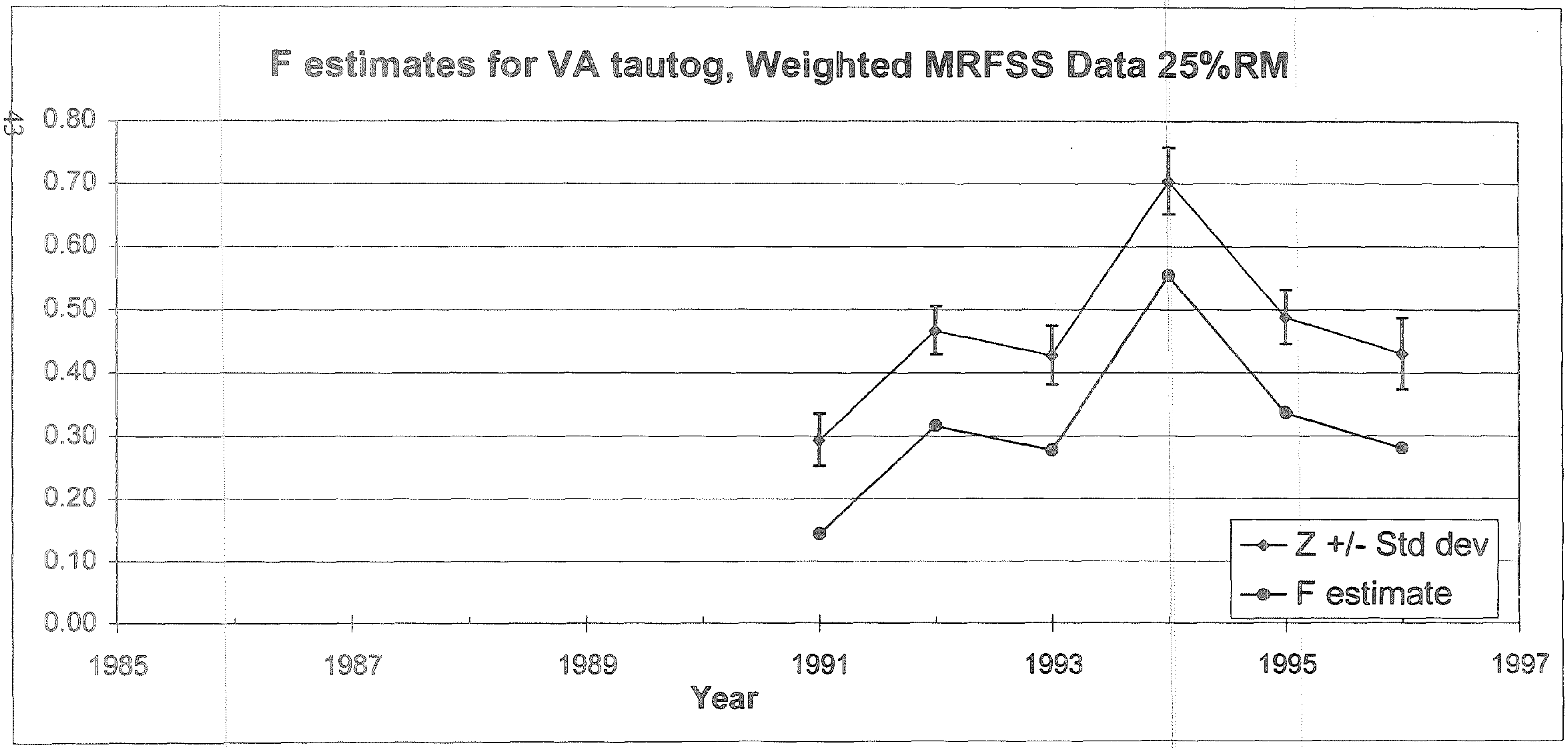


Figure V.2: Summary of Catch Curve Results: weighted MRFSS data, 25% release mortality.

Summary of single year estimates of F (avg F per year over all age classes)

Year	Z	Std error	Adj R sq	Assumed M	F est
1985					
1986					
1987					
1988					
1989					
1990					
1991					
1992					
1993					
1994	0.5499	0.0473	0.9110	0.15	0.400
1995	0.4691	0.0372	0.9185	0.15	0.319
1996	0.3581	0.0314	0.9082	0.15	0.208

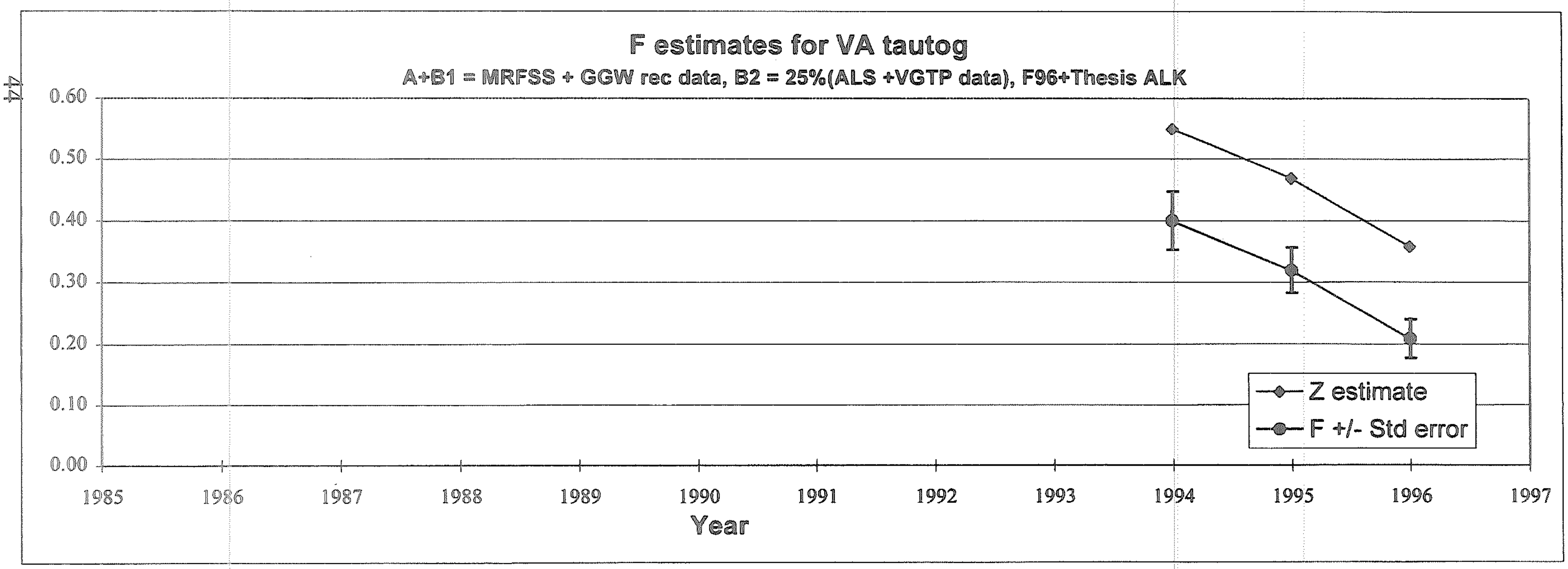


Figure V.3: Summary of Catch Curve Results: MRFSS + other data, 25% release mortality.

Summary of single year estimates of F (avg F per year over all age classes)

Year	Z	Std error	Adj R sq	Assumed M	F est
1985	0.3936	0.0512	0.8410	0.15	0.244
1986	0.3251	0.0476	0.7656	0.15	0.175
1987	0.3095	0.0340	0.8627	0.15	0.160
1988	0.3557	0.0513	0.7834	0.15	0.206
1989	0.5797	0.0550	0.9091	0.15	0.430
1990	0.3133	0.0345	0.8443	0.15	0.163
1991	0.2809	0.0417	0.8012	0.15	0.131
1992	0.4170	0.0365	0.9086	0.15	0.267
1993	0.2629	0.0347	0.8124	0.15	0.113
1994	0.5760	0.0413	0.9416	0.15	0.426
1995	0.4840	0.0331	0.9423	0.15	0.334
1996	0.4315	0.0318	0.9337	0.15	0.282

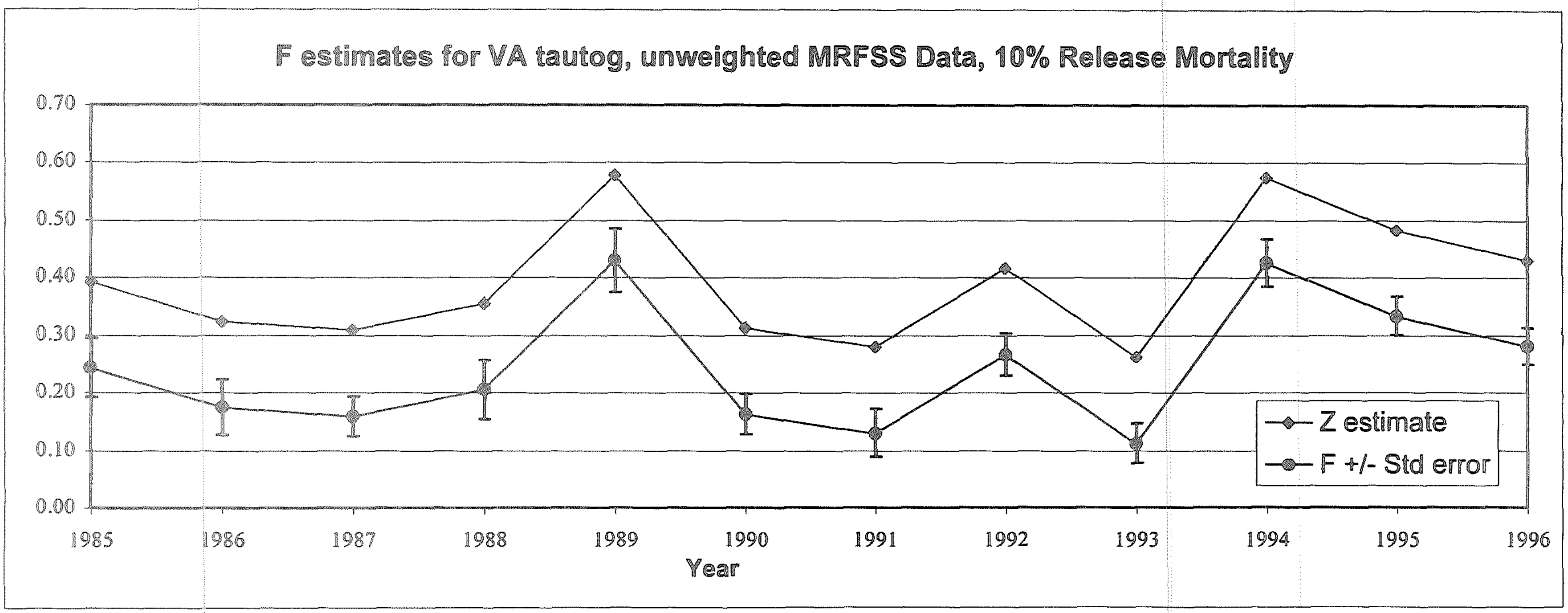


Figure V.4: Summary of Catch Curve Results: unweighted MRFSS, 10% release mortality.

Summary of single year estimates of F (avg F per year over all age classes)

Year	Z	Std error	Adj R sq	Assumed M	F est
1985					
1986					
1987					
1988					
1989					
1990					
1991	0.2809	0.0417	0.8012	0.15	0.131
1992	0.4675	0.0381	0.9143	0.15	0.318
1993	0.4266	0.0460	0.8676	0.15	0.277
1994	0.7028	0.0537	0.9342	0.15	0.553
1995	0.4880	0.0429	0.9080	0.15	0.338
1996	0.4077	0.0562	0.8114	0.15	0.258

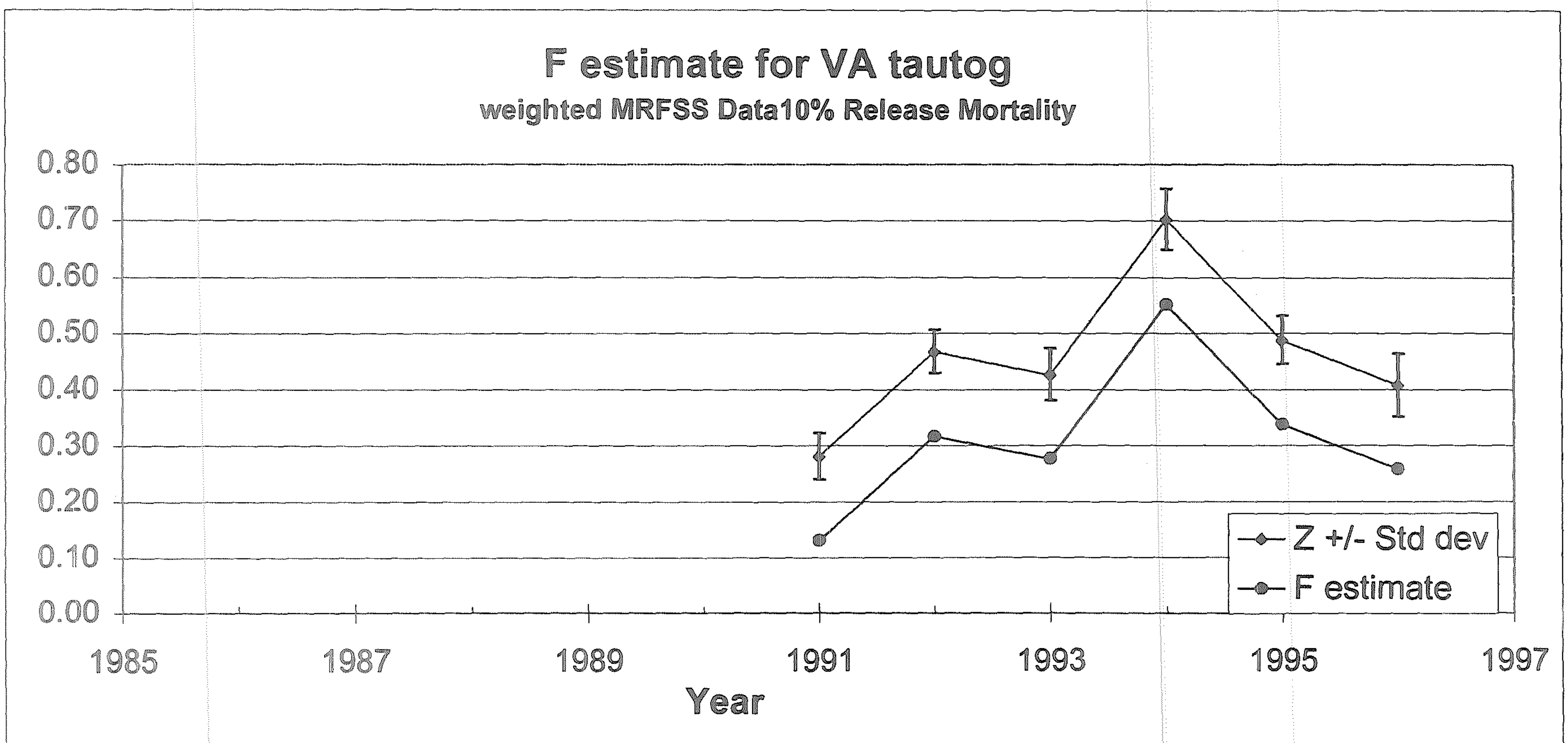


Figure V.5: Summary of Catch Curve Results: weighted MRFSS data, 10% release mortality.

Summary of single year estimates of F (avg F per year over all age classes)

Year	Z	Std error	Adj R sq	ssumed	F est
1985					
1986					
1987					
1988					
1989					
1990					
1991					
1992					
1993					
1994	0.5480	0.0476	0.9099	0.15	0.398
1995	0.4660	0.0375	0.9162	0.15	0.316
1996	0.3542	0.0316	0.9055	0.15	0.204

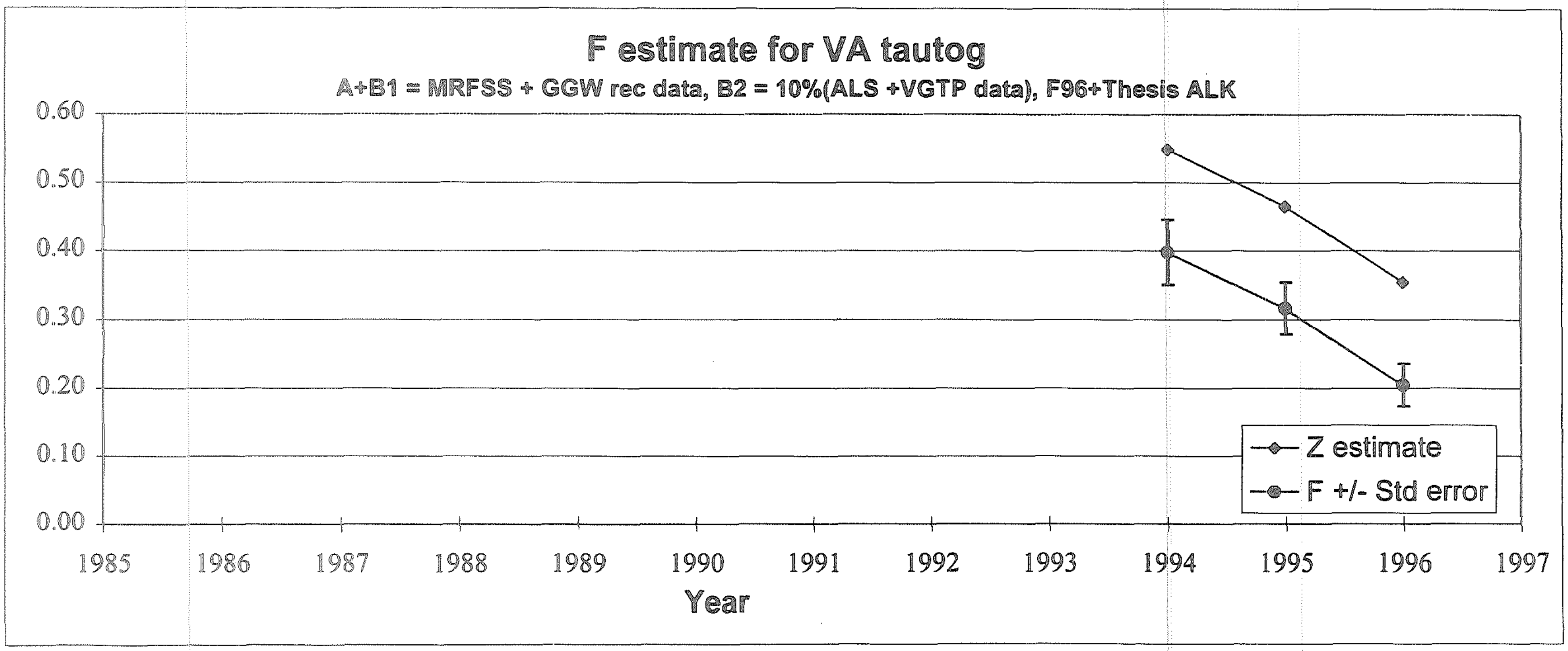


Figure V.6: Summary of Catch Curve Results: MRFSS + other data, 10% release mortality.

Summary of single year (Horizontal) estimates of F in Virginia (avg F per year over all age classes)

Year	MRFSS Unweighted 10% RM	MRFSS Unweighted 25% RM	MRFSS Weighted 10% RM	MRFSS Weighted 25% RM	MRFSS+Other VA data 10% RM	MRFSS+Other VA data 25% RM	F '96 Samples (not expanded) 10% RM	F '96 Samples (not expanded) 25% RM
1985	0.244	0.247						
1986	0.175	0.176						
1987	0.160	0.164						
1988	0.206	0.208						
1989	0.430	0.430						
1990	0.163	0.168						
1991	0.131	0.144	0.131	0.144				
1992	0.267	0.270	0.318	0.317				
1993	0.113	0.116	0.277	0.278				
1994	0.426	0.388	0.553	0.554	0.398	0.400		
1995	0.334	0.336	0.338	0.338	0.316	0.319		
1996	0.282	0.280	0.258	0.280	0.204	0.208	0.285	0.290
1997								
Avg 94-96	0.347	0.335	0.383	0.391	0.306	0.309		

Figure V.7: Comparison of all Catch Curve Results.

9.0 Literature Cited

Atlantic States Marine Fishery Commission. 1996. Fishery Management Plan for Tautog. Fishery Management Report No. 25 of the ASMFC. April 1996, 56 p.

Atlantic States Marine Fishery Commission. 1997. Fishery Management Plan for Tautog, Addendum 1. 11 p.

Bain, C.M. and J.A. Lucy. 1996. Virginia Game Fish Tagging Program Annual Report - 1995. Virginia Inst. Mar. Sci, College of William and Mary, Virginia Marine Resource Report No. 96-2 (VSG -96-02), 10 p.

Bain, C.M. and J.A. Lucy. 1997. Virginia Game Fish Tagging Program Annual Report - 1996. Virginia Inst. Mar. Sci, College of William and Mary, Virginia Marine Resource Report No. 97-7 (VSG-97-06), 14 p.

Bain, C.M. and J.A. Lucy. 1997. Unpublished Virginia Game Fish Tagging Program data - 1997. Virginia Inst. Mar. Sci, College of William and Mary.

Briggs, P.T. 1977. Status of tautog populations at artificial reefs in New York waters and effect of fishing. N.Y. Fish Game J. 24(2): 154-167.

Chapman, D.G., and D.S. Robson. 1960. The analysis of a catch curve. Biometrics, 16: 354-368.

Cooper, R. A. 1966. Migration and population estimation of the tautog, Tautoga onitis (Linnaeus), from Rhode Island. Trans. Amer. Fish. Soc. 95:239-247.

Lynch, T.R. 1991. Marine Finfish Investigation, Sport Fish Population Survey in Rhode Island Marine Waters - Tautog Studies, January 1, 1990 - December 31, 1990. Rhode Island Division of Fish & Wildlife Performance Report Project: F-54-R-1, Study I-I.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. (USA) 82: 898-903.

Hostetter, E. B. and T. A. Munroe. 1993. Age, growth, and reproduction of tautog Tautoga onitis (Labridae: Perciformes) from coastal waters of Virginia. Fish. Bull., U.S. 91:45-64.

Lucy, J.A. 1995. Tautog hook release mortality data from tag retention trials. Virginia Inst. Mar. Sci, College of William and Mary, Virginia Marine Resource Report No. 95-8.

Marine Recreational Fisheries Statistics Survey. 1997. Http://remora.ssp.nmfs.gov/recreational.index.html. Data on recreational fisheries.

National Marine Fisheries Service. 1997. Http://remora.ssp.nmfs.gov/ commercial/landings/ annual_landings.html. Data on commercial fisheries landings.

National Data Bouy Center. October 2, 1997. Www.olld.nos.noaa.gov. Water temperature data at Chesapeake Bay Bridge Tunnel, 1993-1996.

Olla, B.L., A.J. Bejda, and A.D. Martin. 1974. Daily activity, movements, feeding, and seasonal occurrence in the tautog, *Tautoga onitis*. Fish. Bull., U.S. 72(1): 27-35.

Pauly, D. 1984. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer., 39: 175-192.

Ricker, W.E. 1975. Handbook of computations for biological statistics of fish populations. Bulletin 191, Fish. Res. Board of Canada, Ottawa, Canada..

Robson, D.S., and D.G. Chapman. 1961. Catch Curves and Mortality Rates. Trans. Amer. Fish. Soc. 90(2): 181-189.

Simpson, D.G. 1996. Studies in conservation engineering. IN: A Study of Marine Recreational Fisheries in Connecticut. Annual Performance Report March 1, 1995-February 29, 1996. 91-97.

U.S. EPA Monitoring Program. Water Quality Data for Chesapeake Bay, 1985-1993.

Vetter, E. F. 1988. Estimation of natural mortality in fish stocks: A review. Fish. Bull. (USA) 86: 25-43.

White, G.G., T.A. Munroe and H.M. Austin. 1996. Reproductive Biology of tautog (*Tautoga onitis*) in Virginia Waters - Final Report submitted to the Virginia Marine Resource Commission - Saltwater Recreational License Fees. 100 p.

Tautog Citation Data: http://www.state.va.us/mrc/tautog4.htm

Appendix A: Sensitivity analysis of tautog F estimates.

Risk Assessment and Sensitivity Analyses

Specification and Overview of Risk and Sensitivity Analysis:

Given the data available on tautog for the Mid-Atlantic region, estimation of fishing mortality (F) can best be accomplished by conducting a catch-at-age analysis. With this approach, the number of fish, by age, is specified as a semi-log function of a constant and of age:

(1) $Catch_i = \alpha \exp^{\beta * AGE_i} \exp^{u_i}$

where Catch is the number of fish of the i^{th} age-group caught, age is the age of the fish, and u is an error term assumed to be $\sim N(0,\sigma_u^2)$. The parameter ß is an estimate of total mortality (Z). If natural mortality (M) is known, fishing mortality (F) may be estimated by subtracting the value of M from Z (i.e., F = Z - M). With an appropriate natural log transformation, Eq. (1) may be made linear in the parameters and estimated by conventional ordinary least squares (OLS):

(2) $\ln Catch_i = \gamma + \beta * AGE_i + u_i$

where ln indicates the natural logarithm and γ and ß are parameters to be estimated.

An alternative specification is a nonlinear version of Eq. (1) is which the error term is additive rather than multiplicative:

(3) $Catch_i = \alpha \exp^{\beta * AGE_i} + u_i$

where u_i is assumed to be $\sim N(0,\sigma_u^2)$. Equation (3) may not be transformed such that the equation in linear in the parameters; thus, Eq. (3) must be estimated via nonlinear regression. A possible reason for the nonlinear specification is that catch at age may be observed with error. There should, in fact, be some concern about the level of precision of the estimated number of fish caught by age. The number of fish caught at age were estimated using data obtained from relatively small samples over time.

The precision of estimates of total mortality (Z), and subsequently fishing mortality (F), based on catch-at-age analysis depends in large part of the accuracy of estimating the number of fish caught for each age group. Alternatively, an incorrect assignment of fish to a particular age class may lead to erroneous estimates of fishing mortality. All numbers of fish caught by age were estimated from samples obtained by several researchers over the period 1985 through 1996. Because of concerns about measurement error in the number of fish caught by age, both the linear and nonlinear variants of the catch-at-age equation are estimated.

Detailed analyses and conclusions about total and fishing mortalities, however, are based on results obtained from the linear models. This is because the linear models are typically used to estimate fishing mortality using the catch-at-age analysis. Moreover, results obtained from the nonlinear models suggested that fishing mortality was quite low compared to estimates obtained from the nonlinear models. Use of estimates based on the linear models thus offers a cautious regulatory framework or one that ensures resource conservation.

The linear version is subjected to a rather extensive sensitivity analysis. With the conventional catch-at-age approach, data points are determined by finding the maximum catch at age which establishes the first observation of the data set. Next, an end point is established, which is usually the most clearly distinguishable ending age class. With the natural logarithm transform, ordinary-least-squares (OLS) regression is used to estimate ß which is an estimate of total mortality or Z. Fishing mortality or F is estimated as the difference between Z and natural mortality; previous stock assessment work assumes that natural mortality or M equals 0.15.

The initial sensitivity analysis allowed the maximum catch at age point to be in error by 1, 2, 5, 10, 20, and 50 percent; the error was generated with respect to the maximum catch point and the catches for the preceding and succeeding ages (e.g., 1% of age 4 fish were added to the number of age 5 fish and subtracted from the age 4 fish). Another sensitivity analysis considered reducing or increasing the number of fish caught at the maximum age group, which was age 18 in this study. Reductions and additions of 1,2,5,10,20, and 50 percent were considered.

Another analysis used a random number generator based on the normal distribution to generate values with the means and standard deviations obtained from the initial ordinary least squares' estimated residuals; the mean of the error term, as consistent with OLS, approximately equalled zero for the estimates of all 12 years. A conventional random number generator could not be adequately used to assess results since there was no way to force consistency of the catch at age numbers with the age classes. In addition, a conventional generator may yield negative values for catch at age. The lognormal distribution could have been used to generate numbers of a rigorous Monte Carlo analysis or risk assessment; generating via the error term, however, served the same purpose as using the lognormal distribution. A remaining option was to use a truncated normal distribution to generate the catch at age series. Unfortunately, this option tended to generate extremely large numbers of catch at age without any consistency relative to age.

A remaining option was to use the mean and variance of each age group over the 12 year period to generate data series for each year. This latter approach, however, would require generating 100 observations for each of the 18 age groups for each year. That is, 1,800 values would have to be generated for each year. Then, 1,800 regressions would have to be conducted to obtain estimates of Z. It was decided that this latter analysis would be too time consuming. More important, however, is that the estimates of Z would be more indicative of the entire data series rather than of annual values of Z

With the selected approach, randomly generated values, based on the errors or residuals from the ordinary least squares, were added to the natural logarithm of catch to generate alternative values of catch at age. One-hundred sets of 18 observations for each data set characterizing 1985 through 1996 were generated. For each 18 observation dataset, estimates of total mortality were obtained; thus, a total of 1,200 estimates, or one-hundred for each year, of total mortality were made from the randomly generated data. Using this latter approach, the age corresponding to the maximum catch varied considerably for each year. This latter approach allowed for variation over age classes and with respect to the estimated total number of tautog caught by recreational and commercial anglers in each of the 12 years.

Linear vs. Nonlinear Estimates:

Unless there is substantial measurement error in the dependent variable, number of fish caught at age, the semi-log or multiplicative model specification is appropriate (i.e., Eq. 2) for estimating Z and subsequently F. In this study, however, the number of fish caught at age were estimated based on the distribution of age obtained from samples obtained between 1985 and 1996. There is thus an issue of measurement error in the dependent variable.

Unfortunately, there are no completely appropriate statistical procedures for determining whether or not the linear or nonlinear model is appropriate. A test used in this study is Hoel's (1947) test which requires conducting both the linear and nonlinear regressions, and then conducting simple t-tests using the fitted values of the number of fish caught at age. Alternative test procedures include Cox's (1961, 1962) test and Quandt's (1966) test based on minimum sum of squares of coverages. Cox's likelihood ratio test is similar to Hoel's test but is computationally burdensome.

The procedures of the Hoel test used in this study are as follows: (1) estimate the semi-log model and obtain the fitted values, f_1, for number of fish caught at age (i.e., antilog of fitted value of natural logarithm of catch); (2) estimate the nonlinear model and obtain the fitted values for number of fish caught at age, f_2; (3) regress the difference between the observed number of fish caught at age and the fitted number of fish caught at age from the OLS model against a constant and the difference between f_2 and f_1; (4) conduct a simple t-test of the coefficient for the difference between the two fitted values (i.e., test $\beta = 0$ in $(Catch - f_1) = \alpha + \beta (f_2 - f_1))$. If the coefficient in the regression is significantly positive, f_1, or the OLS model, is rejected in favor of the nonlinear model. Relative to the 12 estimates of Z, the OLS model was rejected in favor of the nonlinear model for the years 1986 through 1991 and 1994 through 1996; estimates for 1985, 1992, and 1993 were consistent with the ordinary-least-squares model (Table A1.)

Table A.1. Estimates of Z based on linear and nonlinear models[a]

Year	Linear model Z	R^2	Number Of Observations	Nonlinear model Z	R^{2b}	Reject OLS
1985	0.39744	0.86	12	0.35354	0.90	No
1986	0.32641	0.79	15	0.25741	0.98	Yes
1987	0.31414	0.88	14	0.27831	0.99	Yes
1988	0.35802	0.80	14	0.29791	0.88	Yes
1989	0.54565[c]	0.94	12	0.41115	0.92	Yes
1990	0.28500[c]	0.92	16	0.27202	0.91	Yes
1991	0.29387	0.84	12	0.30890	0.90	Yes
1992	0.41923	0.92	14	0.35504	0.96	No
1993	0.26591	0.83	14	0.27555	0.93	No
1994	0.52237[c]	0.94	14	0.24827	0.91	Yes
1995	0.48546	0.95	14	0.26925	0.93	Yes
1996	0.43012	0.94	14	0.25485	0.96	Yes

[a]Linear model is $\ln \mathit{Catch}_i = \gamma + \mathit{age}_i + u_i$; nonlinear model is $\mathit{Catch}_i = \alpha \exp^{(\beta\, \mathit{age}_i)} + u_i$.

[b]Nonlinear adjusted R^2 is not bounded between 0.0 and 1.0.

[c]Linear and nonlinear estimates corrected for first-order autocorrelation.

Although results of statistical tests suggest that the nonlinear model is appropriate for estimating Z and F for nine of the 12 years, subsequent estimates of F and associated analyses are based on the OLS or linear model. Estimates of F based on the nonlinear model tend to be lower than those obtained from the linear model. Moreover, the Hoel test is an imperfect test with low power. Finally, estimates of Z and F based on the log transformed or linear in parameters model tend to be cautious estimates and supportive of more stringent resource conservation measures.

95 Percent Confidence Intervals for Estimates of Z:

A critical evaluation of the estimates of Z indicate relatively small standard errors of Z. Even with relatively small standard errors, however, the 95% confidence intervals for Z are modestly large (Table A.2). For example, the 95% confidence interval for the 1985 estimate of Z is 0.2846 to 0.5103; the mean value is 0.39744. The 95% confidence intervals for F would be scaled by 0.15, which is the assumed natural mortality; the variance of F must equal the variance of Z since M is assumed constant--variance of Z equals variance of F since variance of M and covariance of F and M equal zero.

Sensitivity Analysis of Maximum Catch-at-age:

In this section, the sensitivity of estimates of Z and F are explored relative to assuming errors for the initial observation or the first observation corresponding to the maximum catch-at-age. For example, the maximum number of tautog caught in 1985

Table A.2. 95 % confidence intervals of Z based on OLS estimates[a]

Year	Mean Value	95% Confidence Interval[b]
1985	0.39744	0.5103,0.2846
1986	0.32641	0.4287,0.2242
1987	0.31414	0.3878,0.2405
1988	0.35802	0.4693,0.2468
1989	0.54565	0.6977,0.3936
1990	0.28500	0.4039,0.1661
1991	0.29387	0.3843,0.2034
1992	0.41923	0.4952,0.3432
1993	0.26591	0.3412,0.1906
1994	0.52237	0.6570,0.3877
1995	0.48546	0.5567,0.4143
1996	0.43012	0.5127,0.3482

[a]The 95% confidence interval for F would equal the 95% interval for Z less 0.15 (e.g., the 95% interval for F in 1985 would equal 0.3603,0.1346 and the mean value of F would equal 0.24744).

[b]The 95% confidence intervals are presented in what appears to be reverse order; the OLS estimates of Z, however, are negative.

corresponded to age 7--16,205 fish. The analysis considers that the number of fish caught at ages 6,7, and 8 may have been misclassified or incorrectly estimated by errors of 1,2,5,10,20, and 50%.

The initial analysis assumes that the maximum number of fish caught was overestimated and the subsequent age group was underestimated by the amount equal to the overestimated (e.g., the maximum number caught in 1985 equalled 16,205 and it is assumed that age class 8 was underestimated by one-percent, etc., of the number of age class 7 fish caught or 162 fish). The second analysis assumes that the subsequent age class was overestimated and the original age class was underestimated (e.g., it is assumed that the 13,495 age class 8 fish caught in 1985 was overestimated by one percent while the number of age class 7 fish caught was underestimated by one percent of the 13,495 age class 8 fish caught). The third analysis considers that the original age class was overestimated while the preceding age class was underestimated (e.g., age class 6 was underestimated in 1985 by an amount equal to one percent of the age class 7 fish or one percent of 16,205 fish). The fourth and final analysis considers that age class 7 was underestimated by an amount equal to a given percentage of age class 6 fish and the age class 6 fish were overestimated by a given percentage of age class 6 fish.

The results of the sensitivity analysis suggest that the estimates of Z and F are robust (Tables A.3-A.14). Errors as large as 50 percent do not substantially change estimates of Z. For example, allowing age class 8 to be underestimated by an error equal to 50 percent of the number of age class 7 fish caught in 1985 only marginally changes the estimate of Z from 0.39744 to 0.41906 (Table A.3).

Table A.3. Estimates of Z assuming errors in maximum catch at age, 1985[a]

Error Assumed	Estimate of Z | on error	Number of Observations
Age 7 overestimated and age 8 underestimated relative to age 7		
1	0.39743	12
2	0.39741	12
5	0.39730	12
10	0.40284	11
20	0.40747	11
50	0.41906	11
Age 7 underestimated and age 8 overestimated relative to age 8		
1	0.39745	12
2	0.39744	12
5	0.39740	12
10	0.39720	12
20	0.39635	12
50	0.38902	12
Age 7 overestimated and age 6 underestimated relative to age 7		
1	0.39706	12
2	0.39667	12
5	0.39547	12
10	0.39339	12
20	0.37654	13
50	0.37263	13
Age 7 underestimated and age 6 overestimated relative to age 6		
1	0.37479	12
2	0.39802	12
3	0.39887	12
10	0.40024	12
20	0.40285	12
50	0.40976	12

[a]Age i over or under estimated and age j under or over estimated relative to age k assumes that the error is applied to age k fish. Thus, the number of fish of age i is over or underestimated by an amount equal to the percent error applied to age k fish, and the number of fish of age j is under or over estimated by the same error. Initial estimate of Z equals 0.39744.

Table A.4. Estimates of Z assuming errors in maximum catch at age, 1986[a]

Error Assumed	Estimate of Z | on error	Number of Observations
Age 4 overestimated and age 5 underestimated relative to age 4		
1	0.32642	15
2	0.32643	15
5	0.32640	15
10	0.33526	14
20	0.33821	14
50	0.34558	14
Age 4 underestimated and age 5 overestimated relative to age 5		
1	0.32640	15
2	0.32639	15
5	0.32632	15
10	0.32612	15
20	0.32542	15
50	0.32014	15
Age 4 overestimated and age 6 underestimated relative to age 4		
1	0.32616	15
2	0.32591	15
5	0.32513	15
10	0.31277	16
20	0.31267	16
50	0.30916	16
Age 4 underestimated and age 6 overestimated relative to age 3		
1	0.32663	15
2	0.32684	15
3	0.32748	15
10	0.32849	15
20	0.33042	15
50	0.33543	15

[a]Age i over or under estimated and age j under or over estimated relative to age k assumes that the error is applied to age k fish. Thus, the number of fish of age i is over or underestimated by an amount equal to the percent error applied to age k fish, and the number of fish of age j is under or over estimated by the same error. Initial estimate of Z equals 0.32641.

Table A.5. Estimates of Z assuming errors in maximum catch at age, 1987[a]

Error Assumed	Estimate of Z | on error	Number of Observations
Age 5 overestimated and age 6 underestimated relative to age 5		
1	0.31417	14
2	0.31420	14
5	0.41424	14
10	0.30287	13
20	0.32460	13
50	0.33368	13
Age 5 underestimated and age 6 overestimated relative to age 6		
1	0.31411	14
2	0.31407	14
5	0.31394	14
10	0.31364	14
20	0.31271	14
50	0.30643	14
Age 5 overestimated and age 4 underestimated relative to age 5		
1	0.31385	14
2	0.31356	14
5	0.30308	15
10	0.30316	15
20	0.30294	15
50	0.29874	15
Age 5 underestimated and age 4 overestimated relative to age 4		
1	0.31440	14
2	0.31467	14
5	0.31544	14
10	0.31669	14
20	0.31903	14
50	0.32509	14

[a]Age i over or under estimated and age j under or over estimated relative to age k assumes that the error is applied to age k fish. Thus, the number of fish of age i is over or underestimated by an amount equal to the percent error applied to age k fish, and the number of fish of age j is under or over estimated by the same error. Initial estimate of Z equals 0.31414.

Table A.6. Estimates of Z assuming errors in maximum catch at age, 1988[a]

Error Assumed	Estimate of Z | on error	Number of Observations
Age 5 overestimated and age 6 underestimated relative to age 5		
1	0.35800	14
2	0.35798	14
5	0.35787	14
10	0.38474	13
20	0.38791	13
50	0.39591	13
Age 5 underestimated and age 6 overestimated relative to age 6		
1	0.35803	14
2	0.35804	14
5	0.35803	14
10	0.35792	14
20	0.35732	14
50	0.35181	14
Age 5 overestimated and age 4 underestimated relative to age 5		
1	0.35773	14
2	0.35744	14
5	0.33282	15
10	0.33289	15
20	0.33264	15
50	0.32837	15
Age 5 underestimated and age 4 overestimated relative to age 4		
1	0.35829	14
2	0.35856	14
5	0.35934	14
10	0.36061	14
20	0.36298	14
50	0.36910	14

[a]Age i over or under estimated and age j under or over estimated relative to age k assumes that the error is applied to age k fish. Thus, the number of fish of age i is over or underestimated by an amount equal to the percent error applied to age k fish, and the number of fish of age j is under or over estimated by the same error. Initial estimate of Z equals 0.35802.

Table A.7. Estimates of Z assuming errors in maximum catch at age, 1989[a]

Error Assumed	Estimate of Z | on error	Number of Observations
Age 7 overestimated and age 8 underestimated relative to age 7		
1	0.54531	12
2	0.54495	12
5	0.54389	12
10	0.56354	11
20	0.56929	11
50	0.58450	11
Age 7 underestimated and age 8 overestimated relative to age 8		
1	0.54597	12
2	0.54627	12
5	0.54716	12
10	0.54866	12
20	0.55165	12
50	0.55868	12
Age 7 overestimated and age 6 underestimated relative to age 7		
1	0.54513	12
2	0.54459	12
5	0.54293	12
10	0.54007	12
20	0.51023	13
50	0.52067	13
Age 7 underestimated and age 6 overestimated relative to age 6		
1	0.54301	12
2	0.54652	12
5	0.54777	12
10	0.54980	12
20	0.55368	12
50	0.56402	12

[a]Age i over or under estimated and age j under or over estimated relative to age k assumes that the error is applied to age k fish. Thus, the number of fish of age i is over or underestimated by an amount equal to the percent error applied to age k fish, and the number of fish of age j is under or over estimated by the same error. Initial estimate of Z equals 0.54565.

Table A.8. Estimates of Z assuming errors in maximum catch at age, 1990[a]

Error Assumed	Estimate of Z | on error	Number of Observations
Age 3 overestimated and age 4 underestimated relative to age 3		
1	0.28465	16
2	0.28430	16
5	0.28325	16
1	0.30536	15
20	0.31079	15
50	0.32396	15
Age 3 underestimated and age 4 overestimated relative to age 4		
1	0.28530	16
2	0.28559	16
5	0.28648	16
10	0.28795	16
20	0.29083	16
50	0.29795	16
Age 3 overestimated and age 2 underestimated relative to age 3		
1	0.28448	16
2	0.28395	16
5	0.28233	16
10	0.27950	16
20	0.25977	17
50	0.25200	17
Age 3 underestimated and age 2 overestimated relative to age 2		
1	0.28538	16
2	0.28576	16
5	0.28688	16
10	0.28868	16
20	0.29209	16
50	0.30095	16

[a]Age i over or under estimated and age j under or over estimated relative to age k assumes that the error is applied to age k fish. Thus, the number of fish of age i is over or underestimated by an amount equal to the percent error applied to age k fish, and the number of fish of age j is under or over estimated by the same error. Initial estimate of Z equals 0.28500.

Table A.9. Estimates of Z assuming errors in maximum catch at age, 1991[a]

Error Assumed	Estimate of Z | on error	Number of Observations
Age 7 overestimated and age 8 underestimated relative to age 7		
1	0.29411	12
2	0.29433	12
5	0.29370	13
10	0.29413	13
20	0.29428	13
50	0.30953	13
Age 7 underestimated and age 8 overestimated relative to age 8		
1	0.29375	12
2	0.29362	12
5	0.29321	12
10	0.29244	12
20	0.29052	12
50	0.28066	12
Age 7 overestimated and age 6 underestimated relative to age 7		
1	0.29349	12
2	0.29313	13
5	0.29325	13
10	0.29333	13
20	0.29302	13
50	0.28759	13
Age 7 underestimated and age 6 overestimated relative to age 6		
1	0.29296	12
2	0.29462	12
5	0.29571	12
10	0.29746	12
20	0.30075	12
50	0.30919	12

[a]Age i over or under estimated and age j under or over estimated relative to age k assumes that the error is applied to age k fish. Thus, the number of fish of age i is over or underestimated by an amount equal to the percent error applied to age k fish, and the number of fish of age j is under or over estimated by the same error. Initial estimate of Z equals 0.29387.

Table A.10. Estimates of Z assuming errors in maximum catch at age, 1992[a]

Error Assumed	Estimate of Z | on error	Number of Observations
Age 5 overestimated and age 6 underestimated relative to age 5		
1	0.41921	14
2	0.41919	14
5	0.41910	14
10	0.42631	13
20	0.43283	13
50	0.43944	13
Age 5 underestimated and age 6 overestimated relative to age 6		
1	0.41923	14
2	0.41922	14
5	0.41921	14
10	0.41908	14
20	0.41432	14
50	0.41284	14
Age 5 overestimated and age 4 underestimated relative to age 5		
1	0.41894	14
2	0.41865	14
5	0.40219	15
10	0.40230	15
20	0.40213	15
50	0.39804	15
Age 5 underestimated and age 4 overestimated relative to age 4		
1	0.41948	14
2	0.41974	14
5	0.42050	14
10	0.42171	14
20	0.42400	14
50	0.42994	14

[a]Age i over or under estimated and age j under or over estimated relative to age k assumes that the error is applied to age k fish. Thus, the number of fish of age i is over or underestimated by an amount equal to the percent error applied to age k fish, and the number of fish of age j is under or over estimated by the same error. Initial estimate of Z equals 0.41923.

Table A.11. Estimates of Z assuming errors in maximum catch at age, 1993[a]

Error Assumed	Estimate of Z | on error	Number of Observations
Age 5 overestimated and age 6 underestimated relative to age 5		
1	0.26589	14
2	0.26585	14
5	0.26763	13
10	0.26927	13
20	0.27233	13
50	0.27355	13
Age 5 underestimated and age 6 overestimated relative to age 6		
1	0.26594	14
2	0.26590	14
5	0.26577	14
10	0.26091	14
20	0.25732	14
50	0.25006	14
Age 5 overestimated and age 4 underestimated relative to age 5		
1	0.26563	14
2	0.26534	14
5	0.26445	14
10	0.25591	15
20	0.25440	15
50	0.24708	15
Age 5 underestimated and age 4 overestimated relative to age 4		
1	0.26609	14
2	0.26626	14
3	0.26678	14
10	0.26761	14
20	0.26922	14
50	0.27355	14

[a]Age i over or under estimated and age j under or over estimated relative to age k assumes that the error is applied to age k fish. Thus, the number of fish of age i is over or underestimated by an amount equal to the percent error applied to age k fish, and the number of fish of age j is under or over estimated by the same error. Initial estimate of Z equals 0.26591.

Table A.12. Estimates of Z assuming errors in maximum catch at age, 1994[a]

Error Assumed	Estimate of Z | on error	Number of Observations
Age 5 overestimated and age 6 underestimated relative to age 5		
1	0.52000	14
2	0.52045	14
5	0.52177	14
10	0.52389	14
20	0.52779	14
50	0.53816	13
Age 5 underestimated and age 6 overestimated relative to age 6		
1	0.52382	14
2	0.52408	14
5	0.52482	14
10	0.52599	14
20	0.52954	14
50	0.53002	14
Age 5 overestimated and age 4 underestimated relative to age 5		
1	0.52307	14
2	0.51954	14
5	0.51094	15
10	0.50471	15
20	0.49832	15
50	0.48161	15
Age 5 underestimated and age 4 overestimated relative to age 4		
1	0.52392	14
2	0.52426	14
5	0.52529	14
10	0.52695	14
20	0.53007	14
50	0.53816	14

[a]Age i over or under estimated and age j under or over estimated relative to age k assumes that the error is applied to age k fish. Thus, the number of fish of age i is over or underestimated by an amount equal to the percent error applied to age k fish, and the number of fish of age j is under or over estimated by the same error. Initial estimate of Z equals 0.52237.

Table A.13. Estimates of Z assuming errors in maximum catch at age, 1995[a]

Error Assumed	Estimate of Z | on error	Number of Observations
Age 5 overestimated and age 6 underestimated relative to age 5		
1	0.48547	14
2	0.48546	14
5	0.48541	14
10	0.51605	13
20	0.51941	13
50	0.52414	13
Age 5 underestimated and age 6 overestimated relative to age 6		
1	0.48546	14
2	0.48545	14
5	0.48539	14
10	0.48519	14
20	0.48417	14
50	0.47862	14
Age 5 overestimated and age 4 underestimated relative to age 5		
1	0.48218	14
2	0.48489	14
5	0.48400	14
10	0.48245	14
20	0.44874	15
50	0.44580	15
Age 5 underestimated and age 4 overestimated relative to age 4		
1	0.48567	14
2	0.48587	14
3	0.48646	14
10	0.48742	14
20	0.48926	14
50	0.49414	14

[a]Age i over or under estimated and age j under or over estimated relative to age k assumes that the error is applied to age k fish. Thus, the number of fish of age i is over or underestimated by an amount equal to the percent error applied to age k fish, and the number of fish of age j is under or over estimated by the same error. Initial estimate of Z equals 0.48546.

Table A.14. Estimates of Z assuming errors in maximum catch at age, 1996[a]

Error Assumed	Estimate of Z | on error	Number of Observations
Age 5 overestimated and age 6 underestimated relative to age 5		
1	0.43119	14
2	0.43006	14
5	0.45675	13
10	0.45841	13
20	0.46149	13
50	0.46975	13
Age 5 underestimated and age 6 overestimated relative to age 6		
1	0.43014	14
2	0.43000	14
5	0.42916	14
10	0.42109	14
20	0.42501	14
50	0.42018	14
Age 5 overestimated and age 4 underestimated relative to age 5		
1	0.42983	14
2	0.42954	14
5	0.42865	14
10	0.39501	15
20	0.39846	15
50	0.39493	15
Age 5 underestimated and age 4 overestimated relative to age 4		
1	0.43035	14
2	0.43057	14
5	0.43124	14
10	0.43232	14
20	0.43437	14
50	0.43975	14

[a]Age i over or under estimated and age j under or over estimated relative to age k assumes that the error is applied to age k fish. Thus, the number of fish of age i is over or underestimated by an amount equal to the percent error applied to age k fish, and the number of fish of age j is under or over estimated by the same error. Initial estimate of Z equals 0.43012.

Analysis Assuming Errors in Number of Age Class 18 Fish Caught:

In this section, the sensitivity of estimates of Z relative to over and under misclassifications of the number of fish caught at age 18 is explored. Errors equal to 1,2,5,10,20, and 50% of the number of age 18 fish caught are considered. For example, if it is assumed that the number of age 18 fish caught is overestimated by 1%, the number of fish caught at age 18 is set equal to the original value less 1% of the original value of age 18 fish. Subsequently, ordinary-least-squares, with appropriate corrections for first-order autocorrelation, are used to obtain estimates of Z for each of the 12 years. Overall, the estimates of Z are very robust and not particularly sensitive to changes in the number of age 18 fish caught (Table A.15).

Another analysis relative to the number of fish caught at age 18 is conducted. It is assumed that age 18 fish cannot be distinguished from age 19 plus fish or the sampling distribution is in error. Thus, the ending or maximum age group is age 17. Estimates were found to be very robust and only modestly sensitive to changes in the number of fish assigned to the ending or maximum observable age group (Table A.16). For example, the estimate of Z for 1996 based on the original data equalled 0.43012; the estimate of Z based on deleting the observation for age group 18 or using only the observations corresponding to age 5 through age 17 equalled 0.39743.

Table A.15. Estimates of Z assuming errors in number of fish at age 18 caught[a]

Year	Initial Estimate	Error Level-% of age 18, Age 18 overestimated, Z: 1	2	5	10	20	50	Error Level-% of age 18, Age 18 underestimated, Z: 1	2	5	10	20	50
1985	0.39744	0.39783	0.39822	0.39972	0.40150	0.40603	0.42410	0.39706	0.39668	0.39557	0.39378	0.39043	0.38185
1986	0.32641	0.32666	0.32692	0.32770	0.32905	0.33199	0.34374	0.32616	0.32592	0.32519	0.32403	0.32186	0.31628
1987	0.31414	0.31442	0.31471	0.31560	0.31715	0.32051	0.33394	0.31385	0.31357	0.31274	0.31141	0.30893	0.30285
1988	0.35802	0.35831	0.35860	0.35949	0.36103	0.36440	0.37783	0.35774	0.35746	0.35663	0.35530	0.35281	0.34644
1989	0.54565	0.54623	0.54680	0.54856	0.55165	0.55854	0.58776	0.54512	0.54457	0.54297	0.54043	0.53577	0.52437
1990	0.28500	0.28542	0.28586	0.28720	0.28957	0.59490	0.31731	0.28458	0.28416	0.28295	0.28105	0.27761	0.26958
1991	0.29387	0.29426	0.29465	0.29585	0.29793	0.30246	0.32053	0.29349	0.29311	0.29200	0.29021	0.28686	0.27828
1992	0.41923	0.41951	0.41980	0.42069	0.42224	0.42560	0.43903	0.41894	0.41866	0.41783	0.41650	0.41402	0.40764
1993	0.26591	0.26620	0.26649	0.26738	0.26892	0.27229	0.28572	0.26563	0.26535	0.26452	0.26319	0.26070	0.25433
1994	0.52237	0.52406	0.52455	0.52606	0.52867	0.53428	0.55504	0.52308	0.52260	0.52118	0.51891	0.51465	0.50386
1995	0.48546	0.48575	0.48604	0.48693	0.48847	0.49184	0.50527	0.48518	0.48490	0.48407	0.48274	0.48025	0.47388
1996	0.43012	0.43040	0.43069	0.43158	0.43313	0.43649	0.44992	0.42983	0.42955	0.42872	0.42739	0.42491	0.41853

[a]Number of fish caught at age 18 set equal to number of fish caught at age 18 plus (minus) 1,2,5,10,20, and 50% of number of fish caught at age 18. Percent of number of fish caught at age 18 is deducted from original series if believed to be overestimated, and if thought to be underestimated, percent of number of fish caught at age 18 is added to original series.

Table A.16. Estimates of Z conditional (|) on maximum age of 17 (deletion of age 18 fish)

Year	Estimate of Z | maximum age = 18	R^2	Estimate of Z | maximum age = 17	Standard Error	R^2
1985	0.39744	0.86	0.45888	0.04343	0.93
1986	0.32641	0.79	0.38457	0.03854	0.89
1987	0.31414	0.88	0.34556	0.03333	0.91
1988	0.35802	0.80	0.41148	0.04750	0.87
1989	0.54565	0.94	0.62186	0.05790	0.95
1990	0.28500	0.92	0.29111	0.05976	0.92
1991	0.29387	0.84	0.25768	0.04185	0.81
1992	0.41923	0.92	0.41322	0.04052	0.90
1993	0.26591	0.83	0.24407	0.03758	0.79
1994	0.52357	0.94	0.49403	0.06759	0.94
1995	0.48546	0.95	0.44380	0.02582	0.96
1996	0.43012	0.94	0.39743	0.02837	0.95

Sensitivity Analysis Allowing Number of Fish Caught To Change for All Age Classes:

The final sensitivity analysis allows the number of fish caught to change for all age classes. Rather than the conventional Monte Carlo analysis in which the variable under study is allowed to be randomly generated consistent with a given distribution, this analysis uses the error term from the OLS regressions and uses a normal distribution, $N(0,\sigma_u^2)$, to generate 100 values for each age class and each year. Alternative options considered or explored included the following: (1) randomly distributed values consistent with the normal distribution and the mean and variance for the original series for each year; (2) a similar lognormal distribution; (3) a similar truncated distribution with truncation at the original maximum number caught; and (4) randomly distributed values for each age class based on a normal distribution and mean and variance equal to those for the number of fish caught at each age relative to all 12 years.

After preliminary analysis, all four approaches were deemed to be inappropriate. The conventional approach based on the normal distribution, method 1, generated large negative values of catch. The lognormal distribution generated extremely large values and often too few observations for estimation. The truncated normal generated very large values and restricted the first observation to the original first observation, and thus, did not permit an analysis of change in the maximum number caught at age. The last approach, method 4, offered little analytical information relative to a single year and was found to be more appropriate to try to estimate an average Z or F over the 12 years. Because of these problems, it was decided to generate catch numbers based on the error term obtained from OLS and the normal distribution.

The mean value of the error term was approximately zero as expected with OLS. Thus, 100 values of the number of fish caught at each age were generated for each year based on randomly generated values of the error term. Catch was subsequently set equal to the antilog of the natural logarithm of the original catch plus the randomly generated error term-- $Catch_g = \exp^{(\ln Catch_O + U)}$ where g indicates generated catch, O indicates original series and U is the randomly distributed error term. Similar to the preceding sensitivity analyses, estimates of Z and F were found to be very robust with only minor differences in the mean values of the estimated Zs (Table A.17).

Using the semi-log model, Z was estimated 100 times for each year using ordinary-least-squares regression or generalized least squares if autocorrelation or heteroscedasticity was found. While individual estimates of Z were found to be sensitive to changes in the number of fish caught at age, the mean values were quite close to the original estimates; for all years, the mean value of the estimated 100 Z values was within the 95% confidence interval of the original estimated value of Z. Although not presented in this appendix, the probability density functions and cumulative distribution functions were derived for all estimates of Z based on the 100 generated values for each year; graphs of the PDFs and CDFs are available from the authors. In general, the PDFs were quite tight around the central tendency of the estimated values.

References

Cox, D.R. (1961). Tests of separate families of hypotheses. In: Proceedings of the fourth Berkkely symposium on probability and statistics, Vol. 1, pp. 105-123.

Cox, D.R. (1962). Further results on tests of separate families of hypotheses. Journal of the Royal Statistical Society B@$, pp. 406-423.

Hoel, P.G. (1947). On the choice of forecasting formulas. Journal of the American Statistical Association 24, pp. 605-611.

Quandt, R.E. (1966). Old and new methods of estimation and the Pareto distribution. Metrika 10, pp. 55-82.

Appendix B: Letter from Jon Lucy regarding release mortality rates.

The College Of
WILLIAM & MARY

Chartered 1693

Virginia Institute of Marine Science
School of Marine Science

P. O. Box 1346
Gloucester Point, Virginia 23062
804/642-7000, Fax 804/642-7097, Scats 842-7000

December 22, 1997

Mr. Geoffrey White
Virginia Institute of Marine Science
PO Box 1346
Gloucester Point, VA 23062

Dear Geoff:

As requested, I am providing you with preliminary results of our hook release mortality study on tautog, *Tautoga onitis*. During November-December 1997, we captured by hook and line, using fresh hard crab bait, a total of 176 fish, 62 of which were taken from "shallow" water depths (<33 ft/10.3 m) and 114 from "deep water" depths (35-55 ft /10.9-17.2 m). Overall fish size ranged from approximately 9-20 in (229-508 mm) TL and water temperatures 61-49 F (16.1-9.4 C). In general, fish were caught, held in aerated livewells for 10-45 minutes, then transferred to live cages and returned to depth of capture in the vicinity of the capture site. Fish were left on the bottom in cages typically 3-6 days, with one group of 17 deep-water fish left in cages for 14 days (a storm moved the cages and they could not be found until 14 days after deployment). Data collection concluded last week and therefore analysis is continuing.

There was no hook release mortality in the 62 shallow-water caught fish. Three of the 114 deep-water caught fish died in the cages, a hook release mortality rate of 2.6 % for the deep-water fish.. One of the dead fish was deeply gut-hooked with the hook removed, one had a deformed left operculum, and the third fish appeared to have no special hooking-landing problems. For the combined samples of shallow and deep water caught fish, three of 176 fish died in live cages, an overall hook release mortality rate of 1.7 %.

This preliminary data analysis supports levels of tautog hook release mortality also documented by David Simpson in Connecticut. Therefore, similar research results on tautog hook release mortality in both the northern and southern portions of the species' range provide evidence that the Tautog Fishery Management Plan should consider using, at a minimum, a hook release mortality rate of 10 %, not the current rate of 25 %, to more accurately reflect field studies on this issue.

Sincerely,

Jon A. Lucy

Jon A. Lucy
Marine Scientist Supervisor
VA Sea Grant Marine Advisory Program

cc: W. DuPaul

SMS VIMS

Virginia Sea Grant College Program
Marine Advisory Program

Appendix C: Letter from Najih Lazar regarding this project.

Atlantic States Marine Fisheries Commission
1444 Eye Street, N.W., Sixth Floor
Washington, D.C. 20005
(202) 289-6400 phone
(202) 289-6051 fax

December 18, 1997

Jeoffrey White
Virginia Institute of Marine Science
PO Box 1346
Gloucester Point, VA 23062

Dear Jeff,

Please find is my brief review of your report entitled " quantitative assessment of fishing mortality for tautog in Virginia".

Overall your assessment of the status of exploitation on tautog in the waters of Virginia was appropriate using the available data, and results can be averaged for the last several years and used for the state of Virginia estimate of fishing mortality. Caveats related to catch curve analysis should be spelled out and note that this method is not the best for calculating point estimates for reasons known to you such as survival and recruitment variability. Other principal elements that cause a bias in the catch curve analysis need to be pointed out as well. A decrease in vulnerability to fishing with age, which can be the case in tautog, would not be reflected in the catch ratio or would be imperfectly reflected, also a long term trends in recruitment deflect the slope of a catch curve without introducing much of any curvature which would have a tendency in increase in survival rate.

However your significant sampling in both recreational and commercial landings and age samples made your analysis more robust in trying to capture the exploitation trend over time. In addition life history of tautog which is characterized by small changes in recruitment over time helps reduce variability in survival estimate. It is therefore crucial to continue collecting data on tautog fisheries initiated by this project and increasing sample size in the tagging project to be able to better perform future assessments.

On page 2:
The long term goal of the ASMFC plan is to reach F=0.15 and not F=0.24. The later is an interim target to be reached by the end of 1998. You do have the correct statement about the plan goals on page 9.

On bottom page 3:
The statement is not well supported when describing the relationship between the landings and exploitation and use it for comparing north and south stocks. The basic assumption here is a simple linear relationship between catch and stock size with constant effort ($CPUE=q\,B$, where q is the catchability and B is biomass) has little basis in fact. This has been shown to be the case in wide variety of fisheries such as trawl fisheries for cod and purse seine fisheries for sardines. Landings declined in the northern areas in the late 1980's due in part to stringent regulations in addition to heavy exploitation on a already depressed stock(s). The size structure between areas were not formally compared, but did not show any size truncation over the 16 year period that we examined. The reason this size distribution remained extended is because of practices in this fisheries exploring new grounds (reefs) every year.

Despite the short time period of the tag and recapture data, it is still a very essential element for supporting estimates of mortality that you performed. Because you do not have an index of abundance that can calibrate you catch-at-age analysis, the continuation of this program will be needed to build a good time series for VAP tunings. I performed a very simple exploitation index for the 1995 and 1996 using the matrix on Table 5x of your report, and found a range of fishing mortality from 0.2-0.3 in 1995 and 0.25-0.37 in 1996 assuming a wide variety of tag induced mortality and tag loss rates. These values, as you can see, are within the range of your catch curve estimates.
I would suggest to develop a catch-per-unit of effort from either commercial or recreational fisheries in order to run a comparison of individual year-classes and avoid the difficulties caused by variable recruitment. A sensitivity analysis of catch curve introducing errors in the catch-at-age data which can be caused by sampling or age data would be useful.

Please call if you have any questions regarding my comments.

Najih Lazar
Stock Assessment Biologist

Cc: Lisa Kline
George Lepointe

Table 14. Percent reductions in tautog recreational fisheries at different possession limits by state. No discard mortality assumption is included.

Possession Limit/State	CT	DE	MD	MA	NJ	NY	RI	VA
1	72.75	83.06	78.35	85.61	74.93	80.30	85.18	78.89
2	58.95	70.82	63.23	75.64	60.87	66.83	73.90	64.41
3	48.15	60.89	53.36	68.35	50.94	56.68	64.72	54.62
4	39.79	52.49	44.98	62.92	43.79	48.41	56.84	47.73
5	32.39	45.17	38.96	58.28	37.85	41.85	50.09	41.27
6	25.97	38.87	32.54	54.54	33.34	36.36	44.53	35.91
7	22.10	33.42	28.41	51.15	29.73	31.87	39.84	32.05
8	18.95	28.87	25.08	47.98	26.30	27.89	35.67	28.77
9	16.71	24.79	21.99	45.07	23.44	24.49	32.22	25.75
10	14.82	21.19	18.98	42.47	20.73	21.39	29.24	22.79
11	13.17	18.72	17.18	40.36	18.47	18.94	26.60	20.17
12	11.75	16.42	14.88	38.36	16.36	16.63	24.11	17.69

Note: Percent reductions in Table 14 are based on an assumption of no seasonal closure. See * below.

Table 15. Percent reduction in tautog recreational landings for bi-monthly seasonal closures (percent landings from MRFSS by state and wave, no discard mortality assumption).

Wave	CT	DE	MD	MA	NJ	NY	RI	VA	Mean
Jan-Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar-Apr	1.01	7.61	16.86	1.83	3.91	1.98	2.04	18.46	6.71
May-June	35.50	13.95	17.61	23.32	19.24	28.69	19.45	17.20	21.87
July-Aug	19.61	8.23	5.54	29.61	7.40	4.33	20.17	6.04	12.62
Sep-Oct	31.25	51.77	59.47	32.81	54.90	46.23	38.97	35.88	43.91
Nov-Dec	12.63	18.44	0.51	12.44	14.55	18.77	19.37	22.42	14.89

Note: Percent reductions in Table 15 are based on an assumption of no possession limit. See* below.

* The values in Tables 14 and 15 are not additive. Therefore, if both possession limits and seasonal closures are used, the total reduction is not the sum of the values from each table. To determine the total reduction, it is necessary to account for the effects of one measure on the other. This can be done using the following formula:

Total reduction = X + {(1-X)*Y};
X = the percent reduction value from the seasonal closure table,
Y = the percent reduction value from the possession limit table.