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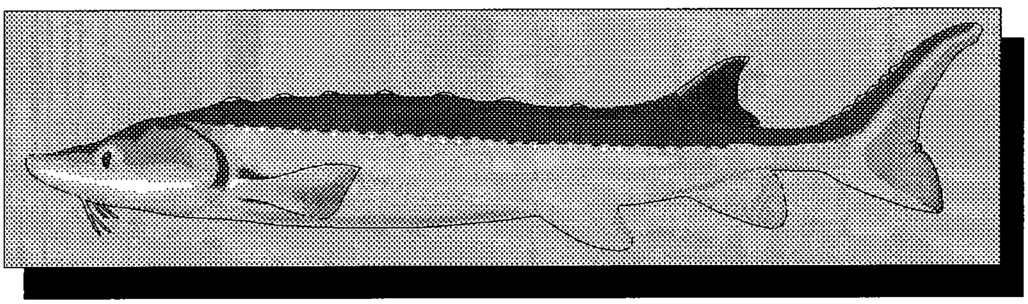
Demographic Analysis of Atlantic Sturgeon Fisheries in the New York Bight



Jill T. Stevenson
and
David H. Secor

The University of Maryland System
Center for Environmental and Estuarine Studies
Chesapeake Biological Laboratory
Solomons, MD 20688-0038

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INTRODUCTION

The Hudson River Atlantic sturgeon population supports commercial fisheries in New York and New Jersey. Levels of exploitation which can be sustained by these fisheries depend upon rates of mortality, individual growth , and reproduction. This report provides preliminary demographic data and analysis of the Hudson River Atlantic sturgeon population. The demographic analysis is part of a larger study on the life history and migrations of Atlantic sturgeon, funded by the Hudson River Foundation.

Age, year-class, and length data are summarized for fisheries in the Hudson River (River Harvest) and coastal regions of Long Island and New Jersey (Ocean Harvest). Estimates of age-at-entry, growth rate, and mortality rate are provided to support fishery management models of the Hudson River population.

METHODS

Pectoral fin rays and otoliths of adult Atlantic sturgeon (>152 cm total length [TL]) from the Hudson River were collected from fish made available to us by commercial fishermen (1992-1995). When total length was not measured directly, we computed total length from dressed carcass weight based upon a regression equation determined for the Hudson River population. The conversion of dressed weight to total length showed much greater precision ($r^2 = 0.96$) than conversion of dressed carcass length to total length ($r^2 = 0.79$) (Secor 1995). Samples from New Jersey and Long Island marine waters (1991, 1993, 1995 [NJ] and 1993 [LI]) were provided by New York Dept. of Environmental Conservation (NYDEC) and New Jersey Dept. of Environmental Protection (NJDEP). Fin rays and otoliths were also obtained from smaller, immature fish which were gillnetted by research teams on the Hudson River. Pectoral fin rays were embedded, sectioned, and polished for age estimation. Ageing precision was determined between two readers at Chesapeake Biological Laboratory (CBL.) ageing the same fin ray preparations, and between one reader at Univ. of California-Davis (U.C.-Davis) and one reader at CBL ageing different fin rays and preparations from the same fish. Ages were also estimated using the sagittal otolith and these ages were compared to those estimated from fin ray sections. Because fin ray age estimates have not yet been determined for the Long Island fishery, ages were computed for length classes using the von Bertalanffy equation determined for the Hudson River fishery (see below). The expression for the age-at-length calculation is given by Gulland (1988) as,

$$T = 1/K * \log_e(L_\infty / [L_\infty - l_t]) + t_0$$

where K, L_∞, and t_0 are von Bertalanffy growth parameters and l_t is length class at age T.

The von Bertalanffy growth model was fit to length-at-age and weight-at-age data for the Hudson River fishery sample. To weight ages equally and smooth interannual growth trends, three-year running averages were used. von Bertalanffy models were also fit to age and length data reported in the literature (Dovel and Berrgren 1983; Doroshov et al. 1994; Magnin 1964.)

Estimates of total mortality rate were made from the slope of the descending limb of catch curves from commercial gillnet fisheries in the New York Bight. Because we lacked effort data, we assumed catch data was proportional to population abundance. The number of participants in the Hudson River fishery and their method of fishing did not change substantially during the study period. Therefore, effort may have been fairly constant over the sampling years in the Hudson River. However, this was not the case in the New Jersey fishery where fishermen have shifted targeted harvest from Atlantic sturgeon (1991, 1993 samples) to monkfish (1995 samples). In 1995, sturgeon were harvested predominantly as incidental catch. Changing regulations and coastal storms resulting in destruction of gear have also altered fishing effort trends (B. Andrews, pers. comm., NJDEP, Port Republic, N.J.). Because of these uncertainties, we did not calculate a mortality rate for the New Jersey fishery. Gear used in the Long Island fishery selectively exploits smaller and younger sturgeon (K. McKown, pers. comm., NYDEC, Stony Brook, NY). Therefore, mortality rate for this fishery may be overestimated. Natural mortality can be estimated with a regression based on growth parameters and water temperature:

$$M = 10^{[-0.0066 - 0.279 \log_{10}(L_\infty) + 0.6543 \log_{10}(K) + 0.4632 \log_{10}(T)]} \quad \text{(Pauly 1980)}$$

where M = instantaneous rate of annual mortality, K and L_∞ are parameters from the von Bertalanffy growth model, and T = 13°C, the mean annual water temperature for the mid-Hudson River at river mile 66 (Macroni et al. 1992).

RESULTS AND DISCUSSION

Precision and Accuracy (Figure 1)

Precision was estimated based upon the absolute mean difference between age estimates from different readers. The relative mean difference between age estimates was used to estimate bias. Precision between readers at the same laboratory and at different laboratories was 1.2 years and 4.6 years, respectively. There was no significant bias between age estimates ($P>0.05$) for between lab and within lab comparisons. This suggests that an underlying structural feature was consistently recognized as an annulus regardless of differences in preparation or observation techniques. Because no bias was detected between readers, and ageing precision was unaffected by age (difference in annuli counts regressed upon age resulted in a non-significant relationship; $P>0.05$), discrepancies in age estimates probably did not affect growth and mortality estimates. Ageing imprecision will affect the distribution of assigned ages and year-classes. Because precision was reduced in the between-laboratory comparison, age estimates combined from different laboratories should be used cautiously.

Ages estimated from otoliths were significantly lower than those estimated from fin rays (bias = -5.5 years, df = 95, $P>0.05$), especially for fish with fin ray ages >20 years old. Fin rays were easier to prepare, and associated age estimates were more precise. Therefore we recommend the use of fin rays over otoliths in demographic studies of Atlantic sturgeon. We are now evaluating the accuracy of age estimates using radiometric dating, oxytetracycline marking experiments, chemical microanalysis, and marginal increment analysis.

Size and Age Distributions

Hudson River Harvest (Figure 2)

Large, spawning females were targeted in the River Fishery for their roe using 10-14" stretched mesh gillnets. River harvested sturgeon were larger than sturgeon caught in the ocean fisheries ($P = 0.004$). Additionally, harvested females were larger than harvested males ($P<0.001$). Mean sizes of females and males were 209 cm and 175 cm, respectively. The relatively few undersized fish (<152 cm

TL) may have resulted from imprecision in converting reported dressed weight and length measurements to total length.

Atlantic sturgeon harvested in the Hudson River ranged in age from 9-42 years old (aged sample = 235 fish.). Female ages (n = 50) were broadly distributed with a mode at 19 years of age. Males (n = 215) exhibited a more peaked distribution with a large mode at 16 years of age. Year-classes ranged from 1953 to 1981 for females and 1960 to 1984 for males. There were no apparent gaps in age structure which might indicate a series of failed year-classes. Seventy-five percent of the sample represented 1973-1980 year-classes. Males and females sampled in 1995 were significantly older than those collected in 1992-1994 (Kruskal-Wallis Rank test, males: $P<0.001$; females: $P = 0.03$).

Ocean Harvest (Figures 3 and 4)

Atlantic sturgeon harvested in the ocean fisheries ranged in age from 9-29 years old with a mean age of 16 years (New Jersey aged sample = 96 fish; Long Island fishery ages derived from age-length key = 249 fish). Total lengths ranged from 102-260 cm. The mean total length was 170 cm. There was no significant difference in size or age between males and females for either Long Island and New Jersey fisheries ($P>0.05$). Few large females (>250 cm) were caught in the ocean fisheries. Similar to the Hudson River Fishery, the New Jersey fishery is predominantly comprised of year classes produced from 1973-1980 (80%). Ages converted from length data for the Long Island Fishery also showed a predominance of year-classes from the 1973-1980 period. Gaps in age- and year-classes depicted for the Long Island fishery are probably due to the method of converting length-classes to age (see Methods) rather than missing year classes. These gaps were not apparent in the Hudson River and New Jersey fishery samples.

<u>Sex Distribution</u> (Figure 5)

Hudson River Harvest

Sex ratio of fish sampled from the Hudson River was 3:1 males:females (n = 267), although larger fish were predominantly females. All fish >225 cm TL were females and greater than 90% of fish <176 cm TL were males.

Ocean Harvest

Sexes were more evenly distributed throughout all size-classes for the ocean harvest than the River harvest sample. The sex ratio was 43% males; 57% females (n = 291). Twenty-three percent of the Long Island sample was not sexed. Females comprised 100% and 88% of all fish >225 cm TL in N.J. and L.I., respectively. It is likely that large females were underrepresented in the ocean fisheries due to gear selectivity. Sex distribution probably will change if New York and New Jersey adopt a 7 foot TL minimum size limit as stipulated in the Atlantic States Marine Fisheries Commission (ASMFC) Fishery Management Plan (ASMFC 1990).

Age at Entry (Figure 6)

Fish enter the Hudson River and ocean fisheries (5-ft. limit) at a mean age of 16 years. If a seven foot limit were to be imposed in the Hudson River, mean age at entry would climb to about 21 years of age; most or all of Atlantic sturgeon this size would be female.

Growth Rate (Hudson River Fishery) (Figures 7 and 8)

Males grew quickly (K = 0.16) but reached the asymptotic growth stanza at a younger age and size than females. Few males exceeded 200 cm TL in the Hudson River fishery; males may be incapable of achieving the stipulated 7-ft. minimum size limit (ASMFC 1990). Females approached the asymptote at a similar rate to males (K = 0.15) but achieved a much greater asymptotic length. Our sex-specific growth curves yielded much higher estimates of K and somewhat lower values of L_∞ than values estimated from past studies (Table 1) (Doroshov et al. 1994; Dovel and Berggren 1983; Magnin 1964). The growth model underestimated the observed age at entry for both males and females.

Table 1. Growth parameters as determined by von Bertalanffy growth model.

	CBL	University of Calif-Davis	Dovel and Berggren (1983)	Magnin (1964)	CBL
	Females	Females	Females and Males	Females and Males	Males
L_∞	225.1 ± 7.6 (88.6")	258.9 ± 49.2 (101.6")	361.9 ± 38.5 (142.5")	314.8 ± 9.3 (123.9")	191.4 ± 3.6 (75.3")
K	0.15 ± 0.03	0.08 ± 0.11	0.03 ± 0.006	0.03 ± 0.002	0.16 ± 0.02
t_0	3.8 ± 0.7	-3.3 ± 16.0	-2.8 ± 0.4	-0.7 ± 0.3	2.4 ± 0.72
Range in ages	5 - 42	12 - 26	0 - 29	1 - 60	5 - 35
Age @ 5 feet	11	8	15	21	12
Age @ 7 feet	23	18	27	37	----

The growth parameter, K, is influenced by juvenile growth rates and t_0. The number of juveniles in our aged sample was small (n = 9) and we do not believe that K has been accurately estimated. The estimates of t_0 were 3.8 and 2.4 for females and males, respectively. This indicates that K may be overestimated. Negative values estimated for data reported by Doroshov et al. (1994) (t_0 = -3.3) and Dovel and Berggren (1983) (t_0 = -2.8) for the Hudson River population probably indicate that K was underestimated in these studies. We speculate that a more complete sampling of Hudson River juvenile ages would result in a K value intermediate to those reported by us (K = 0.15) and Doroshov et al. (1994) (K = 0.08). Dovel and Berggren (1983) reported difficulty in ageing fish greater than 152 cm TL and may have misidentified annuli in adults. Magnin's (1964) demographic analysis of the St. Lawrence population yielded a lower K value (0.03) but higher L_∞ (362 cm). Lower growth rate and higher achieved size may indicate a latitudinal (temperature) effect on sturgeon population vital rates (e.g. Jennings and Beverton 1991). L_∞ currently estimated for the Hudson River population may be lower than Dovel and Berggren's estimate due to an increase in fishing pressure on the largest (female) component of the population during the past 10 years.

Data from the ocean harvest (not shown) indicated that growth of sturgeon harvested in New Jersey was similar to growth determined for the Hudson River sample.

<u>Mortality Estimates</u>

Hudson River Harvest (Figure 9)

The Hudson River fishery exploited larger and older fish than the ocean fisheries. Selection of older fish may result in an underestimate of mortality rate by catch-curve analysis. Because female Atlantic sturgeon are not annual spawners, the estimate of female mortality represents a mean annual rate for all the years between one migration and the next (Ricker 1975).

Female age data showed considerable variability and the regression of log abundance on age was less precise than for males. Catch data from 1995 sampling yielded a mortality rate for females that was lower than that estimated for 1992-1994 data. For the combined years 1992-1995, the total mortality estimate was 0.087 ± 0.031 for females harvested in the Hudson River estuary. For males, the total mortality estimate for 1995 was three times that estimated from 1992-1994 period. Nonetheless, the model yielded a good fit for 1992-1995 ($r^2 = 0.85$) with a mortality estimate of 0.245 ± 0.032.

Ocean Harvest (Figure 10)

Total mortality was estimated for combined sexes because male and female age distributions were not significantly different in the ocean harvest. Mortality rate for the Long Island sample was estimated at 0.45 ± 0.003 which was considerably higher than the Hudson River mortality rate estimate. The ocean fisheries in New York and New Jersey intercept sturgeon during their coastal migrations, often harvesting fish that may be immature. Selection for smaller and younger fish in the Long Island fishery probably resulted in an overestimated mortality rate. During our sampling period, effort changed greatly in the New Jersey sturgeon fishery which precluded catch-curve analysis for this fishery (see Methods).

Estimated annual natural mortality rates were 0.07 for females and 0.08 for males.

CONCLUSIONS

Age estimates provided by the interpretation of annuli in sectioned fin rays were precise. The accuracy of these age estimates remains to be comprehensively tested, however preliminary evidence from known-age hatchery fish and marginal increment analysis of field-collected sturgeon suggest that annuli form at an annual rate. Contrary to uncertainties expressed by Dovel and Berggren (1983), we conclude that fin ray estimates can support age-structured models of the Hudson River population.

Year-class distributions among fisheries showed no evidence of particularly strong year-classes or series of poor year-classes. In the Hudson River, significantly older fish were sampled in 1995 than in previous years. We speculate that this could reflect poor year-class strengths for years after 1980.

A shift in year-class structure would be expected if recruitment over-fishing had occurred, the result of past ocean harvests of sturgeon <152 cm before the minimum size limit was imposed (New York, 1992; New Jersey, 1993). Demographic analysis on the population should continue to determine if this shift is now occurring. Age at entry into the fisheries (minimum TL = 152 cm) was estimated to be higher than that used for the current yield-per-recruit and egg-per-recruit analyses (10 yrs., Kim McGown, NYDEC, Stony Brook, pers. comm.). We recommend revision of this input.

Growth rate parameter estimates indicated rapid juvenile growth rates. A positive t_0 suggested that K may be overestimated and juvenile growth rates were not accurately modeled. We believe a larger sample of aged juveniles could improve the model substantially. Prediction of yield in the Hudson River yield-per-recruit analysis is dependent upon the accurate prediction of size-at-age for exploited age-classes. Although high variability in growth rate was observed, we believe that our preliminary growth model can support a yield-per-recruit model. L_∞ determined for females was substantially smaller than historical records of maximum achieved size for this species (Bigelow and Schroeder 1953). High rates of exploitation may be truncating the size and age distributions of the Hudson River population.

Estimation of total mortality rates for Hudson River and ocean harvests by catch-curve analysis was invalid due to the lack of data on effort and gear selectivity. Under the gross assumption of constant effort by the fishery and unbiased sampling on our part, mortality rates were estimated for the Hudson River and Long Island fisheries. Total mortality rates exceeded the expected natural mortality rate, suggesting that fishing mortality could be detected by catch curve analysis. Given expected natural mortality rates of 0.07 and 0.08 for female and male Hudson River Atlantic sturgeon, fishing mortality rates ranged from 0.017 to 0.047 and 0.024 to 0.262 for females and males, respectively. We have little confidence in these estimates, but believe that they indicate that males are being exploited at a higher rate than females. Gulland (1988) suggested a method to estimate total mortality rate from von Bertalanffy growth parameters. Based upon this method, fishing mortality rates were 0.01 and 0.11 for females and males, respectively. Because age at entry into the Hudson River fishery is similar between sexes, lower exploitation of females is probably due to their reduced frequency of spawning relative to males. For instance, if males return to the Hudson River every year to spawn and females return only every third year, fishing effort on females should be substantially less than effort on males. Estimates of fishing effort and gear selectivity will be needed to perform valid catch curve analyses.

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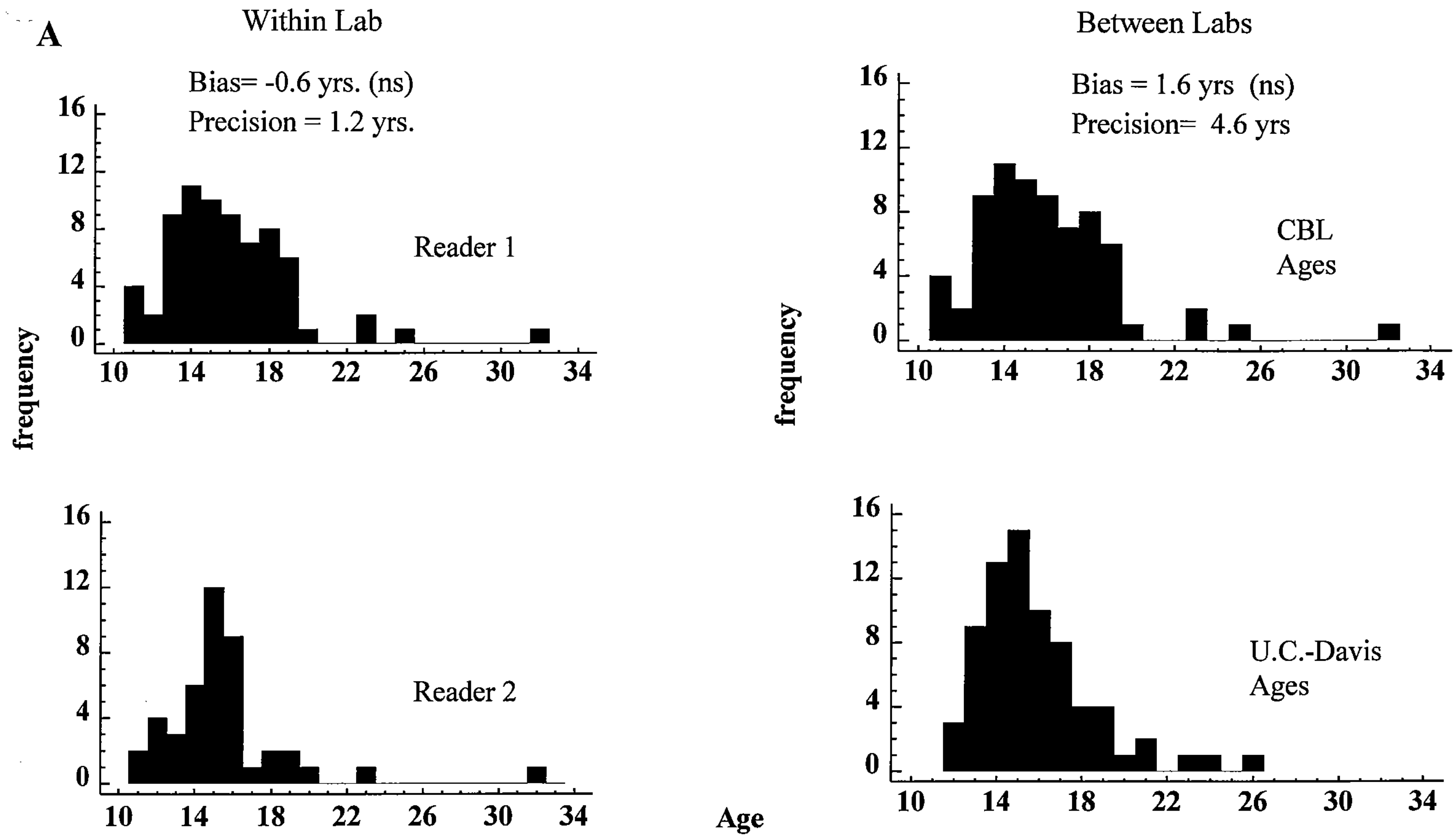
Age Estimate Comparisons: Precision and Bias



Otoliths vs. Pectoral Fin Ray Age Estimates

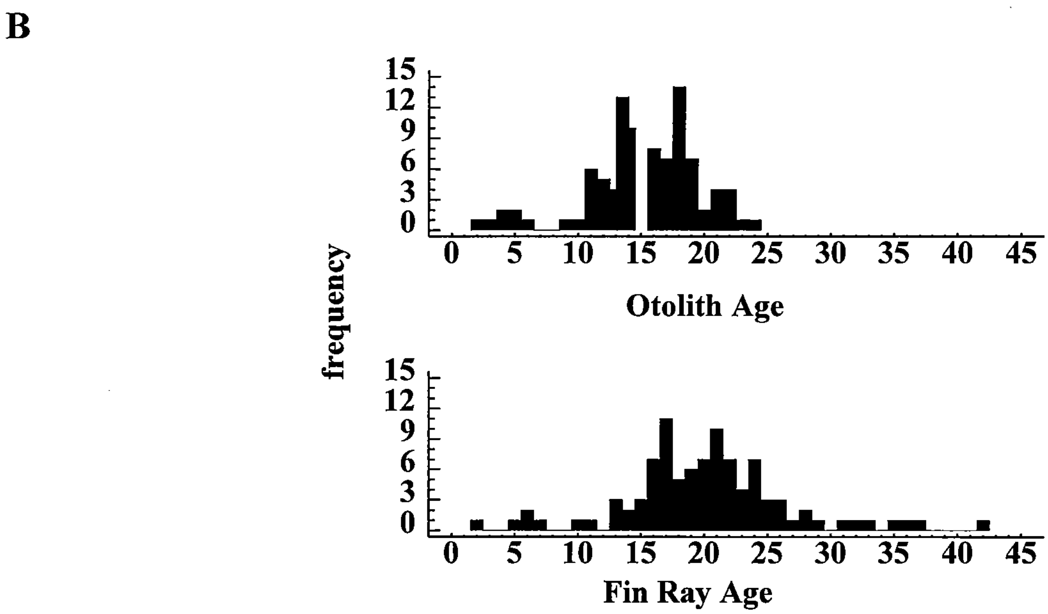


Figure 1. (A). Comparisons of age estimates between two readers at Chesapeake Biological Lab reading the same preparation and two readers from different labs reading different preparations. (B). Comparison of ages derived from Atlantic sturgeon using otoliths and pectoral fin rays. The mean relative difference between age estimates was 5.5 years.

Atlantic Sturgeon Caught in the Hudson River Fishery 1992-1995

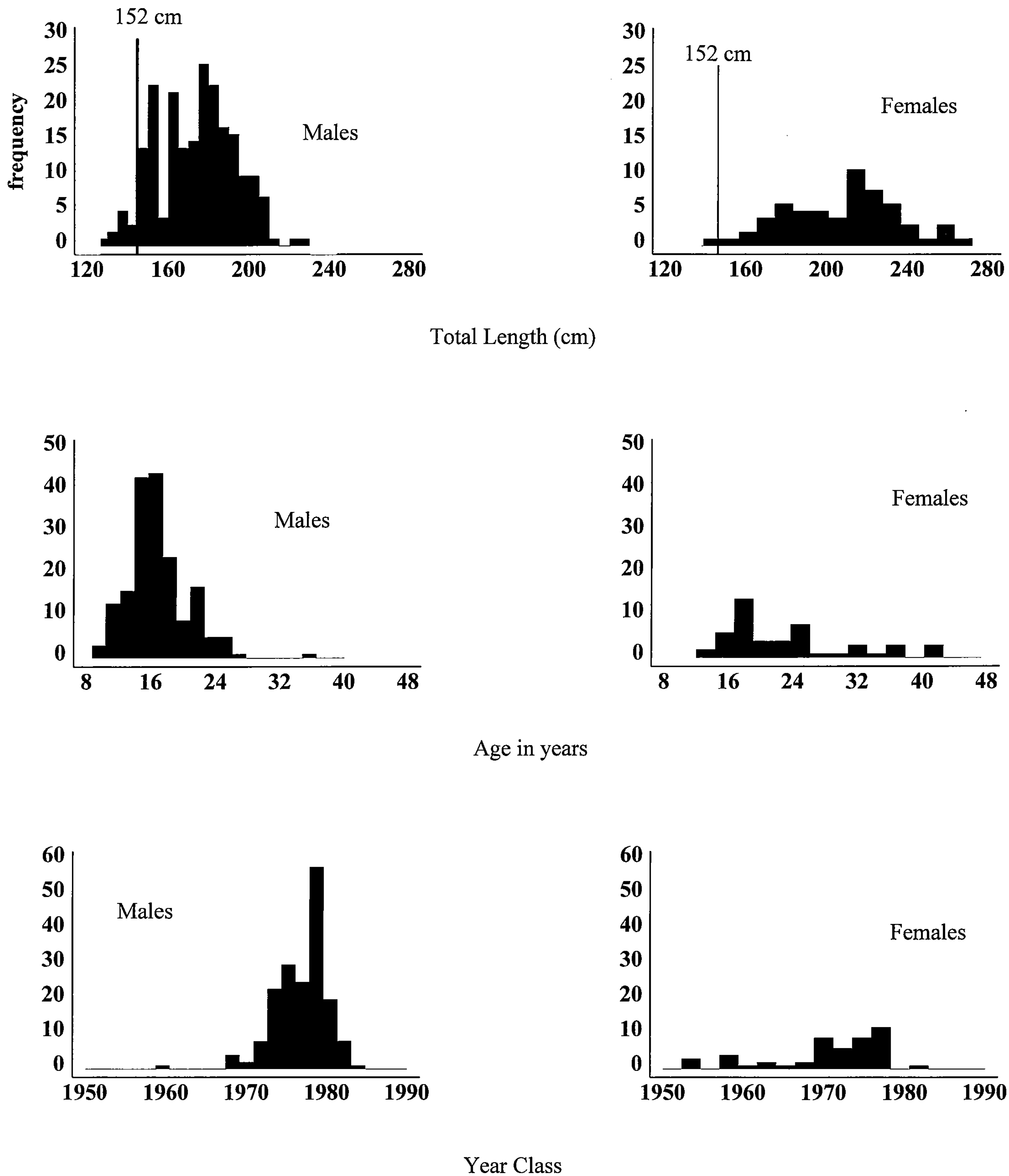


Figure 2. Total length, age, and year-class frequency distributions of Atlantic sturgeon harvested in the commercial gillnet fishery in the Hudson River 1992-1995 (n=278). Minimum size limit is shown (152 cm total length). Ages were determined from annuli in sectioned pectoral fin rays.

Atlantic Sturgeon Caught in the New Jersey Fishery

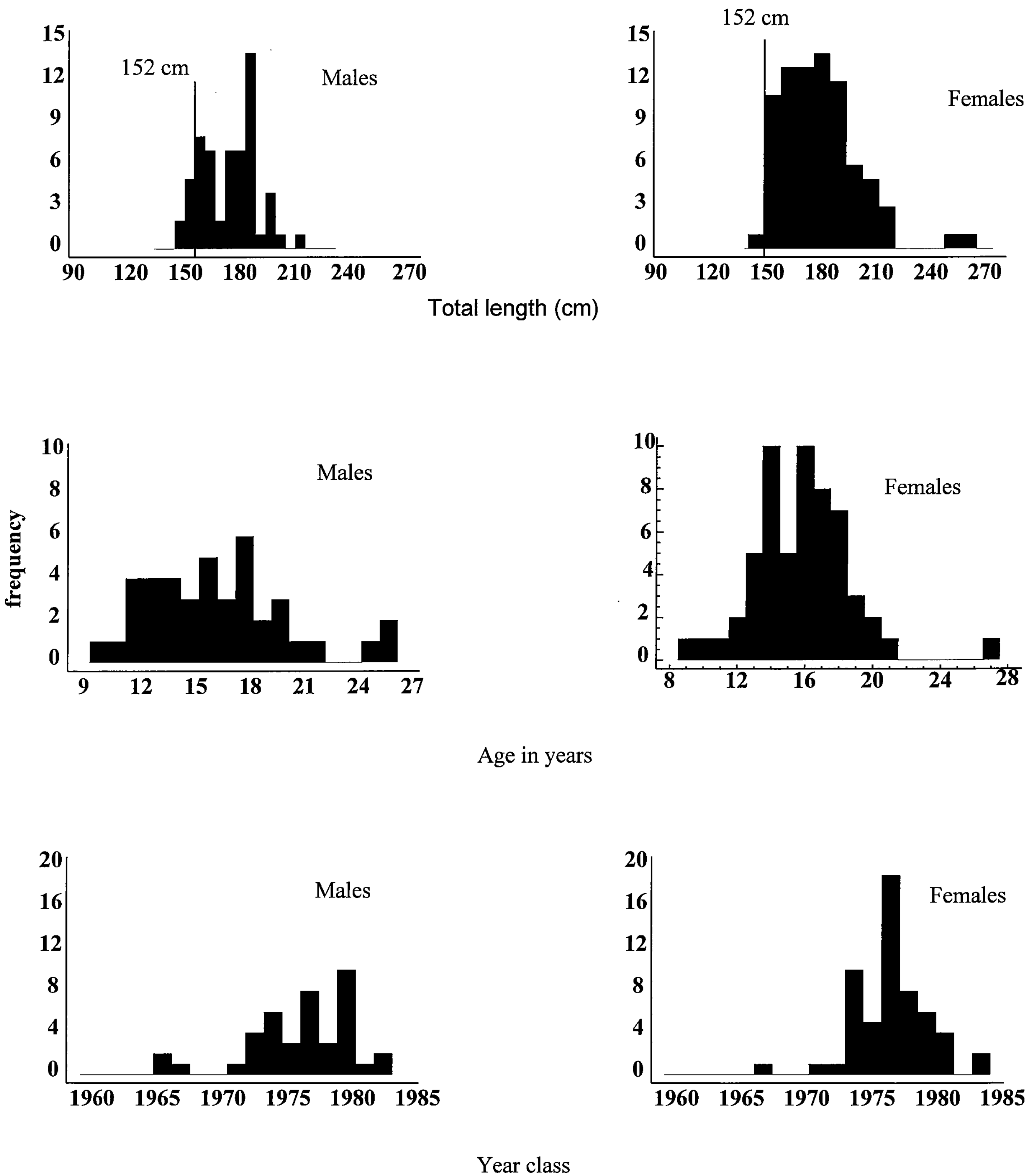


Figure 3. Total length, age, and year-class frequency distributions of Atlantic sturgeon caught in the New Jersey ocean fishery (n=140). Minimum size limit is shown (152 cm total length). Ages were determined from annuli in sectioned fin rays.

Atlantic Sturgeon Caught in the Long Island Fishery

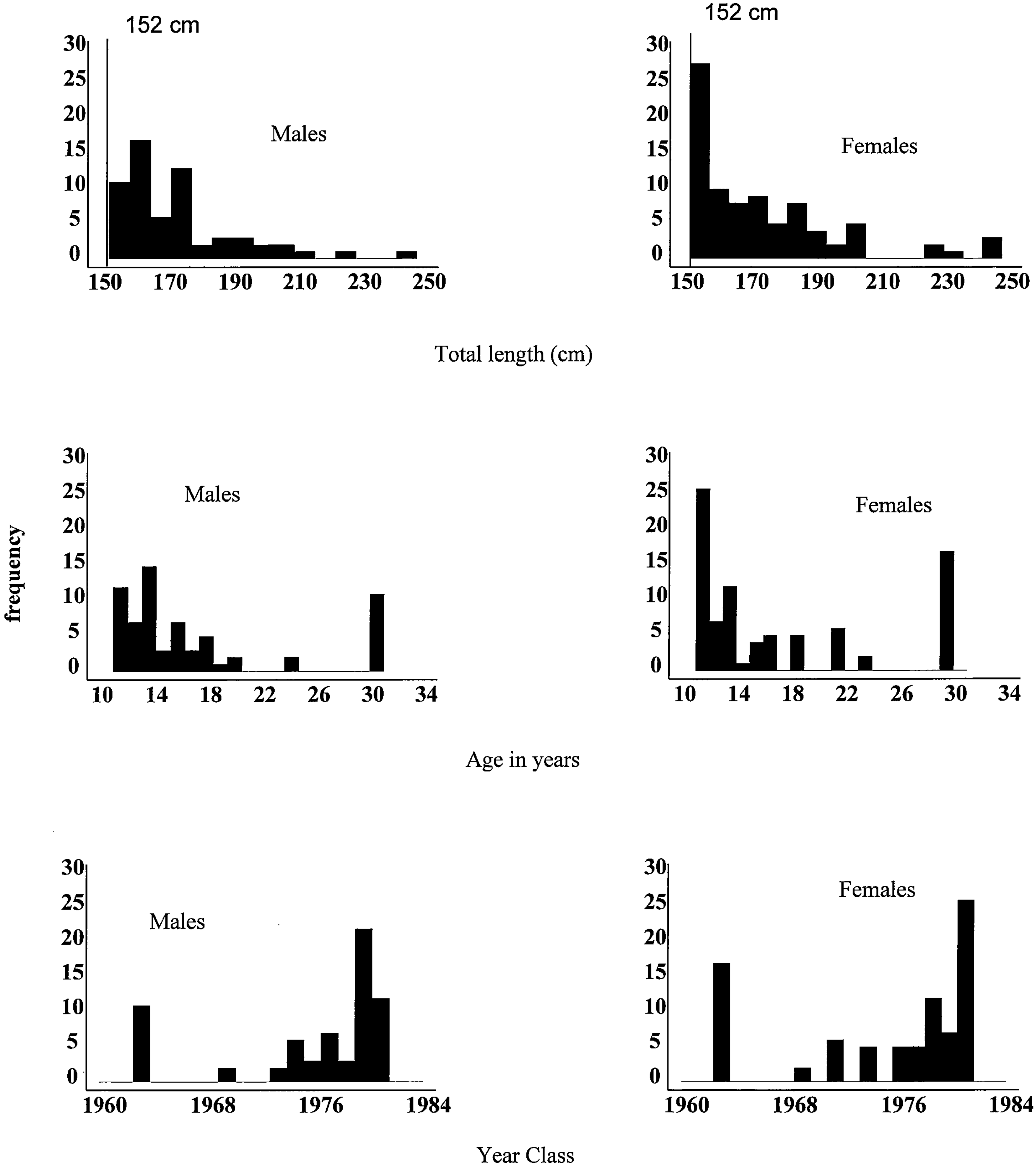


Figure 4. Total length, age, and year-class frequency distributions of Atlantic sturgeon caught in the mmercial ocean fishery and landed in New York in 1993 (n=258). Minimum size limit is shown (152 cm total length). Ages were determined from annuli in sectioned fin rays. Ages were not estimated from pectoral fin rays but were derived from an age-length key. Year class frequencies may be affected by error associated with the age-length key due to large variation in length-at-age.

Sex Composition of Fishery Harvest

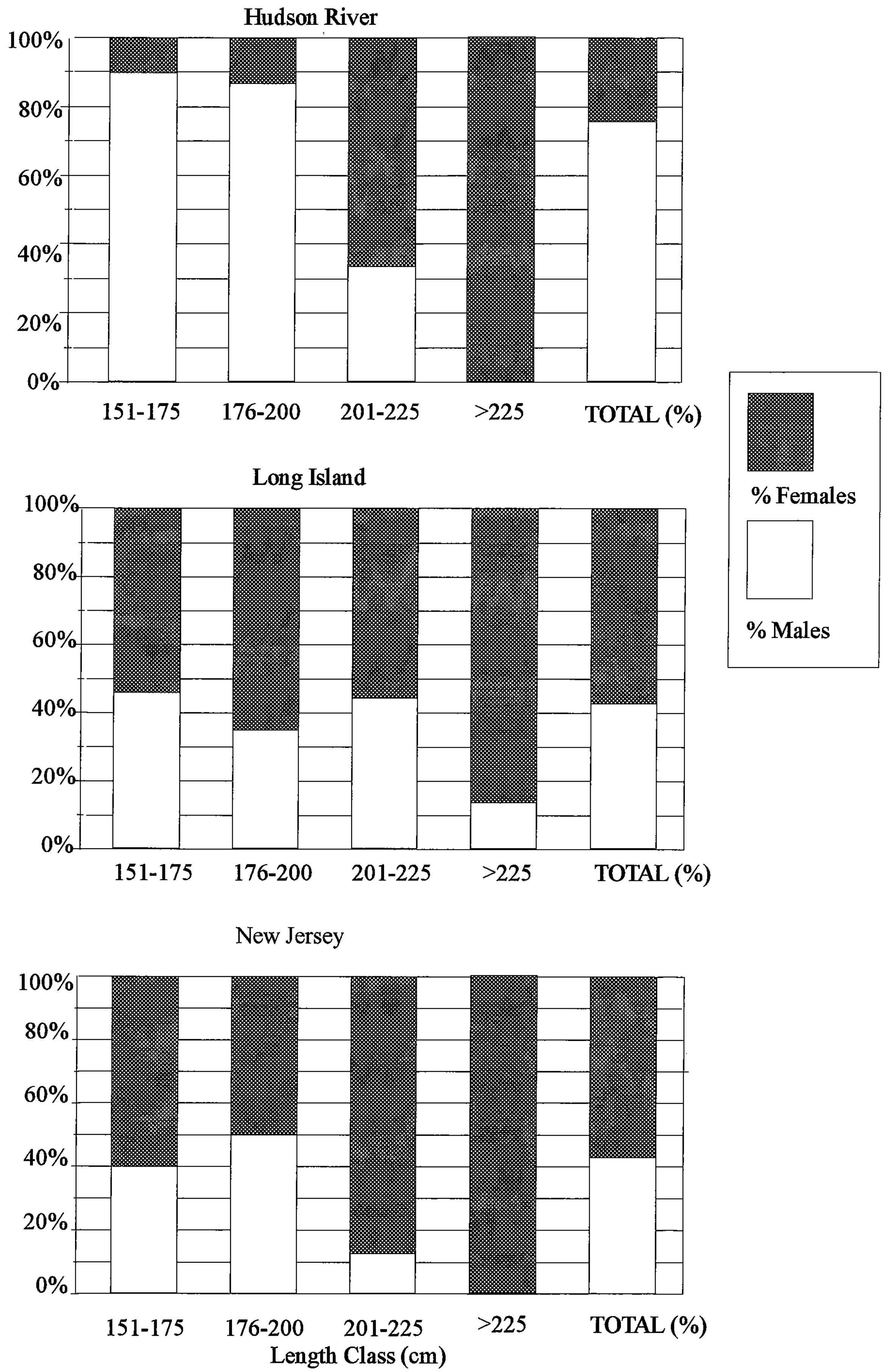


Figure 5. Sex composition of Atlantic sturgeon harvested in commercial fisheries in New York Bight. The length class consisting of fish >225 cm consisted of very few fish in the ocean harvest (n=1 and n=8 in New Jersey and Long Island, respectively).

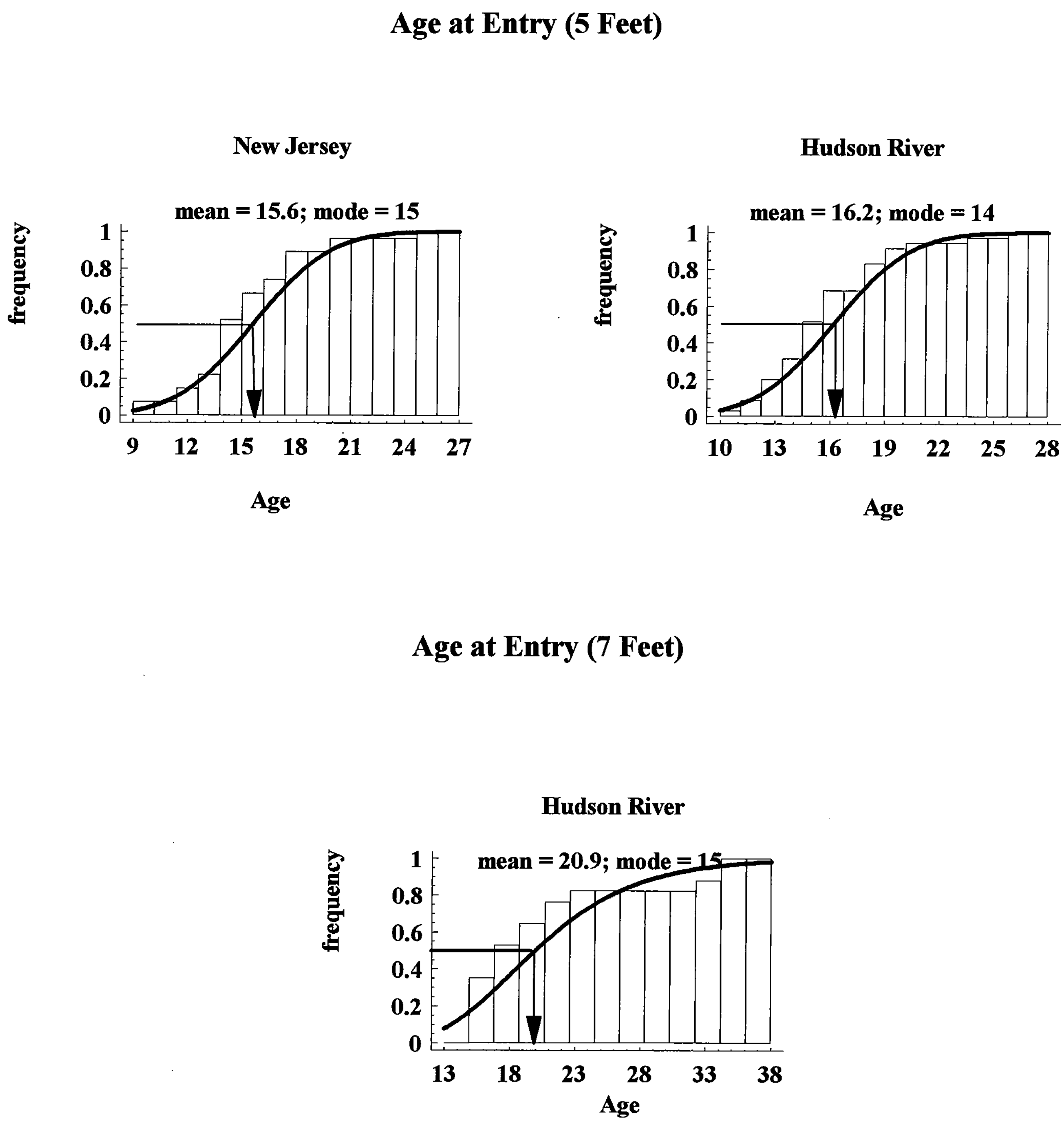


Figure 6. Age of Atlantic sturgeon at entry to commercial fishery with existing size limit (5 feet) and proposed limit of 7 feet.

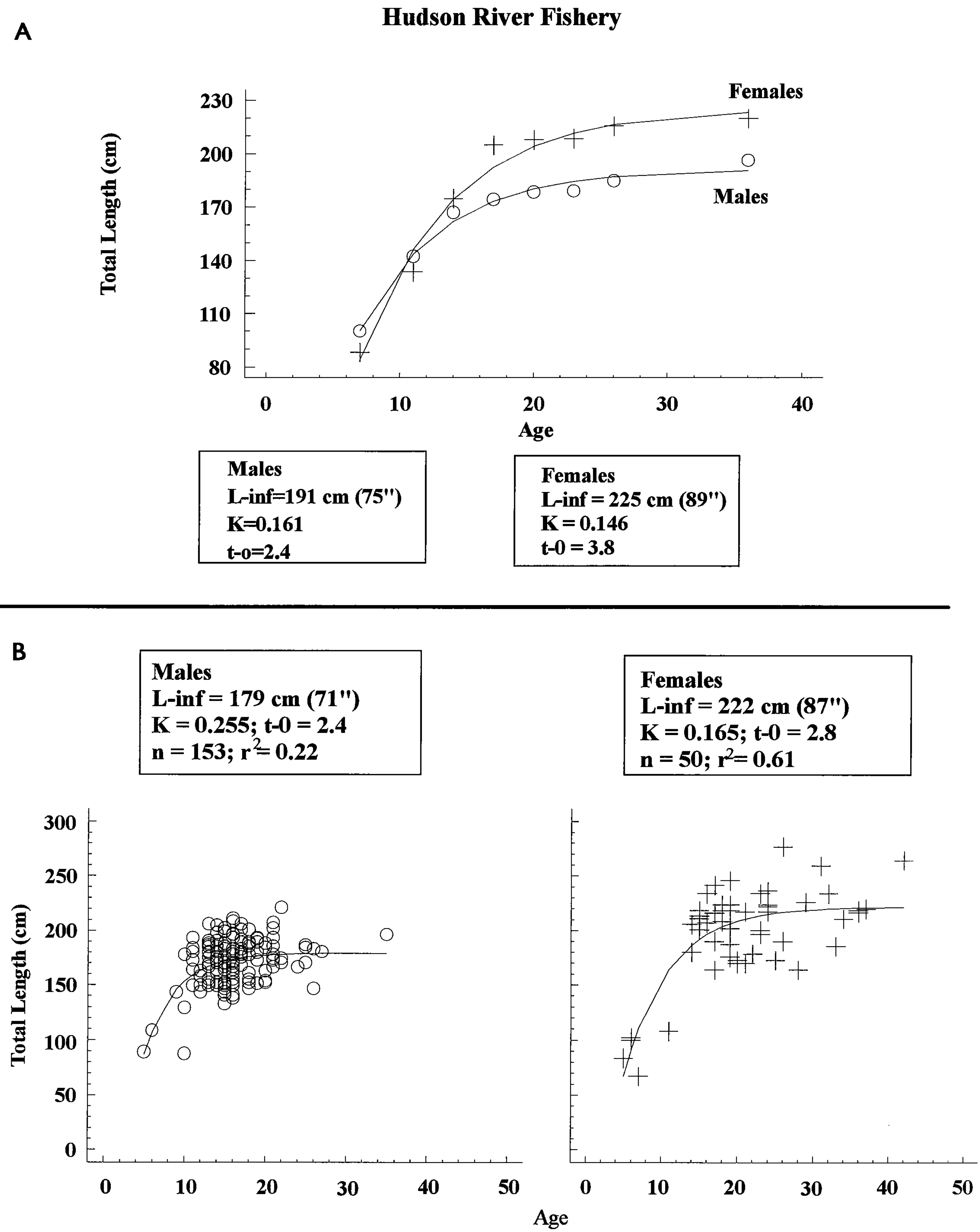


Figure 7. von Bertalanffy growth model for Atlantic sturgeon caught in the Hudson River 1992-1995. (A). Curves were smoothed based upon 3-yr running averages. (B). Growth curves fit to untransformed data.

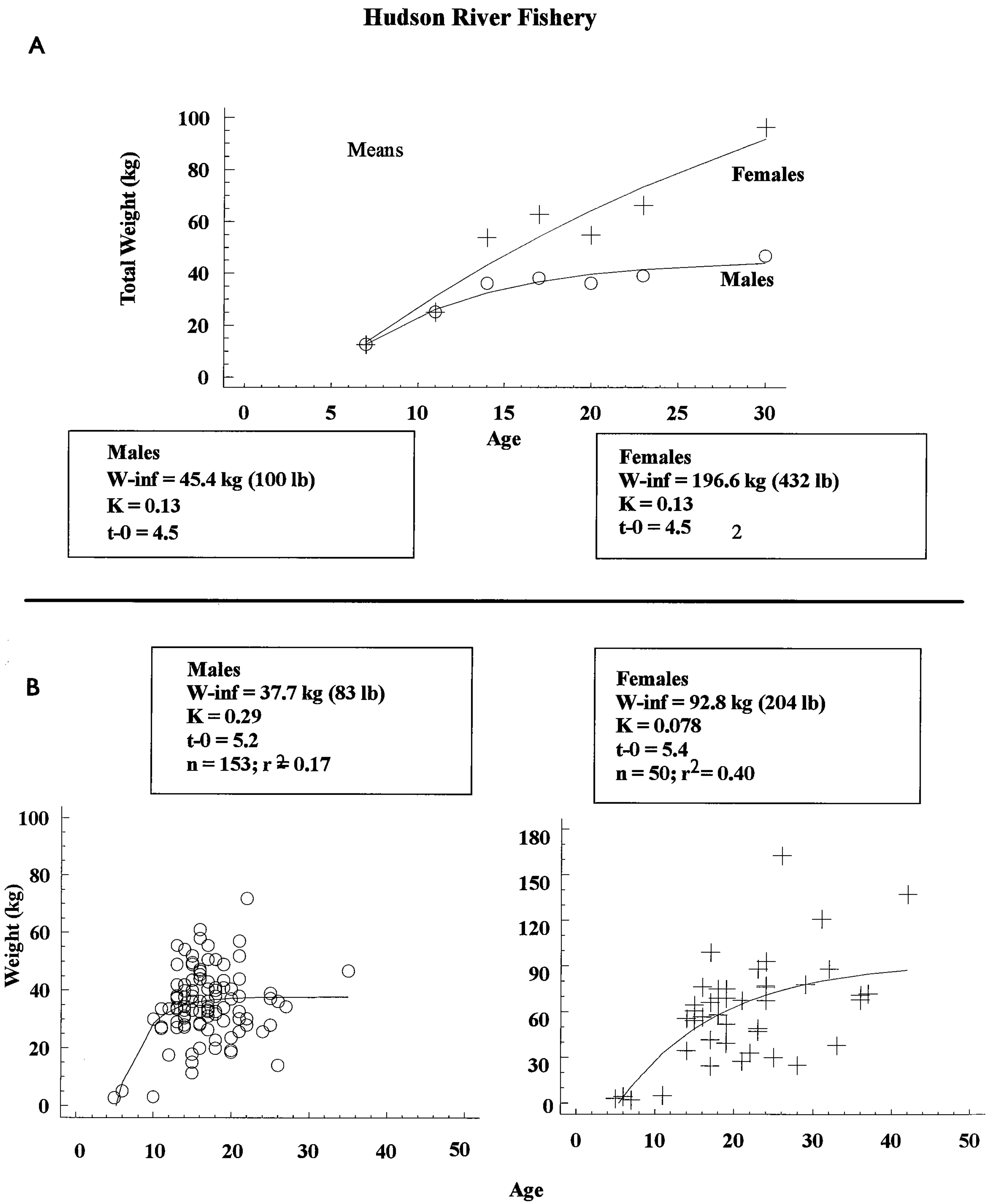


Figure 8. von Bertalanffy growth model for Atlantic sturgeon caught in the Hudson River 1992-1995. (A). Curves were smoothed based upon 3-yr running averages. (B). Growth curves fit to untransformed data.

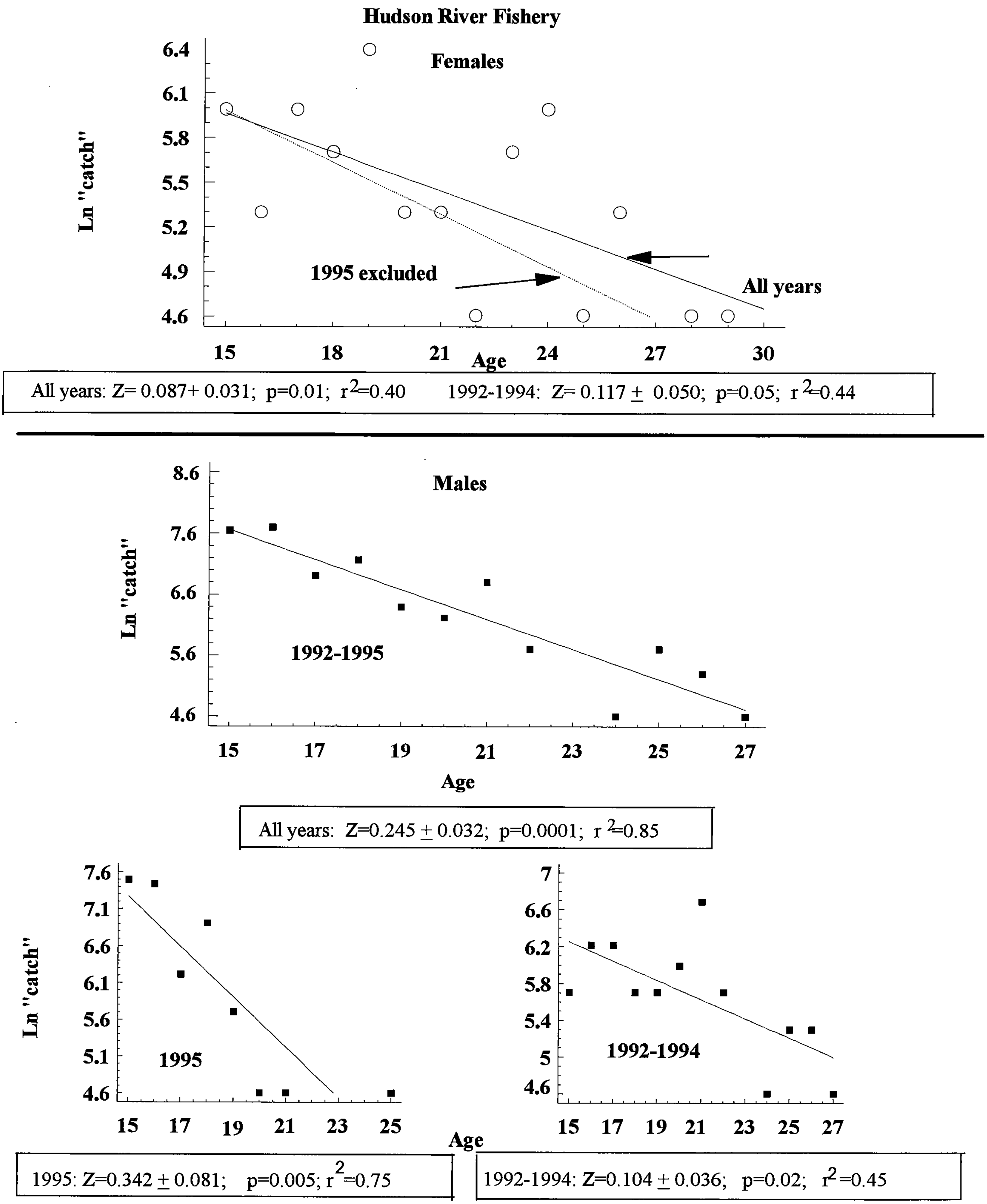
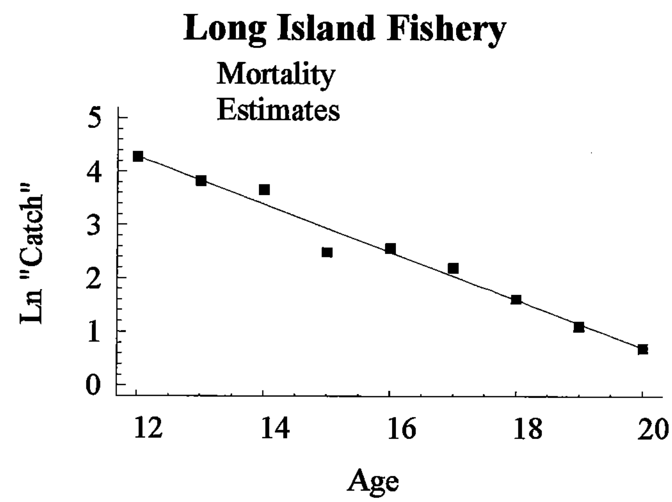


Figure 9. Mortality estimates based on abundance (ln "catch") at age for fish harvested in the Hudson River. Because age structures differed between 1995 and 1992-1994 samples, separate catch curves were determined for each of these periods.



$Z = 0.61 + 0.08$; $p=0.001$; $r^2=0.94$

Figure 10. Mortality estimated from catch curve analysis of Long Island fishery.