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# **FINAL REPORT**

## **Age- and Sex-Dependent Migrations of Hudson River**

### **Anadromous Striped Bass Population**

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## ABSTRACT

Patterns of habitat utilization and migrations of Hudson River striped bass were estimated using otolith microanalysis to chart age and sex-dependent movements. Otoliths from 25 males and 25 females were analyzed for seasonal and age-specific patterns in strontium/calcium level. These levels were converted into salinity estimates based upon a relation derived from experimental studies. Seasonal patterns in salinity habitation indicated annual up-estuary migrations in mature age-classes of males and females, which may represent spawning migrations. Early emigration of young striped bass (<3 years old) into polyhaline waters was observed for both sexes, but females tended to reside at higher salinities throughout their lifespan. Females predominated in polyhaline and euhaline waters. Very few of the sampled Hudson River striped bass spent significant portions of their lives in euhaline coastal waters. A positive relationship between down-estuary movements and age was observed for both sexes, supporting the hypothesis of size-related emigration and anadromy in striped bass populations. Individuals collected during the same season or from the same segment of the river had similar lifetime salinities. This result suggests that group cohesion (schooling) could persist for substantial periods of an individual's lifespan. The most cohesive group was fall-collected males which may reside permanently in freshwater/oligohaline waters. Cohesive migratory groups would have important implications for investigations on effects of contaminants and fishing pressure on Hudson River striped bass. A preliminary comparison between Hudson River and Chesapeake Bay striped bass, suggests that a larger fraction of the Chesapeake Bay population migrates into coastal waters.

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## INTRODUCTION

Anadromous behaviors in several striped bass populations cause migrations among freshwater, estuarine and marine habitats. Seaward migrations which contribute to large aggregations in the coastal Atlantic Ocean and an important coastal fishery occur primarily in the Hudson River and Chesapeake Bay populations (Setzler-Hamilton et al. 1980; Kohlenstein 1978; Boreman and Lewis 1987; Fabrizio 1987; Waldman et al. 1988; Waldman et al. 1990). As individual striped bass migrate among habitats and regions, they are exposed to interjurisdictional fisheries. Stock assessments for regional fisheries thus require methods to estimate migration (exchange) rates among regions. Studies on the migratory behaviors of anadromous striped bass have demonstrated seasonal and ontogenetic determinants, but have also demonstrated considerable variability among individuals (Clark 1968; McLaren et al. 1981; Waldman et al. 1990). Thus, determination of migration patterns should consider individual variability in migratory behaviors within populations.

The Hudson River striped bass population has expanded in range and abundance since 1980 and is thought to contribute substantially to mixed-stocks coastal fisheries (Fabrizio 1987; Waldman et al. 1990; Wirgin et al. 1993). The population is facultatively anadromous; following spawning runs, adults may remain in riverine or estuarine habitats or migrate into coastal waters. Migrations of Hudson River striped bass among habitats is seasonal but controversy exists over how migrations are related to size, age, sex, and abundance (Clark 1968; McLaren et al. 1981; Waldman et al. 1990). While age and sex-dependent coastal migrations have been clearly documented for the Chesapeake Bay population (Mansueti 1960; Kohlenstein et al. 1983), several studies indicate that the Hudson River population may have evolved different migratory behaviors and schedules.

Extensive tagging studies over the past thirty years; 1959-1963 (Clark 1968), 1976-1977 (McLaren et al. 1981) and 1984-1988 (Waldman et al. 1990) have produced opposing views on migratory behaviors of Hudson River striped bass. Clark (1968) suggested that the Hudson River population was comprised of several "contingents" (sub-populations). One contingent resided in the Hudson River and Estuary, another contingent migrated and resided in the Long Island Sound during summer and fall months, and a third contingent supported farther ranging migrations. To support his assertion of discrete contingents, Clark presented evidence that migration was unrelated to size or sex. Clark's contingent hypothesis recently was criticized because 1) fish were tagged in the

Long Island Sound and could have been drawn from a mixed stock; and 2) most fish were immature ( $<400$  mm, Total Length [TL]) (Waldman et al. 1990). In a tagging study on larger and predominantly mature striped bass ( $>400$  mm TL), tagged on the Hudson River spawning ground, McLaren et al. (1981) observed that both sexes migrated into coastal waters at similar rates regardless of age, although there was some indication that striped bass over 800 mm TL tended to migrate farther into coastal waters. Based upon a recent study of a tagged sample of more equally distributed small and large size classes, Waldman et al. (1990) have suggested that coastal migration of Hudson River striped bass is indeed size-specific and that the proportion of migrating adults has increased recently as the abundance of the Hudson River population has increased.

Tagging studies have biases associated with sampling methods. Fishery-dependent collections can be biased due to fishing regulations, efficiencies, preferences and patterns. Results based upon fishery independent collections may suffer when recapture rates are low or insufficient numbers of independent samples are taken. Because multiple recaptures of individual fish are rare, tagging studies on striped bass populations cannot track seasonal and ontogenetic movements of individuals over long periods. To infer these movements, data on individuals must be combined. This can result in biased emphases on relatively few segments of the population (Ricker 1975; Waldman et al. 1990; Hilborn and Walters 1992).

We tested hypotheses on migratory patterns of Hudson River striped bass using otolith microanalysis. Strontium concentration in seawater is approximately one order of magnitude greater than in freshwater and varies in direct proportion to salinity in estuarine environments (Ingram and Sloan 1992). Therefore, strontium levels in otoliths of striped bass exposed to seawater are substantially higher than those exposed to freshwater (Secor 1992). Further, as anadromous striped bass migrate along a salinity gradient, the strontium/calcium (Sr/Ca) level in their otoliths records the rate of migration among freshwater, estuarine, and marine habitats (Secor et al. in review). Thus, Sr/Ca in otoliths of striped bass records age- and season-specific movements between habitats with different salinities (Secor 1992; Secor et al. in review). Otolith microanalysis, like other otolith-based methods, can provide valuable life history information on individual fish. Because otoliths contain information from earlier ages (sizes) for each individual, biases associated with sampling an incomplete range of sizes, ages, seasons, and years are reduced.

The following hypotheses were investigated using otolith microanalysis on mature male ( $n = 25$ ) and female ( $n = 25$ ) striped bass collected in the Hudson River:

1. Only a portion of the Hudson River striped bass population undertakes anadromous migrations.
2. The fraction of the population that migrates into estuarine and marine habitats increases with age.
3. With increased age, individuals reside for longer fractions of the year in estuarine and coastal habitats.
4. Females are more likely to undergo anadromous (coastal) migrations than males.
5. Growth rate is positively related to occurrences at higher salinity levels.
6. Age at which striped bass migrate into coastal habitats has decreased in recent years as year-class strengths have increased.

## METHODS

### Samples

Mature female ( $n = 25$ ) and male ( $n = 25$ ) striped bass were sampled from spring and fall collections made in the Hudson River by NY Department of Environmental Conservation (NYDEC). Spring samples (females = 24; males = 15) were collected during May and June 1992 as part of a spawning stock assessment (Hattala et al. 1993). Fall samples (females = 1; males = 10) were obtained during October and November in a fall stock assessment. Gear used in these assessments were 103- and 304-m haul seines which were deployed at beaches from river km (RK) 138 to RK 184, and RK 117 to RK 243, in spring and fall collections, respectively (Figure 1). Striped bass were measured for total length (TL) and weight, and sex was determined in the field; selected samples were frozen for later otolith extraction.

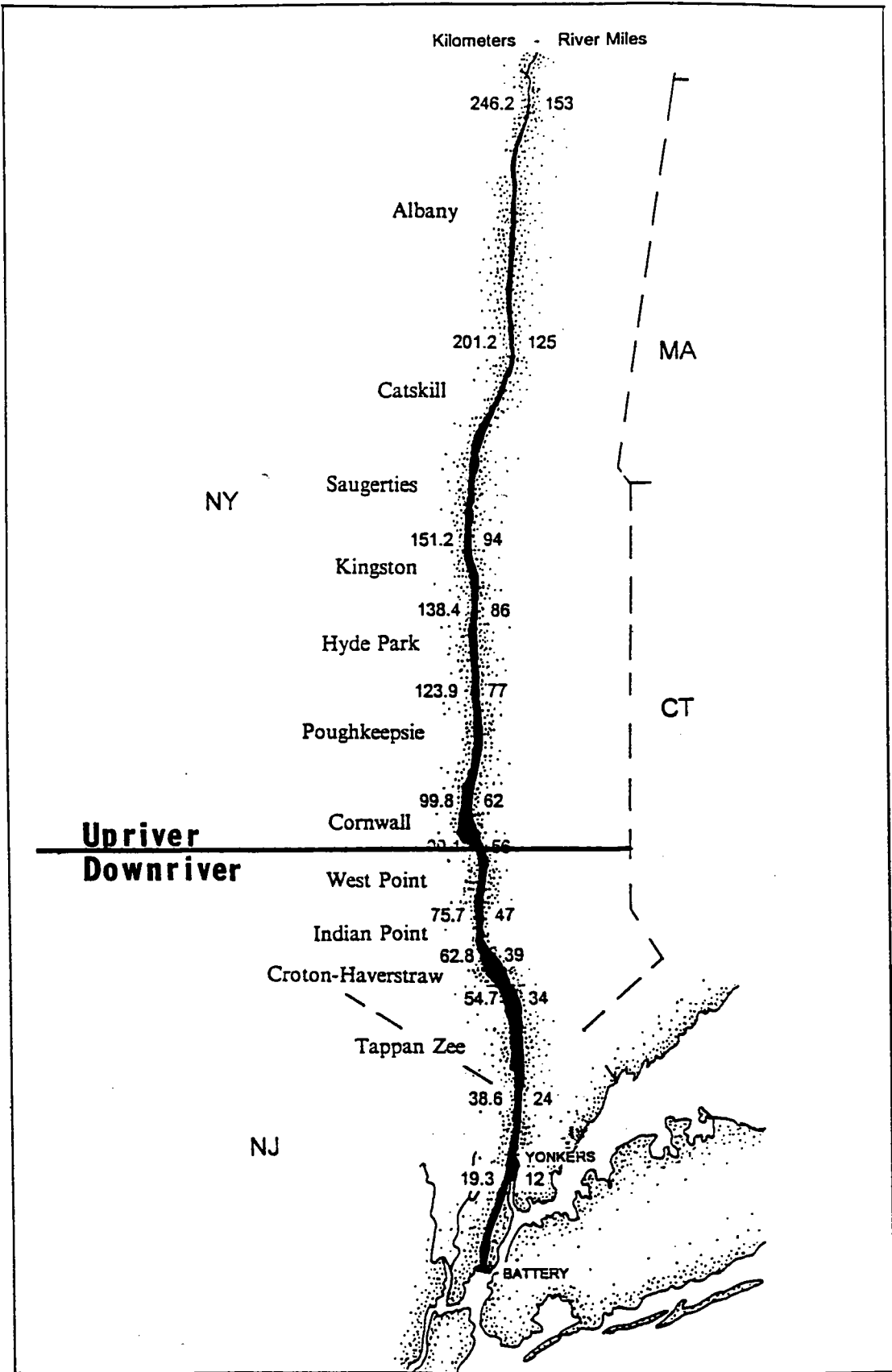


Figure 1. The Hudson River Estuary. Regions of the river designated as upriver and downriver are shown. Modified from Smith 1992. Numbers indicate river km and mile, i.e. distance from the estuary's mouth.

Large adults (>75 cm Total Length [TL]) were selectively sampled from the Hudson River collections to satisfy two criteria: 1) samples were sexually mature; and 2) samples were old enough to provide a useful time-series of exposure to varying salinities. Because males >75 cm TL were relatively rare, smaller males were also included in the analysis from spring (n = 4) and fall collections (n = 5). Mean lengths of selected fish were 86.6 cm  $\pm$  4.7 and 72.9  $\pm$  13.8, for females and males, respectively.

### Age and Growth Measures

Otoliths (sagittae) were extracted, soaked in 10% sodium hypochlorite solution, rinsed with deionized water, and embedded within a Spurr epoxy (Secor et al. 1992). Transverse sections, approximately 1 mm thick, were cut through the otolith cores using a metallurgical wafering saw. The sections were mounted on glass slides, polished on 600 grain sandpaper, and polished again on a slurry of 0.3  $\mu$ m alumina until their surfaces were free of pits and abrasions, which can cause artifacts in microprobe analysis (Kalish 1990).

Annuli in striped bass otoliths have been verified to form at an annual rate and precision in age determination was estimated to exceed 95% (Secor et al. in press). Annuli comprised a narrow opaque zone and a wide translucent zone when viewed under transmitted light microscopy. In electron back-scatter images, the opaque zones were observed as electron-dense regions (Secor 1992). Annuli were counted under light microscopy (magnification 60 or 150X), along the sulcal ridge in transverse sections by a single reader (Figure 2).

Annual growth rates were estimated from increment width and otolith quadrant measures. Annular increment widths were measured along the dorsal sulcal ridge (Figure 2). Otolith quadrants were defined by two axes whose common origin was the core. Axis 1 occurred along the long axis of the dorsal region of the transverse section and axis 2 bisected the dorsal sulcal ridge (Figure 2). Because of changes in growth axes in the otolith, quadrant measures were only possible for the first five annular growth increments (ages 0 to 4) but provided an estimate of early growth rate. Increment widths and otolith quadrants represented linear and area-based measures, respectively. Measures were made using a digitizing pad and imaging system (see Secor and Dean 1992). Precision of both increment widths and quadrants was estimated to be greater than 85% based upon replicated measurements.



Transverse Otolith Section

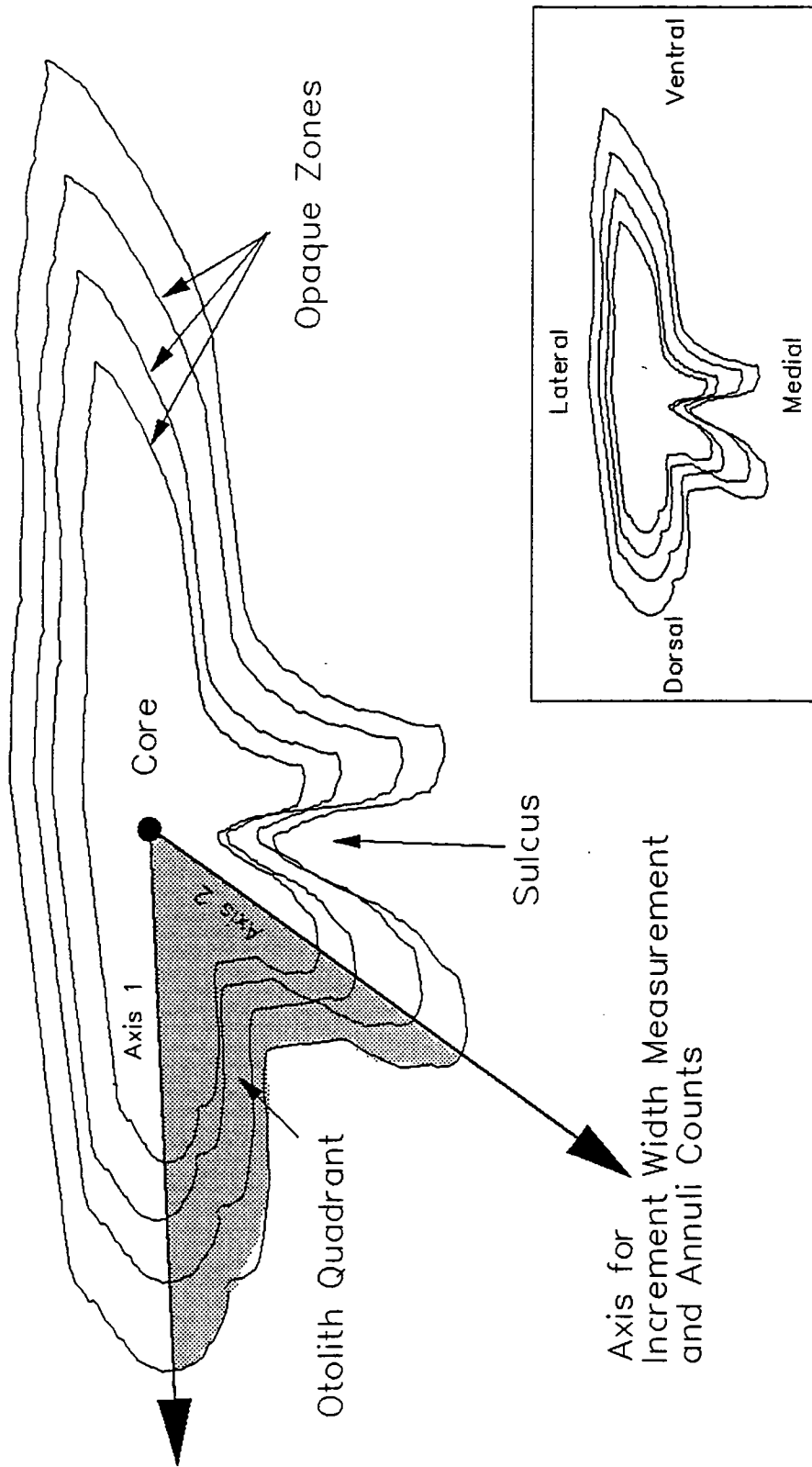


Figure 2. Diagram of transverse section of striped bass sagittal otolith. Opaque zones, sulcus, and anatomical axes are shown. The counting axis and otolith growth measures are also indicated.

## Otolith Microanalysis

X-ray intensities for Sr and Ca elements were quantified using a JEOL JXA-840A wave-length dispersive electron microprobe (Central Facility for Microanalysis, Univ. Maryland, College Park, MD 20742) with Calcite ( $\text{CaCO}_3$ ) and Strontianite ( $\text{SrCO}_3$ ) as standards. Prior to analysis, otoliths were ultrasonically cleaned and carbon-coated in a high-vacuum evaporator. Analytical methods for measuring molar weights of Sr and Ca followed those described by Secor (1992).

Transect probes were series of point measurements of Sr and Ca taken across annuli which served to indicate seasonal and ontogenetic patterns in exposures to differing salinities (Secor et al. in review). Our objective was to obtain 5 point measurements for each annulus. These points were assumed to represent seasonal patterns. The minimal distance within which two adjacent points can be measured is 13  $\mu\text{m}$ . Widths of annuli become progressively narrower with increasing age and were less than 100  $\mu\text{m}$  in fish >7 years old (Figure 3). Therefore, points in annuli corresponding to ages over 5 years in individual fish were measured at ca. 13  $\mu\text{m}$  intervals. Annuli corresponding to younger ages were measured at 20 to 25  $\mu\text{m}$  intervals (Figure 4).

Back-scatter electron micrographs for each analyzed otolith showed series of electron-dense zones which corresponded to the opaque zones of annuli (Figure 4). Point measurements were enumerated according to the annuli they sampled. Points which were directly within an opaque zone were considered to represent early spring, prior to spawning (Secor et al. in press) and were thus the last points associated with a given year of life. Points immediately succeeding the opaque zone were considered to form just after the spawning season and represented the first part of a given year of life (i.e., spring). Points between opaque zones were assumed to sample age in linear proportion. For example, if five points were measured from annulus 5 to annulus 6, then points were assigned ages 5.0, 5.2, 5.4, 5.6, and 5.8 years.

## Analysis

### Age and Growth

Population growth rates were determined by regressing TL on age and fit according to the von Bertalanffy growth model,

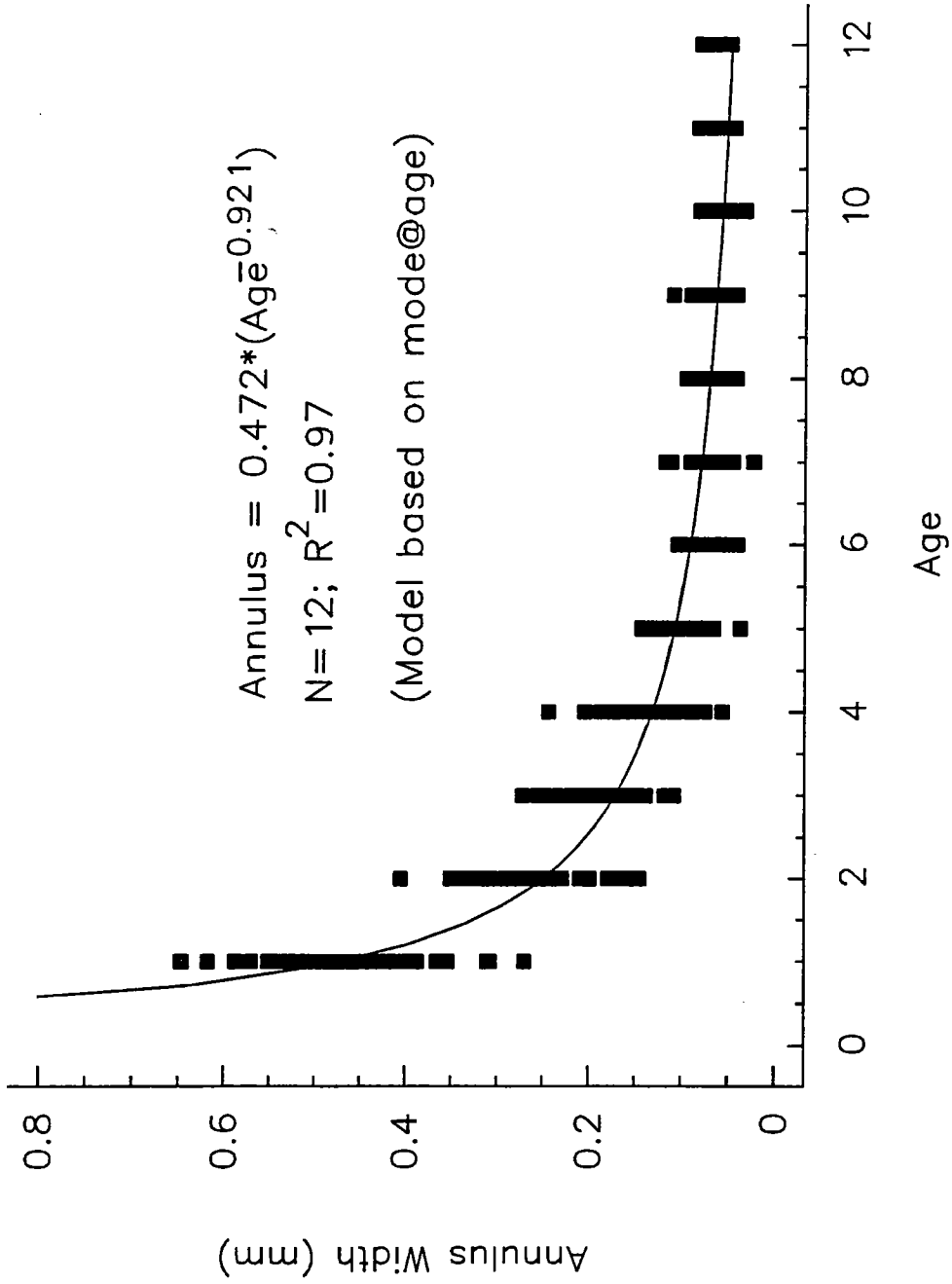


Figure 3. Annulus width versus age for Hudson River striped bass. The negative power function was fit to the mode estimates of annulus width for each age.

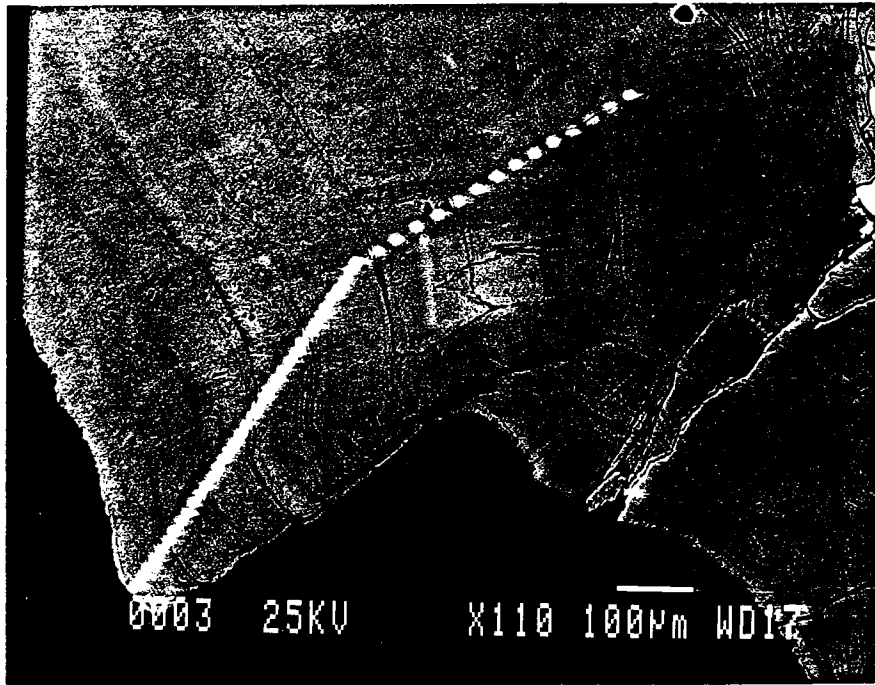


Figure 4. Back-scatter electron micrograph of annuli in an otolith section, from a 9-year-old Hudson River male. Note opaque zones which are regions of electron dense (dark) material. Transect of point measures from the electron microprobe are shown. Inter-point distances were  $25 \mu\text{m}$  for ages 1 to 5 years and  $13 \mu\text{m}$  for ages 5 to 9 years.

$$L = L_{\infty} (1 - e^{-K(t - t_0)})$$

where  $L$  = mean asymptotic total length (cm),  $K$  = Brody growth coefficient,  $t$  = age (yr), and  $t_0$  = intercept estimate (Ricker 1975).

Individual growth rates were estimated from increment width and otolith quadrant measures. Otolith quadrant measures were converted to fish growth by comparing mean otolith quadrant area to mean fish growth rate in simple linear regressions (Figure 5). Mean growth rate was estimated for each individual by dividing ln weight (g) by age. Because otolith quadrants could only be measured in the first five years of life, this analysis was restricted to the first 6 years of life ( $n = 4$ ). It was assumed that mean fish growth over the first 6 years would be reflective of mean quadrant growth during the first 5 years. The resulting regression was:

$$\text{Early Fish Growth (g g}^{-1} \text{ yr}^{-1}) = 0.276 + 1.263 (\text{otolith quadrant [mm}^2]);$$

$$R^2 = 0.93; n = 4 \text{ (Figure 5)}$$

Early growth rates were predicted for all individuals from this regression.

### Otolith Microanalysis

Time series data of Sr/Ca were compiled for each striped bass. Based upon laboratory and field experiments Secor et al. (in review) developed a logistic relationship between salinity and otolith Sr/Ca:

$$\text{Salinity habitation (ppt)} = 40.327 (1 + 55.926 e^{-1185.296 (\text{Sr/Ca})})^{-1};$$

$$R^2 = 0.94; n = 54$$

This model was used to convert Sr/Ca values to salinity habitation. Salinity habitation estimated the salinity inhabited for the period of time represented for each Sr/Ca datum. Residuals from the logistic model indicated that Sr/Ca typically predicted salinity habitation with a precision error less than 6 ppt (Secor et al. in review).

To weight seasonal data among ages, time series were edited so that 5 seasonal points were included for all annuli. Annuli that had fewer than 3 seasonal points were omitted from the analysis. An additional point was interpolated for annuli with 4 seasonal points (<7% of sampled annuli). The mean of the second and third seasonal points was calculated and inserted

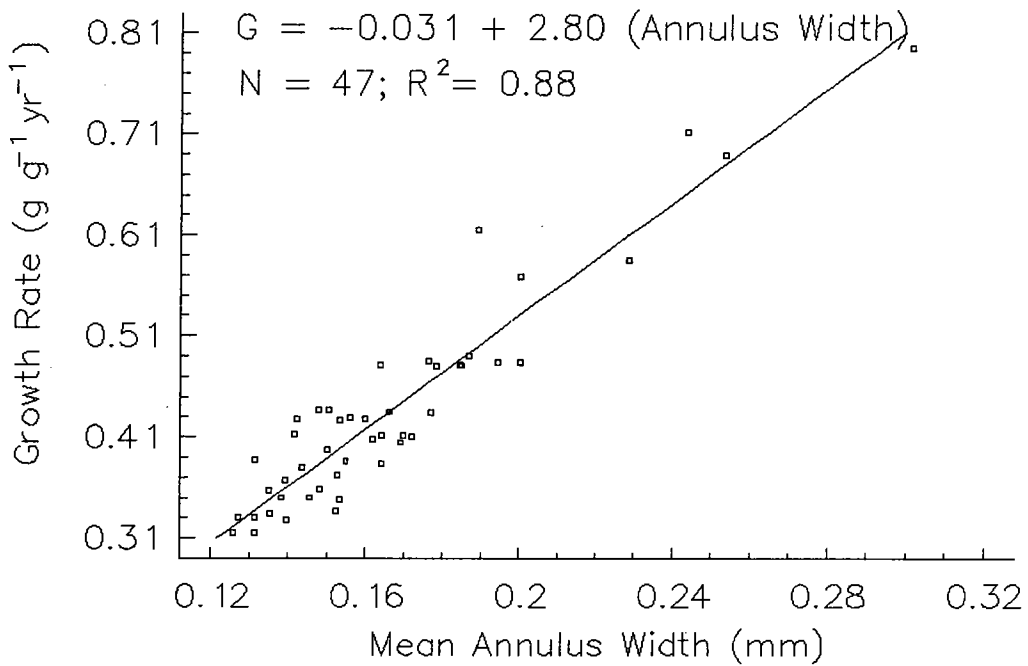
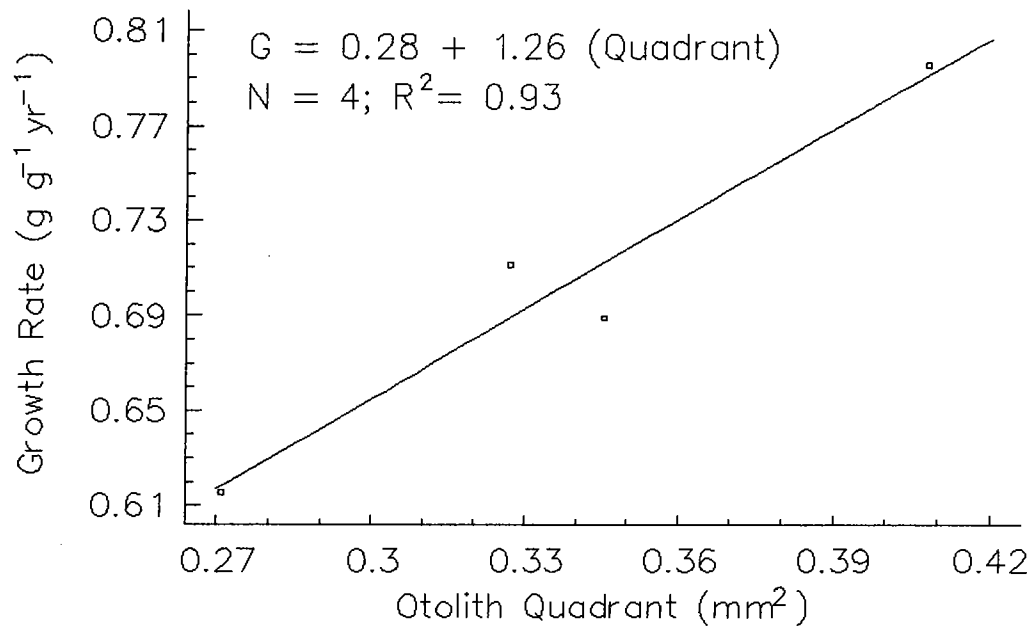


Figure 5. Somatic growth versus otolith growth. **Top Panel:** Somatic growth rate versus mean otolith quadrant area for Hudson River striped bass. See Figure 2 for diagram of otolith quadrants. **Bottom Panel:** Somatic growth rate versus mean annulus width.

between those points. For annuli sampled by more than 5 seasonal points, points were omitted from analysis. Selection of points to be included for these annuli was based upon their proximity to the values of  $t+0.2$ ,  $t+0.4$ ,  $t+0.6$ , and  $t+0.8$ , where  $t$  is the age of the fish.

Time series data were aggregated at three levels of analysis:

- 1) Seasonal Stratum analysis used individual point measurements within annuli to evaluate seasonal trends in migration and habitat utilization patterns.
- 2) Ontogenetic Stratum analysis used means and maxima of point measures for each annulus to evaluate ontogenetic trends in migration and habitat utilization patterns.
- 3) Individual Stratum analysis used means and maxima of point measures for each individual and represented life-time estimates of habitat utilization.

Time series data at Seasonal and Ontogenetic Strata were expected to show autocorrelation. For example, the salinity experienced by an individual at age 5.6 will influence the salinity it will experience at age 5.8. Similarly, mean salinity experienced at age 5 is likely to influence the mean salinity experienced at age 6. An appropriate method of data analysis which shows interdependence among repeated measures on the same sample is multivariate analysis of variance (Chambers and Miller, in press). Multivariate analysis of variance (MANOVA) simultaneously fits several dependent variables to independent factors of interest (SAS 1987) and evaluates the matrix equation,

$$Y = XB + E$$

where  $Y$  is a matrix of  $p$ -dependent variables (columns) and  $n$  observations (rows),  $X$  contains  $k$  treatment levels for each factor (columns), and  $n$  observations (rows),  $B$  contains  $k$  treatment levels (columns) for each  $p$ -dependent variable (rows), and  $E$  is the matrix of model residuals. Degrees of freedom for the analysis depends upon  $p$ , which represents the number of individual fish. In univariate analysis of variance, otolith Sr/Ca observations within each fish would be tallied, inflating the degrees of freedom. The resulting analysis would misrepresent the true number of samples (i.e. each fish should comprise a sample unit rather than each year or season) (Chambers and

Miller in press). MANOVA was used to evaluate 1) salinity habitation among ages for individual fish or 2) salinity habitation among seasons for each age-class. Independent factors of interest were sex, year-class and site of collection. A disadvantage of the MANOVA was that all cells of  $Y$  must have contained data. For any row  $p$  with missing data, the entire row was omitted from analysis.

The season of collection (spring or fall) had a significant influence on lifetime mean and maximum salinities for the Individual Stratum (see results). Therefore, separate analyses were conducted for spring and fall samples. Due to the small sample of fall-collected fish, MANOVAs were performed only for spring-collections unless otherwise designated.

### Statistical Models

#### 1. Seasonal Stratum

A matrix of observations and treatment levels was compiled for the following model:

$$S_{0.0} S_{0.2} S_{0.4} S_{0.6} S_{0.8} = \text{Sex}$$

where  $S_i$  = salinity at seasonal point  $i$ . To avoid the problem of interdependence of seasonal data for combined ages, separate MANOVAs were performed for ages 1 through 10. Thus, for each age, there were analyses for seasonal salinity differences within that age. Sex-related differences among seasonal salinity occurrences also were evaluated. Ages  $> 10$  were not analyzed due to low sample size.

#### 2. Ontogenetic Stratum

Matrices of observations and treatment levels were compiled for the following models:

$$S_2 S_3 S_4 S_5 S_6 S_7 = \text{Sex}$$

$$S_2 S_3 S_4 S_5 S_6 S_7 = \text{Year-Class}$$

$$S_2 S_3 S_4 S_5 S_6 S_7 = \text{River Segment}$$



$$M_2 M_3 M_4 M_5 M_6 M_7 = \text{Sex}$$

$$M_2 M_3 M_4 M_5 M_6 M_7 = \text{Year-Class}$$

$$M_2 M_3 M_4 M_5 M_6 M_7 = \text{River Segment}$$

where  $S_t$  = mean salinity for age  $t$ ,  $M_t$  = maximum salinity for age  $t$ , and River Segment = segment of the river in which the fish were collected.  $S_t$  is an estimate of where the individual tended to reside in a given year (see Introduction, Hypothesis 4);  $M_t$  represents the yearly extent of oriented migrations toward coastal waters (Hypothesis 2). Data were classified according to the river segment where fish were collected. Downriver collections were those taken below RK 90; upriver collections were from above RK 91 (Figure 1). The data set was reduced by the requirement of complete time series in the matrix of response variables (Y). The requirement of five points per annulus resulted in the first annulus being incompletely sampled for many individuals. Fish which had transect data for ages over seven years were not common. Therefore, the data set was restricted to ages 2-7 for the spring collection. For similar reasons, ages 3-8 were selected for the fall collection. Because of low degrees of freedom in the analysis, multiple factors and their interactions could not be analyzed with confidence in a single model. Therefore, we considered treatment differences: sex, year-class, and river segment in separate MANOVAs.

### 3. Individual Stratum

The Individual Stratum analysis comprised independent observations and therefore was analyzed through univariate analysis of variance for sex, river segment, and season of collection influences on life-time mean and maximum salinities. Because year-class influences could not be distinguished from age effects in this analysis, they were not considered. In instances where Bartlett's test indicated failure to meet the assumption of similar variances among factor levels, a nonparametric Kruskal-Wallis rank-sum test was applied. Growth effects on dependent variables were tested using regression analysis.

## RESULTS

### Age and Growth

Ages ranged from 8 to 12 and 4 to 14 yr for females and males

respectively. The 1981-1984 year classes included 84% of the sampled individuals (Table 1). The age and year-class frequencies and ranges of our selected spring samples were similar to the larger sample ( $n = 368$ ) measured during the 1992 NYDEC spawning stock assessment (Hattala et al. 1993). For ages  $> 5$  yr (64% of the NYDEC collection), 83% (197/237) were from year-classes 1981 to 1984.

A von Bertalanffy growth model provided an adequate fit to length-at-age data for males ( $R^2 = 0.73$ ;  $n = 25$ ) (Figure 6). Female data could not be fit to the model because of a limited range in lengths. Observed length-at-age data for females indicated that they were larger than males due to higher growth rates. Mean asymptotic length for males was  $L_{\infty} = 83$  cm TL. Female length-at-age data also indicated asymptotic growth, but at a higher  $L_{\infty}$  than for males.

### Salinity Habitation Time Series

Time-series plots showed seasonal and ontogenetic effects on habitat utilization and migrations (Figure 7). Two or more successive annual cycles in salinity habitation were observed for 64% of the analyzed males (ID = 1, 9, 24, 29, 30, 31, 32, 34, 35, 38, 40, 41, 44, 46, 47, and 50) and 32% of the analyzed females (ID = 11, 12, 15, 22, 23, 26, 28, and 39). Females tended to show annual cycles after their sixth year (ID = 11, 22, 23, 26, 28, and 39). Males tended to show annual cycles earlier in their ontogeny.

Most fish (56%) gave some indication of extending their range into higher salinities with age (Males ID = 8, 10, 30, 31, 32, 34, 35, 36, 37, 38, 41, 42, 43, 45, 46, and 47; Female ID = 7, 11, 13, 14, 15, 16, 17, 22, 26, 27, 28, 49). In addition to this trend, many males (44%) and most females (64%) apparently made excursions into polyhaline habitats ( $> 18$  ppt) during their first and second years of life (Male ID = 1, 8, 24, 29, 30, 31, 32, 33, 35, 38, and 40; Female ID = 2, 3, 5, 6, 11, 13, 16, 17, 18, 19, 23, 25, 26, 28, 39, and 49). In several instances, fish entered euhaline salinities ( $> 30$  ppt) during their first two years (Male ID = 1 and 8; Female ID = 3, 18, and 49). However, most euhaline records were observed after the fifth year (Male ID = 30, 31, 32, 33, 34, and 41; Female ID = 7, 11, 13, 14, 16, 17, 26, 28, and 49).

Ranges in salinities experienced by individuals over their life-times indicated that most fish tended to occur in mesohaline (9 to 18 ppt) and polyhaline habitats throughout their lives, with relatively infrequent excursions into oligohaline ( $\leq 8$  ppt) or euhaline habitats (Male ID = 1, 8, 9, 24, 29, 30,

Table 1. Collection and biological data for Hudson River striped bass samples. ID = identification number; season = season of collection; TL = total length (mm); RK = river kilometer; Mean Sal = mean life-time salinity (ppt); Max Sal = maximum life-time salinity (ppt).

ID	Season	TL	Weight	Sex	RK	Age	Mean Sal	Max Sal
1	Spring	766	5090	Male	115	9	20.84	33.45
2	Spring	823	7380	Female	115	8	14.06	21.80
3	Spring	870	6640	Female	87	8	33.25	39.41
4	Spring	846	7220	Female	86	9	18.74	25.97
5	Spring	838	6260	Female	86	10	24.11	34.64
6	Spring	892	8400	Female	86	11	26.21	34.31
7	Spring	885	8600	Female	86	9	16.68	32.60
8	Spring	428	700	Male	86	4	22.76	36.37
9	Spring	499	1200	Male	86	5	9.31	14.94
10	Spring	557	1520	Male	86	4	5.73	15.96
11	Spring	942	8640	Female	86	12	21.86	33.02
12	Spring	812	6770	Female	86	10	9.54	19.62
13	Spring	830	7350	Female	86	9	18.41	35.62
14	Spring	822	7610	Female	86	10	15.77	35.42
15	Spring	828	7600	Female	86	8	10.00	18.88
16	Spring	823	7140	Female	86	8	22.16	38.21
17	Spring	935	8250	Female	86	9	22.16	32.25
18	Spring	882	7150	Female	86	11	29.40	35.45
19	Spring	901	7000	Female	86	10	18.58	27.64
20	Spring	890	6880	Female	96	9	13.01	20.74
21	Spring	837	6100	Female	96	12	16.78	24.34
22	Spring	929	7000	Female	96	8	17.65	28.21
23	Spring	944	8560	Female	96	9	13.72	23.82
24	Spring	748	4300	Male	96	11	23.12	32.36
25	Spring	868	7400	Female	96	8	18.81	26.15
26	Spring	842	7020	Female	96	8	17.75	37.55
27	Spring	829	7140	Female	96	8	15.15	25.09
28	Spring	770	5350	Female	96	10	22.32	30.91
29	Spring	881	7260	Male	97	10	20.71	32.03
30	Spring	788	4980	Male	97	9	25.22	36.42
31	Spring	876	7140	Male	96	11	24.29	38.37
32	Spring	811	6160	Male	97	12	15.63	34.15
33	Spring	879	7080	Male	97	9	17.69	38.30
34	Spring	937	8780	Male	96	11	14.49	31.19
35	Spring	838	5150	Male	97	11	13.99	23.17
36	Spring	905	8080	Male	97	9	10.24	20.88
37	Spring	395	570	Male	86	4	11.53	16.64
38	Spring	750	4800	Male	86	11	16.25	27.73
39	Spring	868	8370	Female	111	8	16.49	25.63
40	Fall	698	3790	Male	113	7	13.40	19.60
41	Fall	790	5240	Male	73	9	14.64	27.45
42	Fall	674	3240	Male	73	6	11.56	15.69
43	Fall	622	2600	Male	73	6	11.30	19.33
44	Fall	780	5080	Male	152	9	6.95	12.94
45	Fall	750	4700	Male	73	9	4.5	9.80

Table 1. (Continued).

ID Season	TL	Weight	Sex	RK	Age	Mean Sal	Max Sal
46 Fall	712	4340	Male	111	11	5.57	15.71
47 Fall	736	3780	Male	73	9	11.64	19.24
48 Fall	711	4400	Male	115	9	6.35	8.85
49 Fall	948	10900	Female	115	11	21.64	34.05
50 Fall	697	3940	Male	152	14		

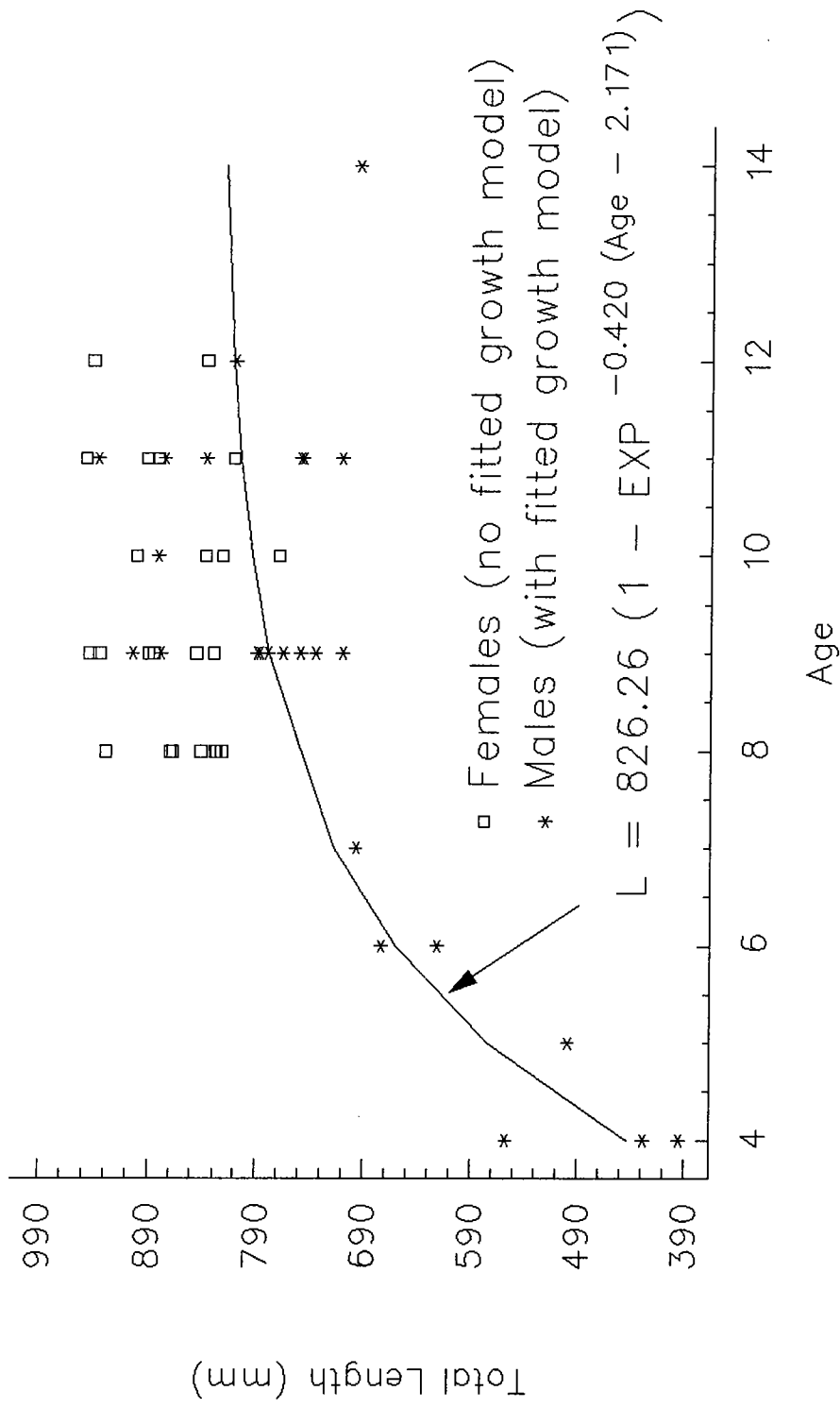


Figure 6. Total length-at-age data for female and male Hudson River striped bass. A von Bertalanffy growth model was fit to the male data. An insufficient number of small females precluded application of a growth model.

# Males

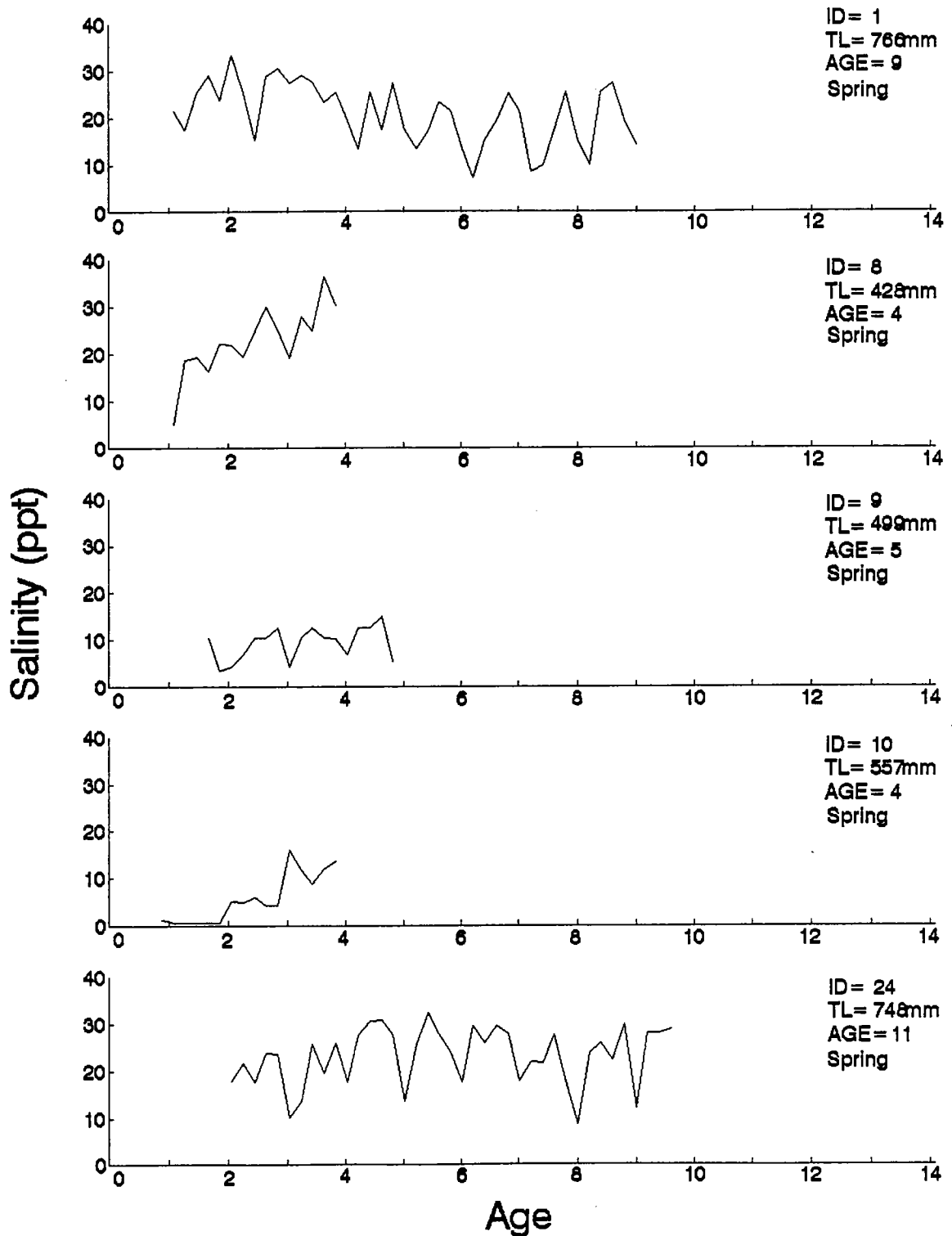


Figure 7. Time series records of salinity habitation for female and male Hudson River striped bass. Salinity habitation was determined based upon microanalysis of Sr/Ca. Gaps in the series for several individuals represent annuli which were sampled by less than 4 point measures. Season of collection (spring or fall), total length, age, and identification (ID) number are given on each series.

# Males

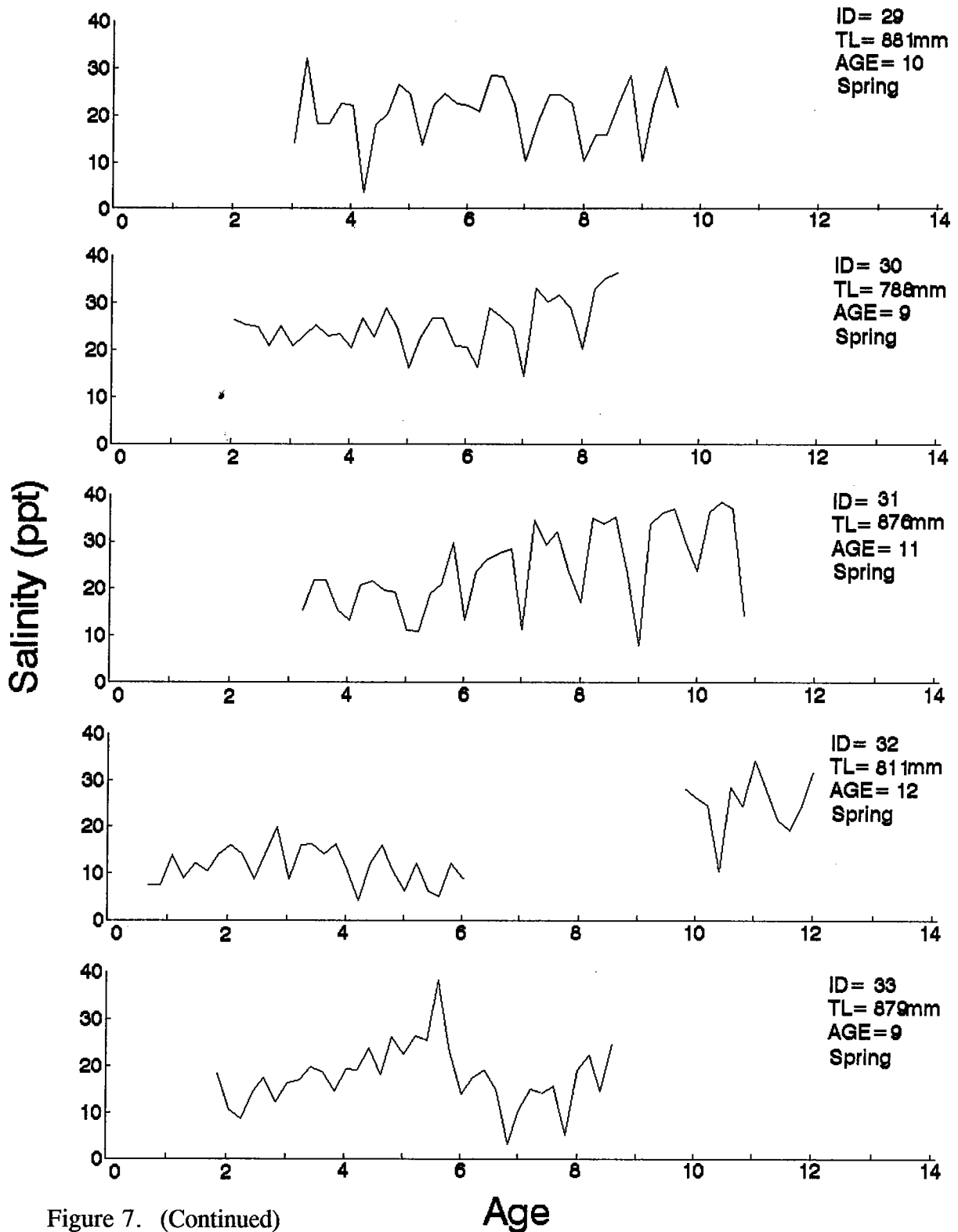


Figure 7. (Continued)

# Males

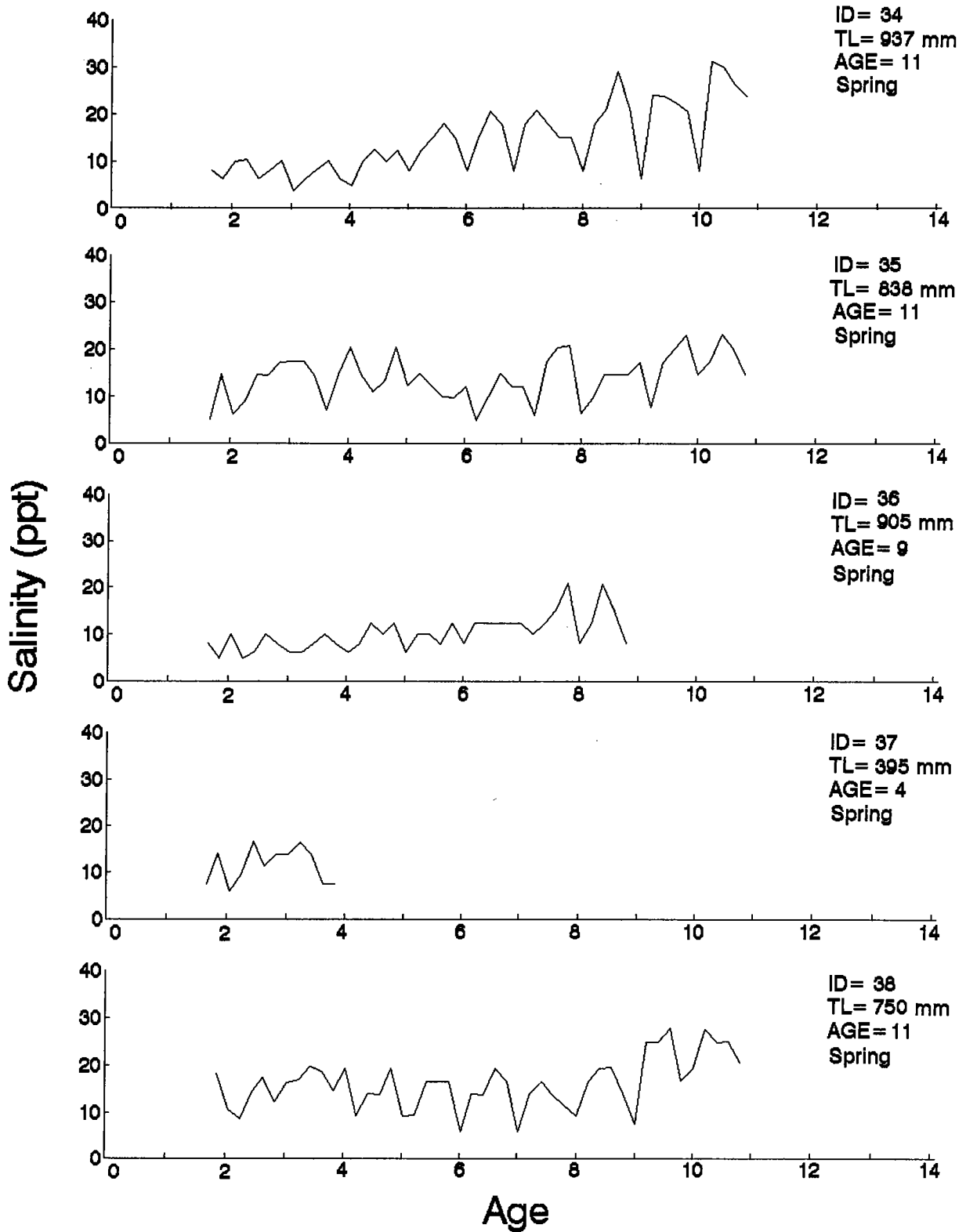


Figure 7. (Continued)



# Males

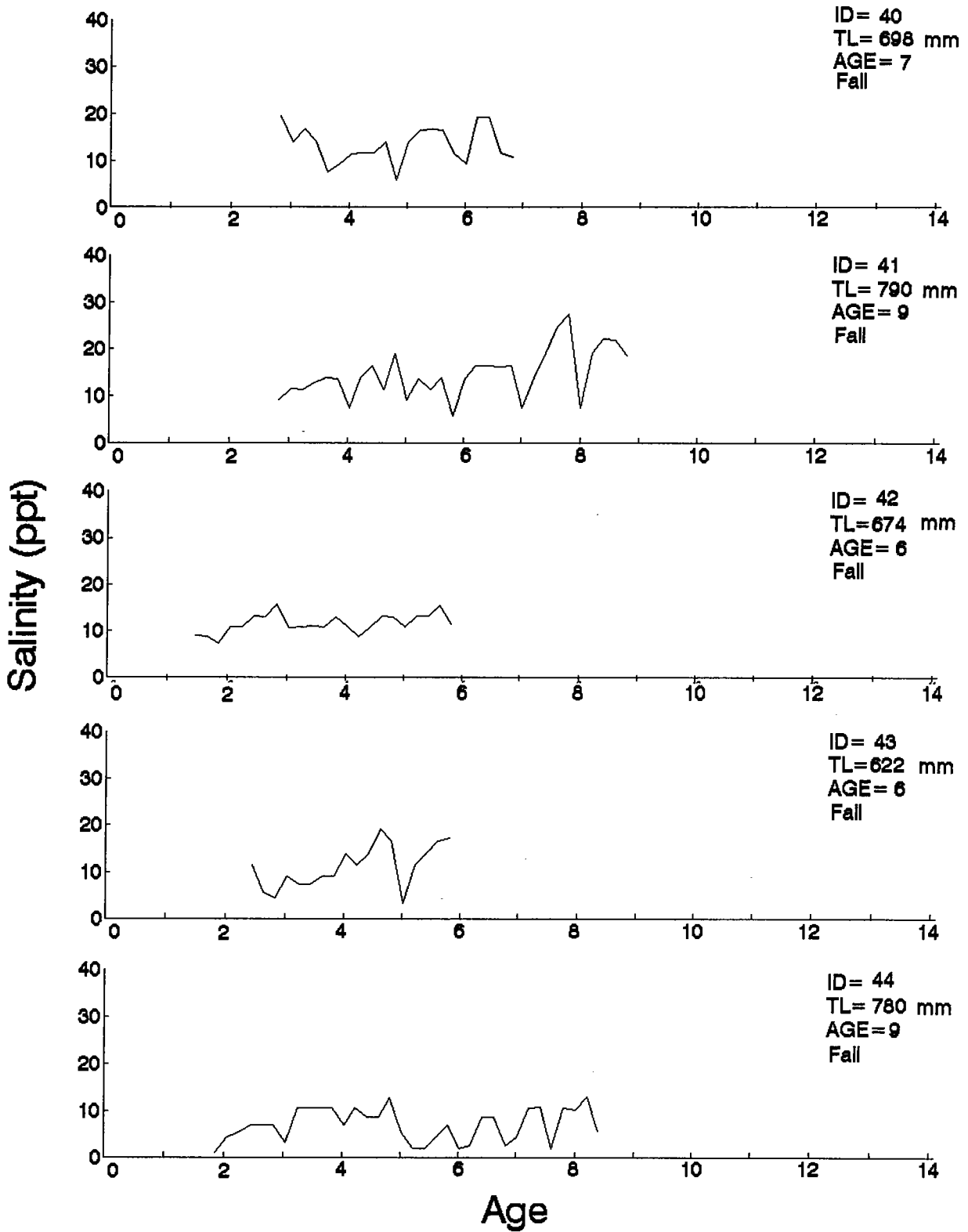


Figure 7. (Continued)

# Males

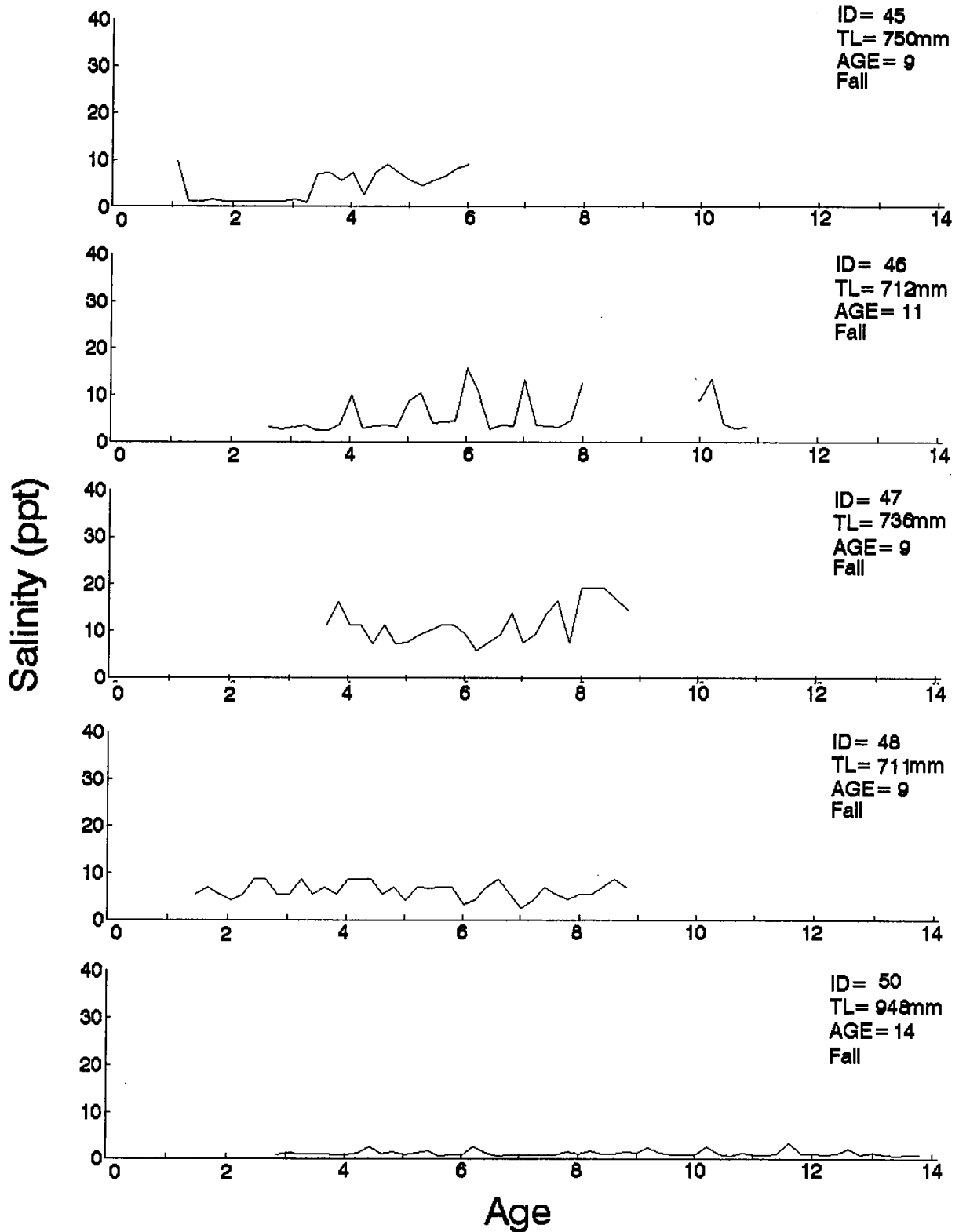


Figure 7. (Continued)

# Females

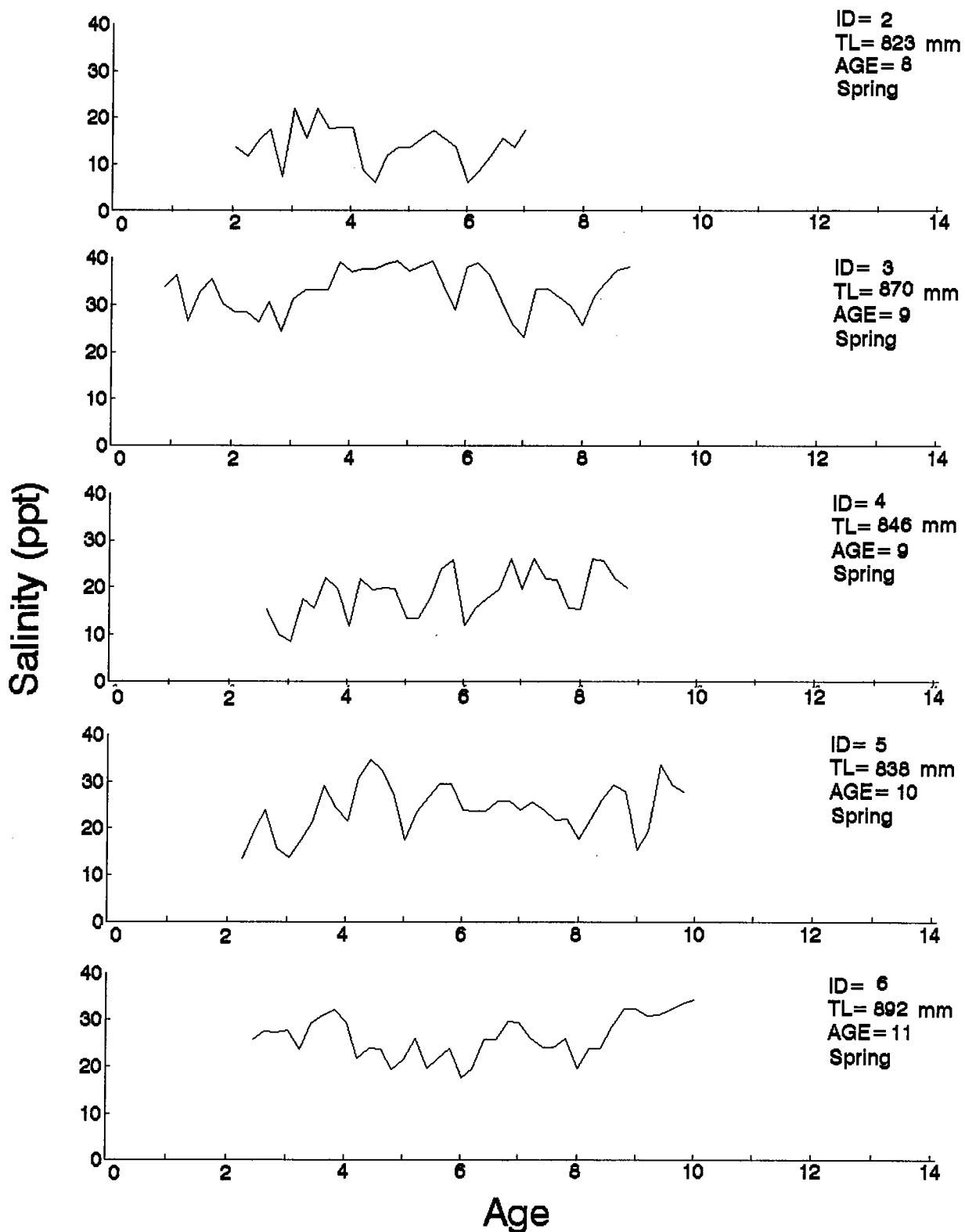


Figure 7. (Continued)

# Females

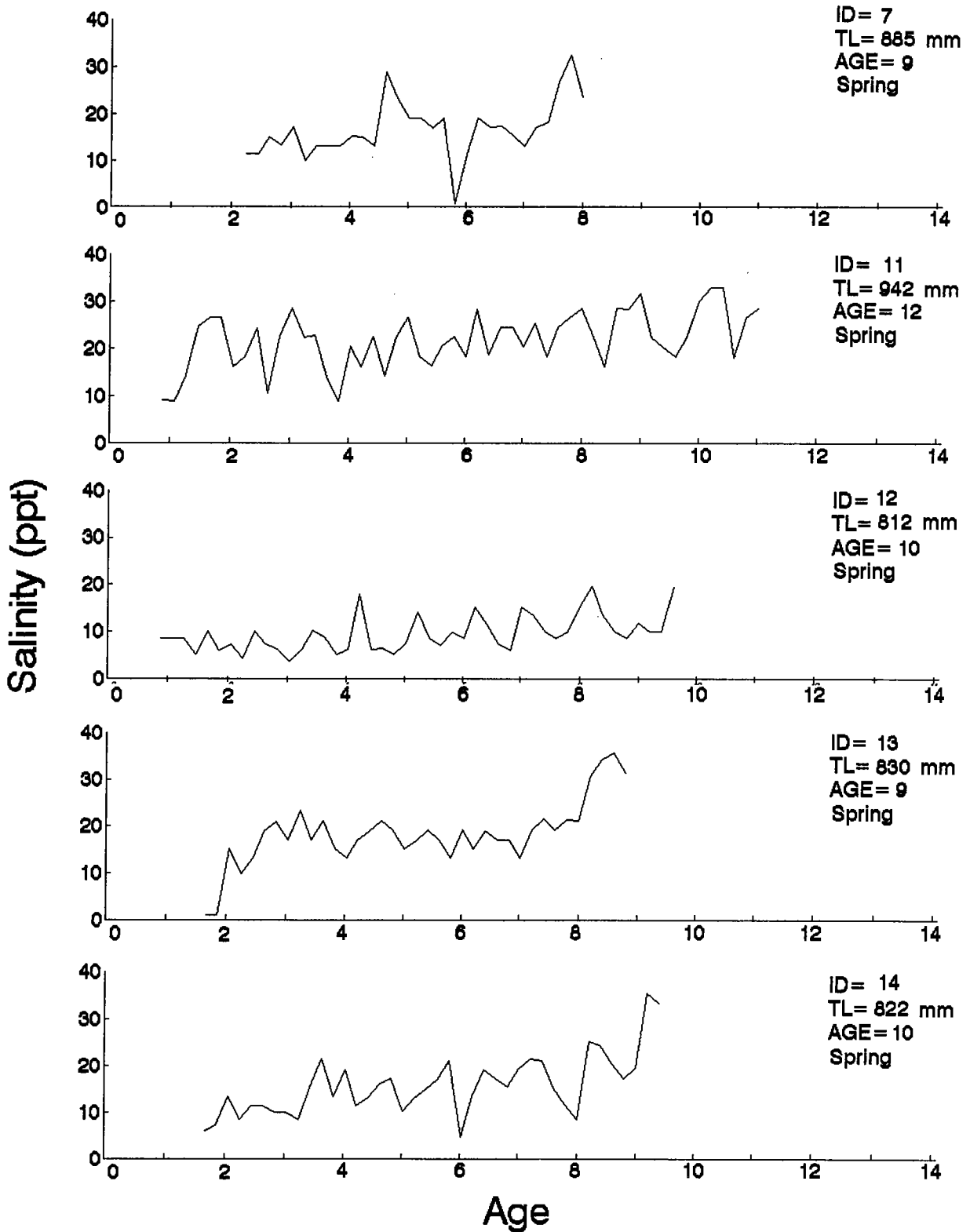


Figure 7. (Continued)

# Females

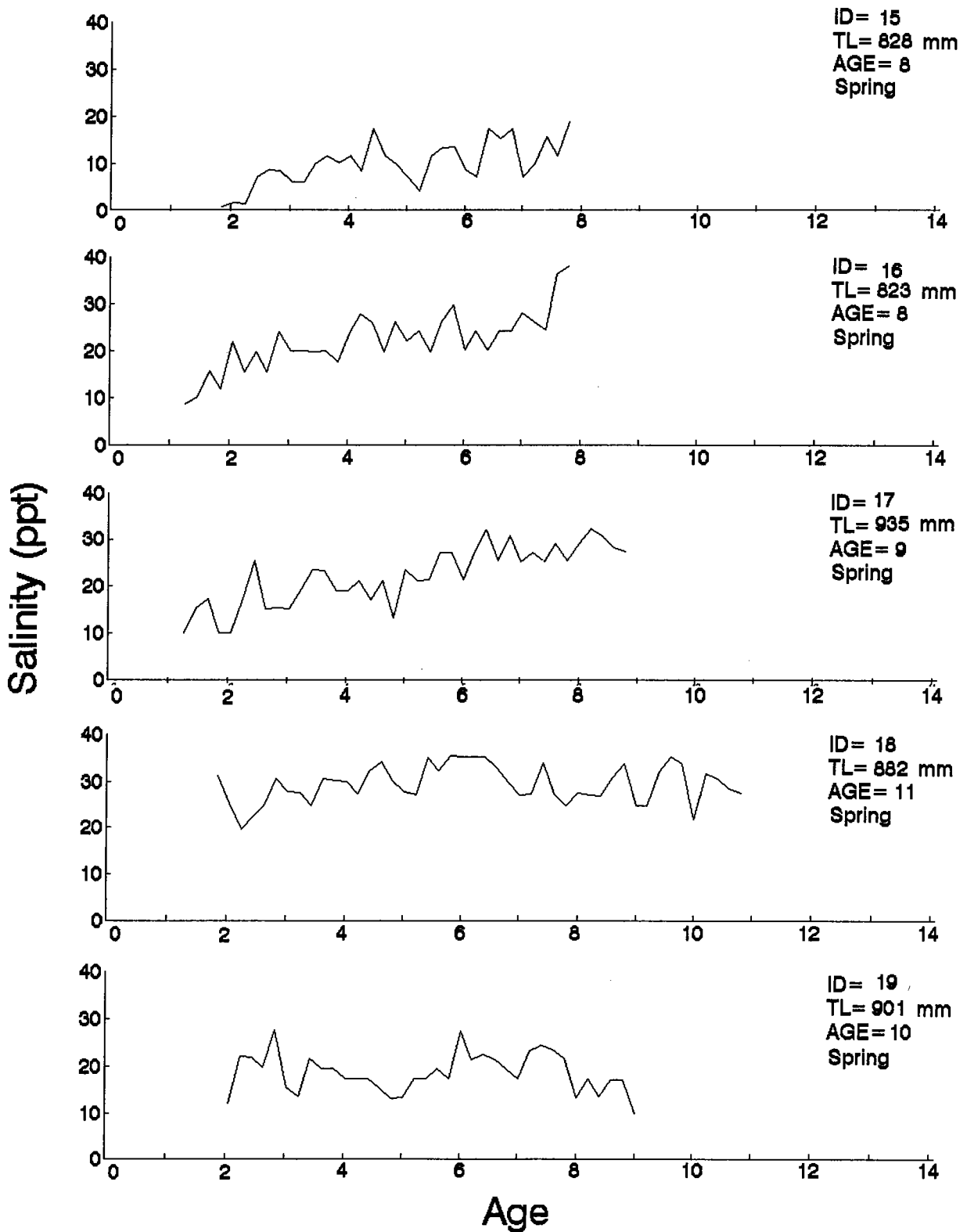


Figure 7. (Continued)

# Females

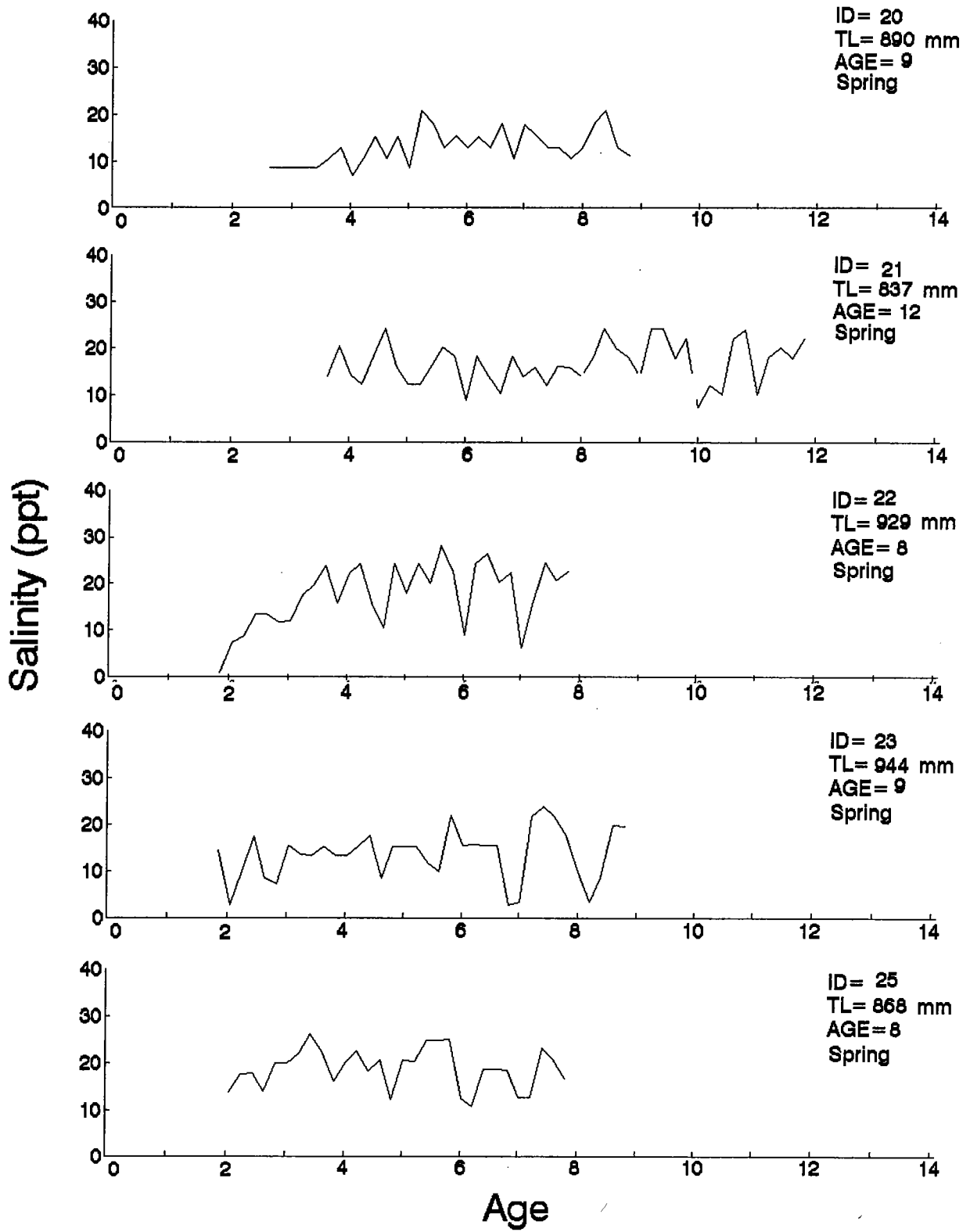


Figure 7. (Continued)