

Use of tag data to compare growth rates of Atlantic coast striped bass stocks

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Abstract Migratory stocks of Atlantic coast striped bass, *Morone saxatilis* (Walbaum), range primarily from North Carolina (NC) northward to Canadian waters. Between 1986 and 2000, 267 045 wild striped bass were tagged and released from NC to Massachusetts as part of the Cooperative Striped Bass Tagging Program. Direct measurements of growth of individual fish can be obtained from tag data and are useful for understanding the dynamics of fish populations. Growth rates from regressions of length-increment vs. time-at-liberty were estimated for striped bass tagged and released in three southern states [NC, Virginia (VA) and Maryland (MD)] and three northern states (New Jersey, New York and Rhode Island). Striped bass tagged in waters of northern states grew faster (significantly steeper regression slopes) than those tagged in southern areas. Migratory patterns, stock mixing, and unmeasured biotic and abiotic influences on growth precluded conclusions that observed growth patterns are stock-specific. These results, however, indicate latitudinal differences in growth rates, and should be considered in future research and management of Atlantic coast striped bass.

KEYWORDS: growth, striped bass, tag data.

Introduction

Striped bass, *Morone saxatilis* (Walbaum), are anadromous migrants of the Atlantic coast and have supported a commercially-important coastal fishery since colonial times (Richards & Rago 1999). A dramatic decrease in striped bass abundance during the late 1970s and early 1980s was confronted by fishing moratoria in several coastal states (Richards & Rago 1999) and a Cooperative Striped Bass Tagging Program was initiated in 1986 to aid management of declining striped bass stocks [US Department of the

Interior (USDOI) & US Department of Commerce (USDOC) 1989]. Tag data from this cooperative effort were used to examine survival (Smith, Burnham, Kahn, He, Goshorn, Hattala & Kahnle 2000) and migration (Dorazio, Hattala, McCollough & Skjveland 1994), but not growth rates.

Tag-based estimates of stock-specific growth rates of striped bass are complicated by patterns of migration. In the last two decades, the migratory stocks of Atlantic coast striped bass have largely comprised fish spawned in tributaries of the Chesapeake Bay [Maryland (MD) and Virginia (VA)] and the Hudson River

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[New York (NY)] (Berlinsky, Fabrizio, O'Brien & Specker 1995). The Roanoke and Delaware River stocks were minor contributors to the migratory stock [Atlantic States Marine Fisheries Commission (ASMFC) 1990; Waldman & Fabrizio 1994], but the contribution of the Delaware River has increased in recent years (D. Kahn, personal communication). Mature striped bass of the Chesapeake Bay stock typically spawn in early spring and migrate northward during late spring to coastal waters of the mid-Atlantic and New England states, and then move southward to over wintering grounds off the coast of North Carolina (NC) (Boreman & Lewis 1987). Mature striped bass of Hudson River origin typically spawn in late spring, move north-eastward (late spring and early summer), and then move southward in autumn to over wintering grounds (Boreman & Lewis 1987; Waldman, Dunning, Ross & Mattson 1990). Consequently, a mixed stock of striped bass occurs in coastal waters during summer, autumn and winter (Wirgin, Maceda, Waldman & Crittendon 1993; Dorazio *et al.* 1994).

An understanding of growth rates within and between stocks of striped bass allows managers to predict when individuals within a specific size range will reach legal length limits, and may be important to future studies on sexual maturation, fecundity, recruitment, and migration. Previously, length-at-age data of striped bass were used to set size limits (ASMFC 1990). However, studies on juvenile striped bass from the Atlantic coast indicated that growth rate is positively correlated with latitude (Brown, Ehtisham & Conover 1998), but little is known about whether latitudinal or stock-specific growth rates occur in sub-adult and adult striped bass. This study compares regional variation in tag-based growth rates of sub-adult and adult Atlantic striped bass.

Materials and methods

Between 1986 and 2000, 267 045 wild striped bass were tagged with Floy internal anchor tags and released along the Atlantic coast from NC to Massachusetts. These fish were tagged as part of the Cooperative Striped Bass Tagging Program, which currently involves 15 state and federal agencies. Details of the cooperative coast wide tagging effort were summarised by USDOJ & USDOC (1989), Dorazio *et al.* (1994), Richards & Rago (1999) and Smith *et al.* (2000). The tag database was queried for release and recapture dates, and length of individuals at times of release and recapture. Total lengths (mm) and release dates of tagged striped bass were reported by researchers of state and federal agencies. Lengths (assumed total

length, mm) and recapture dates of tagged striped bass were reported by recreational anglers, commercial watermen and researchers; however, most (85%) of the lengths and recapture dates used herein were reported by anglers. Although anglers may overestimate lengths, it was assumed that reporting errors would not differ among recapture areas. Data without lengths, or where lengths were known to be approximated, were excluded. Length and date information were used to calculate the growth increment (change in length between time of release and time of recapture) and time-at-liberty (time difference between date of release and date of recapture) for individual striped bass.

In general, tagging data often contain inaccurate reporting dates and length measurements, as well as incorrectly reported tag numbers. Gross data errors lead to improbably large or small estimates of growth rates, and these data were removed from the analysis. Several statistical methods are available to identify and determine the influence of extreme or 'outlying' observations; however, the removal of influential observations is inherently subjective (Neter, Wasserman & Kutner 1985). To eliminate gross data errors, observations where individuals at liberty for over 5 years grew < 50 mm, and where individuals grew at a rate ≥ 3 mm day⁻¹ were removed. Many influential outliers were not removed by this approach, but there was a concern that their removal would exaggerate the strength and generality of underlying relationships.

Release and recapture data were used from fish tagged between 1986 and 2000 in waters of MD (spring and autumn), New Jersey (NJ) (early spring), NY (autumn), Rhode Island (RI) (autumn), VA (spring and autumn), and offshore waters of NC (winter) (Table 1). Sex information was available for most individuals released during spring in MD and VA waters. From preliminary analyses it was determined that plots of length-increment vs. time-at-liberty depicted linear relationships for tagged striped bass separated into 10-cm segments of release-length. Hence, growth rates of tagged striped bass were examined for two 10-cm segments of release-length (457–557 and 558–658 mm). Growth rates (mm day⁻¹) were represented as slopes of length-increment vs. time-at-liberty regressions, where steeper slopes indicated faster growth rates. Analysis of Covariance (ANCOVA) was conducted with PROC GLM of SAS software (SAS Institute Inc. 1999) to determine if growth rates (i.e. slopes) of striped bass separated by state of release, season of release and sex were equal. The significance level for all tests was $P < 0.05$; however, when

Table 1. Regression coefficients of growth rates (slopes) based on length-increment vs. time-at-liberty data for two length groups of striped bass tagged and released in waters of six states during 1986–2000

Release agency and state	Sex	457–557 mm length group			558–658 mm length group				
		n	Y-intercept	Slope	r ²	n	Y-intercept	slope	r ²
North Carolina (SEAMAP) cooperative winter trawl survey	C	222	13.79 (5.19)	39.96 (2.03)	0.64	290	34.47 (6.93)	28.80 (1.89)	0.45
Virginia Department of Game and Inland Fisheries (VDGIF) and Virginia Institute of Marine Science (VIMS),	C	755	22.58 (2.42)	27.48 (1.00)	0.50	414	21.22 (4.02)	26.37 (1.44)	0.45
VDGIF and VIMS (released during autumn)	C	493	20.10 (2.95)	29.80 (1.28)	0.53	201	25.10 (5.20)	27.70 (2.35)	0.41
VDGIF and VIMS (released during spring)	C	262	27.52 (4.17)	23.84 (1.60)	0.46	213	13.37 (6.35)	27.19 (1.95)	0.48
MDDNR, VDGIF and VIMS (females)	F					91	20.11 (9.07)	28.99 (2.49)	0.60
MDDNR, VDGIF and VIMS (males)	M					347	31.48 (5.18)	21.42 (1.51)	0.37
Maryland Department of Natural Resources (MDDNR)	C	1314	23.76 (1.99)	33.96 (0.81)	0.57	897	29.59 (2.81)	26.60 (0.97)	0.46
MDDNR (released during autumn)	C	974	17.38 (2.28)	40.18 (1.18)	0.54	570	19.70 (3.13)	36.36 (1.41)	0.54
MDDNR (released during spring)	C	340	30.25 (4.33)	29.33 (1.23)	0.63	327	35.10 (5.56)	21.59 (1.46)	0.40
New Jersey Department of Environmental Protection	C	201	49.49 (6.99)	46.71 (2.43)	0.65	801	40.85 (3.36)	40.53 (1.17)	0.60
New York Department of Environmental Conservation	C	324	38.30 (6.52)	46.61 (1.82)	0.67	289	34.47 (7.46)	39.77 (1.89)	0.61
Rhode Island Department of Fish and Wildlife	C	483	35.32 (5.65)	48.79 (1.12)	0.80	220	53.12 (8.86)	39.30 (1.73)	0.70

Parenthetic values are standard errors, n, sample size; SEAMAP, Southeast Area Monitoring and Assessment Program; C, sexes combined.

ANCOVA concluded that slopes were not all equal, then the ADJUST = SIMULATE option for the LSMEANS statement was used to test for differences between each pair of slopes and control the experiment-wise error rate (Westfall, Tobias, Rom, Wolfinger & Hochberg 1999). The tag database contained the year class (from scale analysis) for a sub sample of individuals released in waters of MD, VA, NY and NC. The year class was converted to an estimated ‘hatch date’ (i.e. 1 June of the year class) and then subtracted from the capture date to estimate age in days. Age distributions within each length group were then compared among tagged striped bass released in waters from each state. Additionally, sample sizes from the screened recapture data of striped bass tagged and released each year were compared among the six release states.

Results

Length-increment vs. time-at-liberty regressions of both 10-cm length groups indicated that striped bass released in northern locations (NJ, NY and RI) grew significantly faster than those released in southern areas (MD, NC and VA) (Table 1). For both length groups, growth rates of striped bass released in northern states (NJ, NY and RI) were not significantly different. The growth of the larger (558–658 mm) length group of striped bass tagged in waters of MD (spring and fall data combined) was not significantly different from those of NC and VA (spring and autumn data combined; Table 1). The growth rate of the larger length group of striped bass tagged in waters of VA (spring and fall data combined) was not significantly different from that of MD (spring and autumn data combined) but was significantly lower than the growth rate of fish tagged offshore of NC (Table 1). For the smaller (457–557 mm) length group, the growth rate of the mixed stock of offshore NC was significantly higher than striped bass released in VA waters, but did not differ significantly from those released in MD. The growth rate of the smaller length group of striped bass tagged in MD waters of the Chesapeake Bay significantly exceeded that of striped bass released in VA waters (Table 1).

The smaller and larger length groups of striped bass released during autumn in MD waters had faster growth rates than those released in spring in MD, but this difference was not significant between autumn and spring releases of the smaller length group (Table 1). The smaller and larger length groups released in autumn in VA waters had faster growth rates than those released in spring, but these differences were not significant (Table 1). Striped bass tagged and released

Table 2. Mean, standard errors, and sample sizes (*n*) of age distributions of striped bass tagged and released during two time periods (1986–1992 and 1993–2000) separated by release state and two release-length groups

State	1986–1992		1993–2000	
	<i>n</i>	Mean age	<i>n</i>	Mean age
457–557 mm length group				
VA	184	7.1 (0.17)	355	4.7 (0.06)
MD	78	8.5 (0.35)	67	5.8 (0.16)
NY	108	7.8 (0.26)	181	5.7 (0.12)
558–658 mm length group				
NC	51	9.6 (0.48)	11	7.9 (0.61)
VA	129	8.2 (0.20)	164	6.1 (0.11)
MD	81	9.4 (0.30)	54	7.3 (0.23)
NY	146	8.1 (0.23)	137	7.0 (0.17)

VA, Virginia; MD, Maryland; NY, New York; NC, North Carolina.

in spring from MD and VA waters of the Chesapeake Bay were predominantly males (females were < 1% of the smaller length group of individuals tagged and released in MD and VA, and of the larger length group of MD). For the larger length group, the growth of females tagged and released in MD and VA was faster than that of males, but this difference was not significant (Table 1).

For both length groups, age distributions for the 15-year time series were similar among striped bass tagged and released in waters of MD, VA, NY and NC. Means of age distributions of striped bass tagged and released during the first half of the time series (1986–1992) were higher than those tagged and released between 1993 and 2000 (Table 2). Additionally, the screened recapture data contained more striped bass tagged in southern states than in northern states during the latter half of the time series (Table 3).

Discussion

Many factors influence growth rates of fishes, e.g. age, sex, genetics, density-dependence (competition and/or disease), temperature and diet. Given that striped bass stocks mix during coastal migrations, similar growth rates among stocks might be expected. Additionally, large variation of within-stock growth rates, because of temporal and geographical variation of food availability, temperature and competition, may obscure stock-specific differences. Despite the potential for large variation of growth rates within and among stocks, striped bass tagged on NC wintering grounds and in the Chesapeake Bay grow slower than those tagged in northern areas. These differences may result from genetic differences among stocks that affect growth

Table 3. Number of tags recovered from striped bass separated into two release length groups and tabulated by state of release, season of release, and year of release (columns)

State of release	Season released	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
457–557 mm length group																	
Offshore NC	Winter	0	0	6	0	8	0	5	7	84	2	0	5	12	0	93	222
Chesapeake Bay, MD	Autumn and spring	5	36	37	21	8	11	87	138	116	181	189	271	86	114	18	1318
Chesapeake Bay, VA	Autumn and spring	0	23	17	34	53	60	22	50	73	38	55	127	91	112	0	755
NJ	Spring	0	0	0	9	4	12	13	34	36	17	21	16	11	16	12	201
NY	Autumn	0	17	22	9	18	17	27	41	32	10	69	31	17	14	0	324
RI	Autumn	181	261	41	0	0	0	0	0	0	0	0	0	0	0	0	483
558–658 mm length group																	
Offshore NC	Winter	0	0	46	5	31	21	7	14	120	6	1	14	16	2	7	290
Chesapeake Bay, MD	Autumn and spring	1	26	43	42	21	29	78	112	131	172	111	67	26	39	3	901
Chesapeake Bay, VA	Autumn and spring	0	17	21	26	12	44	32	47	58	38	28	40	28	23	0	414
NJ	Spring	0	0	0	24	8	12	53	95	162	104	99	33	44	108	59	801
NY	Autumn	0	41	41	6	26	16	17	41	34	18	13	14	20	1	0	288
RI	Autumn	69	127	24	0	0	0	0	0	0	0	0	0	0	0	0	220

NC, North Carolina; MD, Maryland; VA, Virginia; NJ, New Jersey; NY, New York; RI, Rhode Island.

directly or indirectly through stock-specific migratory patterns. It is also possible that the differences in growth rates result from a combination of biotic or abiotic influences that are independent of fish origin, or reflect artificial differences between northern and southern groups owing to sample effects. Although tagging may reduce growth rates (Xiao 1994; Hughes 1998), retardation effects were assumed equal among release areas.

Stock origin and sex cannot be accurately assigned to striped bass tagged during non-spawning times, and this limited estimates of stock-specific and sex-specific differences in growth rates. General migratory patterns suggest that individuals tagged in northern waters during late spring could be migrants of Chesapeake Bay origin, and those tagged in Chesapeake Bay during the autumn could be fish spawned in northern areas. Striped bass tagged in NY in autumn and offshore NC in winter represent a mixed stock; however, the proportions of individuals spawned from the Chesapeake Bay and Hudson River are unknown and likely vary with year class strength. Individuals tagged on the spring spawning grounds in MD and VA waters of the Chesapeake Bay are likely to be of Chesapeake Bay origin, and most of these were males. Females grow faster than males (ASMFC 1990), and it is possible that the number of females in northern samples exceeded that of southern samples. Sex influenced the present estimates of growth rates (females grew faster than males, although this difference was not significant), but growth differences between males and females tagged during spring in Chesapeake Bay were small relative to growth differences between southern and northern groups.

Slower growth rates of striped bass tagged and released in the southern part of the range may result from the timing of migration, a lack of migration, or the bioenergetic costs of migration. Berlinsky *et al.* (1995) found that mature fish (age-classes 4, 5 & 6) sampled during spring were significantly longer than immature fish of the same age class, and Dorazio *et al.* (1994) reported that the probability of migration of mature striped bass increased with fish size. Dorazio *et al.* (1994) also found that striped bass in the Chesapeake Bay migrate at different times or not at all. It is possible that individuals in Chesapeake Bay with faster growth rates mature and migrate sooner than those with slower growth rates. Therefore, slow growers may be vulnerable, and for a longer period, to the Chesapeake Bay fishery than fast growers that migrate northward and become available to the northern fishery. Alternatively, striped bass tagged in the Chesapeake Bay may experience longer migrations

to reach northern feeding areas and southern wintering grounds than striped bass of northern origin, and thus may budget more energy for migration and less energy for growth. An understanding of migratory influences on growth rates requires information on residence times in northern and southern areas. Unfortunately, the tag data contain only a part of this history (i.e. only release and recapture locations), and inferences based on recapture locations would mislead the growth analysis because proportions of time in northern and southern areas are unknown for individuals at liberty for several years.

Differences in growth rates between striped bass tagged and released in northern and southern areas could also be explained by geographical and temporal variation in food availability and competition. Energetic growth costs of northward migration from Chesapeake Bay may be offset by faster growth rates due to increased availability or quality of food in northern areas. Density-dependent effects (disease and competition for food) or low habitat quality may reduce growth rates of striped bass that remain in the Chesapeake Bay. From habitat models, Brandt & Kirsch (1993) found few areas of high growth rate potential within the Chesapeake Bay. Growth rates of striped bass likely vary temporally across geographical areas, and decreased length-at-age has been reported in southern (Waller & Warner 2000) and northern (J. Stockwell & P. Diodati unpublished data) parts of the range. Temporal variation in growth rates were obscured by combining 1986–2000 recapture data, but probably influenced growth slopes of striped bass tagged in Chesapeake Bay because of higher sample sizes during the latter half of the 15-year time series.

Growth rates differed between striped bass tagged and released in northern and southern parts of the range. It is unclear, however, if this results from genetic or behavioral differences between northern and southern stocks, or may be due to other biotic or abiotic factors that influence growth. Further analyses of these tag data that fit growth models, examine the location of recapture, examine temporal variation, or include larger length groups may reveal additional insights into growth rates of Atlantic coast striped bass.

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