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ABSTRACT

We examined a corollary to the hypothesis that striped bass regulate the blue crab population in Chesapeake Bay by preying on juveniles, an expected inverse correlation between striped bass and blue crab abundance. Abundance indices based on Virginia striped bass young-of-the-year beach seine data (1980-1992) were constructed for fish ages 1 - 8, and for the Virginia resident stock component, ages 1 - 5. Fishery-independent, pound net data for fall and spring were also used to construct indices of striped bass abundance in Rappahannock River (1986-1993). Juvenile blue crab abundance indices were constructed based on trawl survey data from the James, York and Rappahannock Rivers. Fall crab abundance correlated positively with predicted Virginia resident striped bass abundance. Crab abundance in the spring did not correlate with any measure of striped bass abundance, nor did fall Rappahannock River crab abundance correlate with the fall Rappahannock River pound net index. Thus, these data do not support the hypothesis that striped bass abundance and blue crab abundance are inversely related. Striped bass populations do not appear to have regulated blue crab population dynamics in the Virginia portion of Chesapeake Bay from 1980 to 1992.

Key words: Chesapeake Bay, striped bass, blue crabs, population regulation, predation

INTRODUCTION

The Chesapeake Bay striped bass (*Morone saxatilis*) stock has made a substantial recovery in recent years, possibly due in part to aggressive management on the part of interstate and state agencies. Concurrently, Chesapeake Bay blue crab (*Callinectes sapidus*) abundance and harvests have been relatively low. Commercial fishermen have suggested that striped bass are depleting the blue crab populations in the Chesapeake Bay. However, only a few attempts have been made to examine this influence (Goshorn and Casey, 1993).

We analysed available data to test the hypothesis that striped bass abundance and juvenile blue crab abundance are inversely related in the Virginia portion of Chesapeake Bay.

METHODS

A model predicting relative abundance of resident Chesapeake Bay striped bass was constructed using the Virginia portion of the Virginia Institute of Marine Science (VIMS) weighted, Chesapeake Bay-wide, juvenile striped bass index (Austin et al.,

1993) (Table 1). This index is based upon the VIMS beach seine survey, in which fixed stations on the James, York and Rappahannock River systems are sampled three times each summer, from July through September. The striped bass juvenile index is a weighted geometric mean of the number of juvenile bass per haul, calculated as

$$\bar{x} = \sum_{k=1}^{3} \left[\log^{-1} \left[\left[\frac{\sum_{i=1}^{n_k} \log(x_{ik} + 1)}{n_k} \right] - 1 \right] w t_k \right], \qquad \text{[Equ. 1]}$$

where k = 1 = James River, 2 = York River and 3 = Rappahannock River. The weighting factor wt_k is calculated from the nursery ground surface area for the respective rivers, and n_k is the number of times the k^{th} river system was visited in a particular year (Austin et al., 1993).

Survival of each year class was calculated for each year t using the expression

$$N_t = N_{t-1} e^{-Z_t}, \qquad \text{[Equ. 2]}$$

where total mortality Z is given by:

$$Z = M + F, \qquad \text{[Equ. 2a]}$$

if fish are recruited to the fishery, and

$$Z = M + C * F, \qquad \text{[Equ. 2b]}$$

otherwise, where C*F (C = 0.20) is an estimate of poaching and hook-and-release mortalities (Rugolo, pers. comm.[1]). Here M = 0.20 is the commonly used value for natural mortality (Lackey and Nielsen, 1980), and F is historical fishing mortality by year (1959-1984: Gibson, 1993; 1985-1992: Rugolo, pers. comm.). The interval 1980-1992 was chosen as these are the years for which uninterrupted VIMS beach seine data were available.

Determination of entry into the fishery was made using length-at-age estimates (Hill and Loesch, 1994a) and Virginia Marine Resources Commission (VMRC) minimum legal length regulations[2] (Table 2). Usually changes in harvest regulations took effect in the middle of the year. For years during which a change occurred, the minimum length that was legal for any part of that year was used to determine entry into the fishery. Although female striped bass grow faster than males (Hill and Loesch, 1994a), the difference was not great enough to cause females of any year class to enter the fishery earlier. Therefore, pooled estimates for length at age were used in the model.

Only the nonmigratory striped bass stock was considered in this model. The migratory stock is not present in large numbers in the rivers where juvenile crabs are plentiful during the months that small crabs are most abundant. This is also the period for which the VIMS blue crab juvenile index is calculated, September through

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1 Louis J. Rugolo kindly provided us with estimates for several parameters used in this model. His research in the Maryland portion of Chesapeake Bay was the best source of information on fishing, poaching and, hook and release mortalities, as well as recent (post 1985)age at migration rates.

2 VMRC revises and publishes Regulation Number450-01-0029 "Pertaining to the taking of Striped Bass" each year. The regulations are available from VMRC.

TABLE 1. The data used in the regressions.

	Yr		1	2		3	4	5	6
80							2.2		
81							0.9		
82							1.6		
83							3.1		
84							3.5		
85	4.9		4.15	22.69	8.25	49.24	1.6		
86	4.3		1.89	7.06	0.74	4.33	5.0	51.07	
87	6.8		2.94	11.82	0.41	4.02	10.2	38.39	10.59
88	12.9	14.8	3.22	13.46	9.88	12.28	3.5	57.04	9.64
89	11.2	14.5	10.76	12.17	7.21	9.80	9.3	74.38	9.98
90	13.4	17.8	15.62	42.97	31.46	65.82	6.3	*	15.55
91	13.5	17.6	8.66	5.48	11.28	7.66	3.1 5	2.87	13.10
92	10.3	15.0	6.72	4.14	3.60	5.33	4.6	140.25	6.26
93	8.2	13.9	5.98	9.10	8.04	10.07	12.4	**	24.57

1. Predicted, relative, resident striped bass
2. Predicted, relative striped bass
3. Fall blue crab index
4. Spring blue crab index
5. Fall, Rappahannock River blue crab index
6. Spring, Rappahannock River blue crab index
7. Striped bass juvenile index
8. Fall Rappahannock River pound net striped bass CPUE
9. Spring Rappahannock River pound net striped bass CPUE

* No data collected.
** Data not available at time of analysis.

TABLE 2. Virginia commercial harvest regulation for striped bass minimumlengths.

Year	70-85	1986	87-90	91-93
Total length (inches)	14	18	24	18

November. Data on commercial catch-per-unit-effort (CPUE) of striped bass are reported by Hill and Loesch (1994a) by year class, season (spring and fall), and by river mile on the Rappahanncock River for the period 1986-1993. From the fall data we recalculated CPUE by fish age for the entire river (Table 3), and found that fish older than five years were not present in abundance. The fraction of each year class not joining the migratory stock was estimated from age at migration rates (Rugolo, pers. comm.), except that age 6+ fish were considered to have entirely recruited to the migratory stock (Table 4). Although it is commonly thought that female striped bass begin migrating at an earlier age (Setzler et al., 1980), no difference arises in predicted population by sex at the ages under consideration here. Therefore, we pooled the estimates for percent migration.

TABLE 3. Fall Rappahannock River striped bass CPUE by age and year.

Yr	Age 1	2	3	4	5	6	7	8
86	29.33	15.40	5.33	0.93	0	0	0	0.07
87	1.36	25.25	7.14	3.82	0.71	0.04	0.07	0
88	3.46	30.64	16.43	5.21	1.11	0.11	0.07	0
89	1.52	29.52	32.71	9.14	1.76	0.19	0	0
90	No Data							
91	0.04	10.43	26.04	11.30	4.22	0.74	0.04	0
92	6.50	35.25	54.25	39.25	4.25	0.25	0	0

TABLE 4. Chesapeake Bay striped bass residency rates.

Age	Rate
0	1.000
1	1.000
2	0.900
3	0.575
4	0.575
5	0.575
6+	0.000

Thus, the resident bass model (RB) has the form

$$RB_t = \sum_{j=t-1}^{t-5} \bar{x}_{gj} \left[e^{-\sum_{i=j=1}^{t} Z_i} \right] R_{t-j}, \qquad \text{[Equ. 3]}$$

where t is the year for which the resident bass are being predicted, and R is the residency rate for fish of a particular age [e.g., suppose t = 1988 and j = t - 2 = 1986, then t - j = 2, so we use the residency rate for two year olds. At the same time, we use

$$\left(e^{-(Z_{1987} + Z_{1988})} \right), \qquad \text{[Equ. 4]}$$

for survival.]

The estimates for surviving, resident, striped bass of ages 1-5 were summed for each of the years 1985-1993 (Table 5). These were regressed against the VIMS juvenile blue crab index for those years (Table 1). This index is calculated using data collected with an otter trawl from September through November. This is also a weighted, geometric mean, and is calculated as above except that the weighting factor and summation across the six strata are moved inside the back-transformation:

TABLE 5. Predicted relative abundance of striped bass by age and year.

Age	1985	1986	1987	1988	1989	1990	1991	1992	1993
5	.04	0.05	0.12	0.54	0.67	0.24	0.61	1.21	0.41
4	.07	0.15	0.67	0.83	0.38	0.95	1.89	0.63	1.64
3	.33	0.84	1.04	0.48	1.48	2.95	0.99	2.56	1.73
2	1.63	2.02	0.92	2.88	5.88	1.96	5.09	3.45	1.70
1	2.80	1.28	4.00	8.16	2.80	7.25	4.91	2.42	3.60
Sum	4.87	4.34	6.75	12.89	11.21	13.35	13.49	10.27	9.08

TABLE 6. Spring Rappahannock River striped bass CPUE by age and year.

	Age												
Yr	1	2	3	4	5	6	7	8	9	10	11	12	13
87	0.02	0.76	2.53	4.55	2.10	0.31	0.16	0.02	0.10	0.02	0	0	0
88	1.97	2.75	2.36	1.86	0.61	0.03	0.06	0	0	0	0	0	0
89	0	0.44	4.81	1.93	1.09	1.21	0.30	0.16	0.02	0	0	0	0
90	0	2.73	2.45	3.09	3.00	2.09	1.09	0.55	0.45	0.09	0	0	0
91	0.40	0.45	2.60	5.05	2.45	1.10	0.45	0.15	0.10	0.30	0.05	0	0
92	0.12	0.29	0.48	1.40	2.36	0.88	0.31	0.24	0.10	0.17	0.07	0	0
93	0.13	0.65	1.17	4.04	10.78	4.13	0.74	0.47	0.65	0.52	0.35	0.30	0.17

$$\bar{x}_g = \log^{-1}\left[\sum_{k=1}^{6}\left[(wt_k)\left[\frac{\sum_{i=1}^{n}\log(x_{ik}+1)}{n_k}\right]\right]\right] - 1\,, \qquad \text{[Equ.5]}$$

where the weights (wt_k) are calculated from the surface areas of the strata, two each for the three Virginia rivers, James, York and Rappahannock (Figure 2). Here k identifies the stratum and n_k is the number of otter trawl tows in the k^{th} stratum (Bonzek, pers. comm.).

Because juvenile blue crabs are active during at least the warmer periods of the winter, the model was adjusted to predict migratory plus nonmigratory relative bass population. This was done by simply removing the residency component R, and summing predicted relative bass of ages 1 - 8 (Table 1). Although the Rappahannock River pound net CPUE data (Hill and Loesch, 1994a) indicate that a few fish older than eight years were present in the winter months, the number is very small.

The juvenile blue crab index was recalculated for the months May and June (1985-1993), taking into account growth since the previous fall. Where crabs ≤ 65 mm were considered juveniles in the fall, the new limits were ≤ 80 mm (May) and ≤ 100 mm (June).

The spring juvenile blue crab index was regressed against the predictions of the striped bass model and the resident striped bass model.

TABLE 7. Summary of results for blue crab v. striped bass linear regression analyses.

Regression	R^2	p
Fall blue crab juvenile index v. predicted resident striped bass index	0.451	0.048
Spring blue crab juvenile index v. resident + nonresident striped bass index	0.283	0.278
Rapp. R. fall blue crab juvenile index v. fall striped bass pound net index	0.001	0.951
Rapp. R. spring blue crab juvenile index v. spring striped bass pound net index	0.059	0.601

Indices of adult striped bass abundance for the Rappahannock River, Virginia were constructed from pound net data (Hill and Loesch, 1994a,b). The catch-per-unit-effort (CPUE) was calculated by year for each of the two collection periods, fall and spring (Table 1). Since few fish older than five years are collected in the fall sampling, this collection is thought to represent only year-round resident fish. The spring collection includes adults up to 13 years old, and is considered a sample of the combined resident and migratory stocks (Table 6).

Indices of juvenile blue crab abundance were constructed for the fall and spring periods defined above, using only data from the Rappahannock River (Table 1). Fall and spring indices of juvenile blue crab abundance were then regressed against respective Rappahannock River striped bass indices.

Data on which all indices are based are fishery-independent, and are independent of each other. The juvenile striped bass data are gathered with a beach seine during the summer (July-Sept.) in the nursery grounds of the three major rivers in the Virginia portion of the Chesapeake Bay. The adult striped bass are collected with pound nets on the Rappahannock River in two collections in the fall and spring, and the juvenile blue crab data are collected by otter trawl throughout the Virginia rivers, during the months September through November for the fall crab index, the months during which small crabs are most abundant, and during the months May and June for the spring blue crab index.

RESULTS and DISCUSSION

We found a significant positive linear relationship between predicted resident bass and juvenile blue crabs (Figure 1 and Table 7). This relationship reflects a rise and subsequent fall in blue crab numbers (Figure 2). The rise and fall in predicted resident striped bass numbers (Figure 2) can be attributed largely to strong year classes in 1987 and 1989 in the following manner. The 1987 year class entered the residence index in 1988, and inflated it. The 1988 year class was small, entered the model in 1989, and at the same time 10% of the 1987 year class emigrated with the migratory stock, causing a decline in the residence index. Then, in 1990, the strong 1989 year class entered the resident stock, elevating the index, and the 1990 year class was strong enough that a decline was not seen until 1992. Relatively weak year classes in 1991 and 1992, along with most of the 1987 and many of the 1989 fish entering the migratory stock, largely explain the decline. Considering the great differences in the life histories of these species, and the different management practices, the apparent association between blue crabs and striped bass may be coincidental.

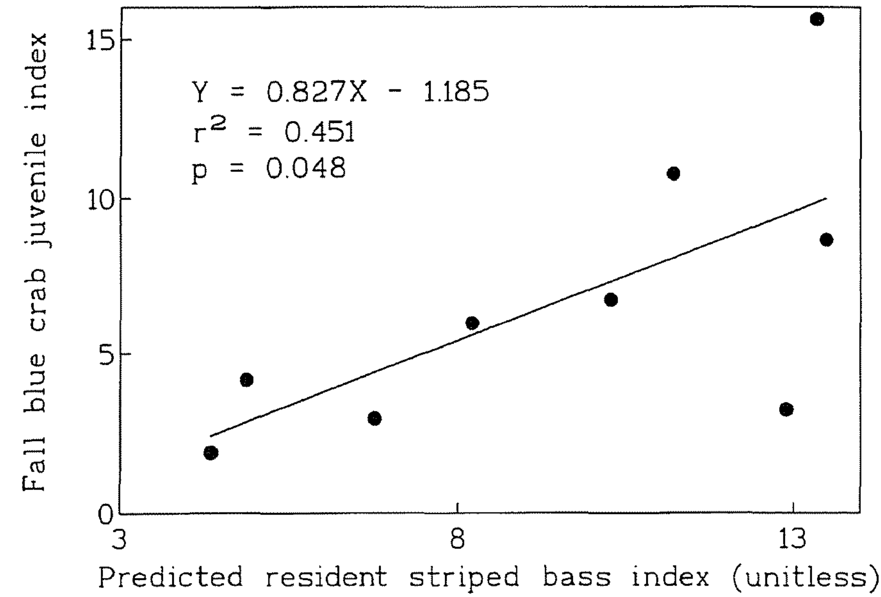

FIGURE 1. Scatter plot and regression analysis of the prediction of the resident striped bass model versus the fall blue crab juvenile index.

Juvenile blue crabs are active in submerged aquatic vegetation beds at least part of the winter (Orth and van Montfrans 1987). To test for predation by striped bass during this period, when the migratory stock is present in the Chesapeake Bay, the migration component was removed from the striped bass model, and predicted adult striped bass were compared to the spring crab index (Table 7). That no relationship was detected may be related to striped bass staying in deep water during the winter, and not in places where crabs are active. Also, after April spawning, fish recruited to the migratory portion of the stock migrate rapidly from the Bay and are gone by mid-May.

The Rappahannock River fall pound net catch-per-unit-effort (CPUE) can be considered a measure of resident striped bass abundance. Migratory fish (ages 6+) constitute a small portion of the fish captured during this period. However, these data do not correlate with the fall blue crab trawl survey index calculated only with Rappahannock River data (Table 7).

The Rappahannock River spring pound net CPUE, a measure of migratory and nonmigratory striped bass abundance, was compared to the Rappahannock River spring blue crab index (Table 7). No relationship was evident in these expressions.

Although striped bass eat juvenile blue crabs (Hollis 1952), examination of the potential relationships between striped bass and juvenile blue crab abundance showed no evidence that increases in bass abundance resulted in declining blue crab abundance. Striped bass predation on blue crabs is dependent on encounters with crabs of suitable size and abundance during times of the year when bass are feeding regularly. For example, striped bass in Long Island Sound, NY showed an increase in fish consumption and a decrease in invertebrate consumption between spring and autumn due to a

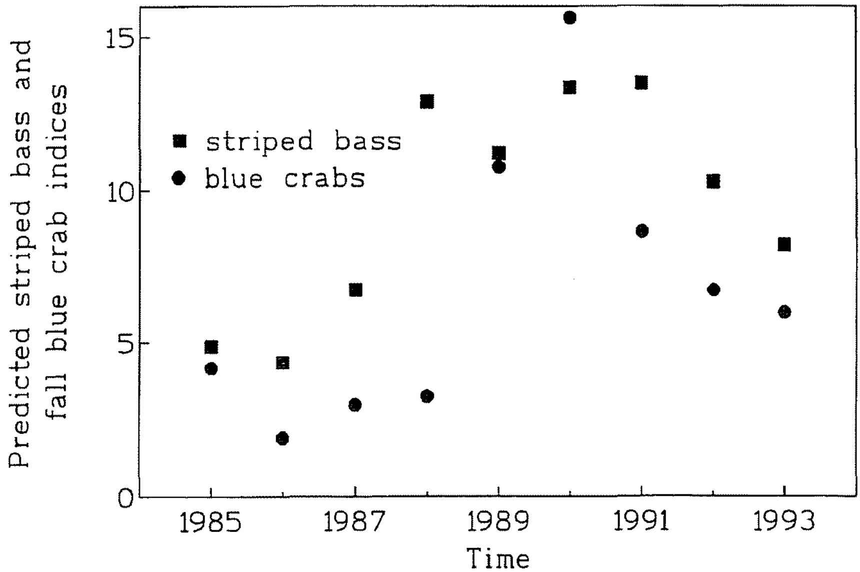

FIGURE 2. Prediction of the resident striped bass model and the blue crab juvenile index over time.

shift in prey availability (Schaefer 1970). Similarly, striped bass in Albemarle Sound, NC consumed more invertebrates in winter and spring than at other times (Manooch 1973).

As migratory fish are present in Chesapeake Bay in winter and spring, we compared juvenile blue crab abundances to resident and non-resident striped bass numbers, using two estimates of bass abundance. Predation by non-resident striped bass should end in May because these fish leave Chesapeake Bay to migrate north. We chose to estimate juvenile blue crab abundance with trawl data from the months May and June because no juvenile recruitment takes place this early and juvenile blue crab abundance should fully reflect predation. Using two different estimates for striped bass abundance compared to appropriate juvenile blue crab abundance estimates, no significant relationships were found (Table 7). The migratory nature of striped bass may influence predation on blue crabs. In Chesapeake Bay and Hudson River, striped bass less than two years old (< 300 mm) do not migrate extensively from their natal rivers (Vladykov and Wallace 1938, Raney 1952, Massman and Pacheco 1961, Mansueti 1961, Setzler et al. 1980), although more two year old striped bass leave the Bay when their cohort is strong (Austin and Hickey 1978). Approximately 10% of two year old striped bass usually leave the Bay (Raney 1952). Extensive migration out of the Chesapeake Bay and northward along the Atlantic Coast normally begins at 3+ years of age (Mansueti and Hollis 1963). Maryland female bass typically make their first oceanic migration at an early age (3+), whereas males may not leave the Bay for the first time until they are 5 or 6 years old (Setzler et al. 1980). During the winter, adult striped bass remain relatively inactive, reduce food consumption, and congregate in deeper (10-50 m) portions of river mouths and the Bay (Raney 1952). As waters warm in early spring, mature fish move upstream to freshwater spawning grounds. After spawning in April and May, migratory bass rapidly leave the Bay and move northward along the Atlantic Coast (Raney 1952). This migratory stock moves southward in the autumn, returning to the Bay in November and December to overwinter with younger bass that remained during the summer. Migratory striped bass are not present in the Bay for most of the time that crabs are active. Younger, non-migratory striped bass are most likely to have a detectable influence on juvenile blue crab abundance because they are present during the times when crabs are most abundant. Our comparisons revealed a significant, positive regression between predicted, resident, striped bass and the fall juvenile blue crab index, not an inverse relationship. While we have no explanation for this apparent coherence between these populations, it certainly does not suggest that striped bass predation controls juvenile blue crab abundance.

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T.C. Mosca III developed the mathematical models, P.J. Rudershausen conducted the literature review, and together Mosca and Rudershausen analysed the data. R.M. Lipcius provided insight into the potential predator-prey relationship, and life history of the blue crab.

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