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The potential for population regulation of the blue crab by striped bass: Do predator and prey abundances correlate in Chesapeake Bay?

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Virginia Marine Resource #93-6

Abstract

Striped bass may regulate the blue crab population in Chesapeake Bay by preying on juveniles. Hence, the recovery of the striped bass fishery may be causing a decline in blue crab abundance. We examined a corollary of this hypothesis: an expected inverse correlation between striped bass and blue crab abundance. Abundance indices based on the Virginia striped bass young-of-the-year beach seine survey were constructed for the stock, ages 1 - 8, and for the Virginia resident component of the stock, ages 1 - 5. Fishery-independent, pound net catch-per-unit-effort data for the fall and spring were also used as indices of adult striped bass abundance in the Rappahannock River, Virginia.

Abundance indices for juvenile blue crabs were constructed based on trawl survey data collected in the three main tributaries to the lower half of the Chesapeake Bay, the James, York and Rappahannock Rivers. These indices are geometric means weighted by stratum areas, with two strata per river.

Crab abundance in the fall 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. Therefore, striped bass do not appear to regulate blue crab population dynamics in the Virginia portion of the Chesapeake Bay.

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 on the U.S. east coast in recent years, possibly due in part to aggressive (and not universally popular) management on the part of interstate and state agencies. Concurrently, Chesapeake Bay blue crab (*Callinectes sapidus*) abundance and harvests have been relatively low (Lipcius et al., in press). Anecdotal reports from commercial fishermen have suggested that striped bass are depleting the blue crab population in the Chesapeake Bay, but few attempts have been made to examine this influence (e.g., Goshorn and Casey 1993). There have been anecdotal reports from the Chesapeake Bay of large striped bass gorged with juvenile blue crabs, and suggestions from industry that striped bass commercial harvest restrictions should be relaxed to protect the blue crab fishery.

We have analysed available data to test the hypothesis that striped bass abundance and juvenile blue crab abundance are inversely related. These data include the Virginia Institute of Marine Science (VIMS) striped bass beach seine survey (Austin et al. 1993), the VIMS blue crab otter trawl survey (VIMS, unpubl. data), and the Rappahannock River striped bass pound net survey (Hill and Loesch 1990). Several models of striped bass populations, using the beach seine data, were developed, incorporating age-based survival and migration rates. Outputs of these models and the Rappahannock River striped bass pound net CPUE were used as measures of bass abundance. Geometric means of blue crab trawl survey data for appropriate intervals during the year serve as estimaters of juvenile blue crab abundance.

Methods

A model predicting relative abundance of resident Chesapeake Bay striped bass was constructed, using as a basis 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 visited three times each summer (Figure 1). The striped bass index was updated to include 1992 data. The striped bass juvenile index is a weighted geometric mean of the number of juvenile bass per haul, and is calculated as follows:

$$\overline{x}_g = \sum_{k=1}^{3}\left[\log^{-1}\left[\left[\frac{\sum_{i=1}^{n_k}\log(x_{ik}+1)}{n_k}\right]-1\right]wt_k\right],$$

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.

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

$$N_t = N_{t-1}e^{-Z}, \qquad (1)$$

where total mortality Z is given by:

$$Z = M + F \qquad (1a)$$

if fish are recruited to the fishery, and

$$Z = M + C*F \qquad (1b)$$

(Rugolo, Louis J. Maryland Division of Natural Resources, Annapolis, Md. 21401., pers. comm.) otherwise. Here M = 0.20 is the commonly used value for natural mortality (e.g., Lackey and Nielsen, 1980), F is historical fishing mortality by year (1959–1984: Gibson 1993, 1985–1992: Rugolo, pers.

comm.), and C*F (C = 0.20) is an estimate of poaching and hook-and-release mortalities (Rugolo, pers. comm.). The interval 1980 – 1992 was chosen because these are the years for which uninterrupted data are available; the VIMS beach seine survey was canceled for the prior six years because of lack of funding.

Determination of entry into the fishery was made using length-at-age estimates (Hill and Loesch, 1990) and Virginia Marine Resources Commission (VMRC) legal length regulations (Barth, Erik. Virginia Marine Resources Commission, Newport News, Va. 23607.) (Table 2). Usually changes in the 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 (e.g., Hill and Loesch, 1990), the difference was not great enough to cause females of any year class to enter the fishery earlier. Therefore, we used pooled estimates for length at age.

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, which is also the period for which the VIMS blue crab juvenile index is calculated (Figure 1). Data on commercial catch-per-unit-effort (CPUE) of striped bass are reported by Hill and Loesch (1990), by year class, season (spring and fall), and by river mile on the Rappahanncock River. 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 calculated using estimates by Rugolo and Jones (1989), except that age 6+ fish were considered to have entirely recruited to the migratory stock (Table 4) (Rugolo and Jones (1989) considered age 6 and 7 fish to be only partially recruited). Although it is commonly thought that female striped bass begin migrating at an earlier age (e.g., Setzler et al., 1980), at the ages under consideration here no difference arises in predicted population by sex. Therefore, we pooled the estimates for percent migration.

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

$$RB_t = \sum_{j=t-1}^{t-5} \overline{x}_{gj} \left[e^{-\sum_{i=j+1}^{t} Z_i} \right] R_{t-j},$$

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, j = t − 2 = 1986, then t − j = 2, so we use the residency rate for two year olds. At the same time, we use $\left(e^{Z_{1987}+Z_{1988}}\right)$ for survival.)

The estimates for surviving, resident, striped bass of ages 1 − 5 were summed for each of the years 1985 − 1992 (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 during the months September - November (Figure 1). This is also a weighted, geometric mean, and is calculated as above except that the weighting factor and summation across the six strata aref moved inside the back-transformation:

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

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. Here k identifies the stratum and n_k is the number of otter trawl tows in the k^{th} stratum

Because juvenile blue crabs are active during at least the warmer periods of the winter, the model was adjusted to predict migratory and 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, 1990) indicate that a few fish older than eight years are present in the winter months, the number is very small.

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

Indices of adult striped bass abundance for the Rappahannock River, Virginia were constructed from pound net data (Hill and Loesch, 1990, updated to 1993 via pers. comm.). 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 the respective Rappahannock River striped bass indices.

Finally, we constructed a simplified version of the striped bass models by summing the respective previous five years (to predict resident fish) or eight years (residents plus migratory stock) juvenile striped bass index (Table 1), and compared these predictions to the appropriate juvenile blue crab indices.

It is important to note that the 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 half 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

We found a significant positive linear relationship between predicted resident bass and juvenile blue crabs (Figure 2). This relationship reflects a rise and subsequent fall in blue crab numbers (Figure 3), and in fact some investigators believe crab abundances are cyclic (Lipcius and Van Engel 1990). The rise and fall in predicted resident striped bass numbers (Figure 3) 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.

Because blue crabs are recruiting to the juvenile stage from their larval stages at a high rate during the period of the fall trawl survey, it could be that the effect of predation cannot be measured until later. For this reason, we regressed the resident bass index against a blue crab index for the following spring, months May and June (Figure 4). No relationship was found.

Juvenile blue crabs are active at least part of the winter, in the submerged aquatic vegetation beds. To test for predation by bass during this period, when the migratory stock is present in the Chesapeake Bay, the migration component was removed from the bass model, and predicted adult striped bass were compared to the spring crab index (Figure 5). That no relationship was detected may be because striped bass are thought to stay in deep water during the winter, and are usually not in the same 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 blue crab fall trawl survey index calculated only with Rappahannock River data (Figure 6).

The Rappahannock River spring pound net CPUE is a measure of migratory and nonmigratory striped bass abundance. Motivated by the possibility of wintertime predation, discussed above, this index was compared to the spring blue crab index (Figure 7). No relationship was evident in these data.

Finally, a five-year running sum of the striped bass juvenile index was regressed against the fall juvenile blue crab index (Figure 8), and an eight-year running sum was regressed against the spring juvenile blue crab index (Figure 9). The purpose was to use the simplist possible estimator of adult striped bass stock size to test the possibility that adjustments in the models were masking relationships. No relationships were found.

Discussion

Although striped bass eat juvenile blue crabs (e.g., Hollis 1952), examination of the potential relationships between striped bass and juvenile blue crab abundance showed no evidence that increases in the bass population are associated with declining blue crab abundance.

Striped bass are opportunistic feeders (Scofield 1931, Merriman 1941, Hollis 1952, Boynton et al. 1981), usually preying on food items that are most abundant (Raney 1952, Calhoun 1953, Thomas 1967). The most important foods of striped bass are schooling fishes such as anchovies, silversides, menhaden, spot, and killifishes (Scofield 1928, Hollis 1952). Invertebrates also constitute a portion of the diet of striped bass (Hildebrand and Schroeder 1928, Curran and Ries 1937, Townes 1937, Merriman 1941, Hollis 1952, Stevens 1966, Thomas 1967).

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, showed an increase in fish consumption and a decrease in invertebrate consumption between spring and autumn due to a 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).

The frequency of occurrence and percent volume of invertebrates in the diet of striped bass are small (Hollis 1952, Manooch 1973) and decrease with bass size (Stevens 1966, Schaefer 1970). In Chesapeake Bay, striped bass stomachs contained negligible quantities of blue crabs (Hollis 1952). In Albemarle Sound, NC crustaceans were less than 3% of the volume of striped bass food items, though small blue crabs (18-30 mm) were the most frequently occurring crustaceans and were found in greater than 5% of striped bass stomachs (Manooch 1973).

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.

Predation has often been shown to affect interannual variability in recruitment of marine invertebrates. Predation by epibenthic fauna has been demonstrated to be the most important source of mortality of juvenile starfish (Acanthaster planci) (Keesing, J.K. and A.R. Halford 1992). Recruitment of barnacle larvae from kelp forests to rocky intertidal habitat can be fifty times higher if predation by juvenile rockfish is absent (Gaines and Roughgarden 1987). In the rocky intertidal, predation by birds may control recruitment of juvenile mussels (Marsh 1986). However, other factors may also be at work.

Many physical effects having controlling influences over juvenile abundance of marine species have been demonstrated. Croaker spawn in the Atlantic Ocean, and recruitment to the juvenile stock in Chesapeake Bay depends largely on the timing, duration, and velocity of wind driven currents (Norcross 1983). Stream flow in May and June explains 80-87% of the variation in American shad recruitment in the Connecticut River (Crecco and Savoy 1987) and survival of larvae of several species of salmon depends on fall and winter stream flow (Kocik and Taylor 1987). Recruitment of juveniles of the Indian oil-sardine (Sardinella longiceps) is thought to depend on the intensity of the southwest monsoon (Raja 1973). Recruitment peaks of amphipods have been found to coincide with increasing water temperature (McBane and Croker 1984), but neither water temperature nor salinity were thought to be important in the recruitment of many species of South African fishes (Blaber and Blaber 1980). Instead, turbidity was the factor having greatest influence, and was thought to reduce predation (Blaber and Blaber 1980). This is an example of a physical effect having an indirect influence expressed as a direct biological influence.

Lower production of blue crabs in Chesapeake Bay could be the result of any number of physical or biological influences, or a combination of them. Commercial and recreational harvest pressure is a factor also. Recruitment of blue crabs to the Maryland portion of the Chesapeake Bay has been demonstrated to be significantly related to radiant energy, freshwater discharge and salinity (Tang 1985). Catch per unit effort (CPUE) data from the Potomac, Deleware and Hudson Rivers have been significantly related by categorical time series regression models to lagged CPUE (stock—recruitment relationship), lagged CPUE plus hydrographic data (e.g. air temperature, freshwater discharge, offshore wind speed and direction), and CPUE plus hydrographic data plus pollution data (e.g. dissolved oxygen, volume of dredged material, sewage discharge, etc.) (Rose and Summers 1992). Harvest pressure, as indicated by license sales, has substantially increased over the years also (Eric Barth, Virginia Marine Resources Commission, Newport News, Va., pers. comm.).

Viable candidates for control of Chesapeake Bay blue crab stock size are plentiful, but our analyses do not support the hypothesis that striped bass abundance is responcible for reduced blue crab abundance.

Citations

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Timetable of events

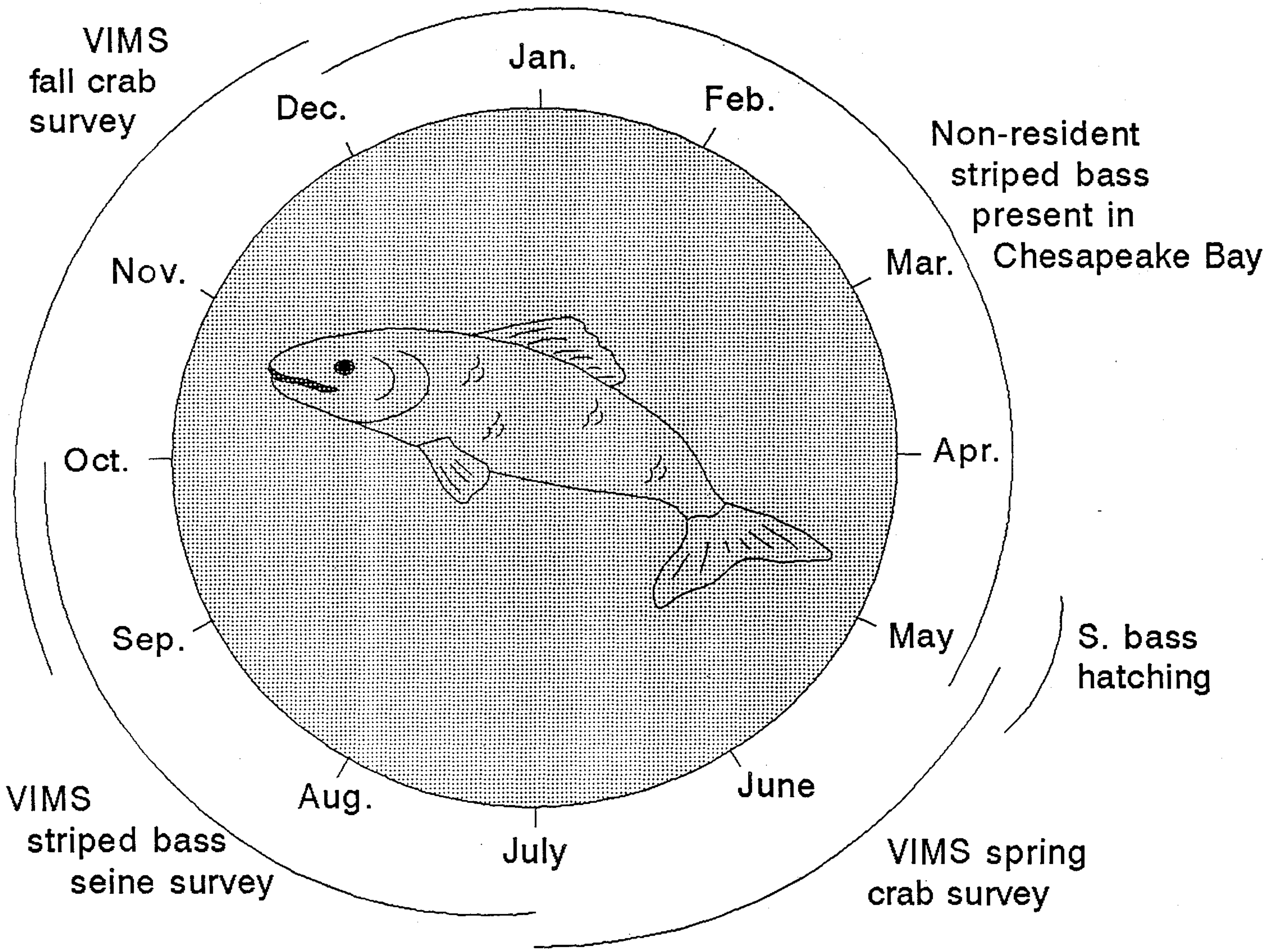


Figure 1.

Timetable of events

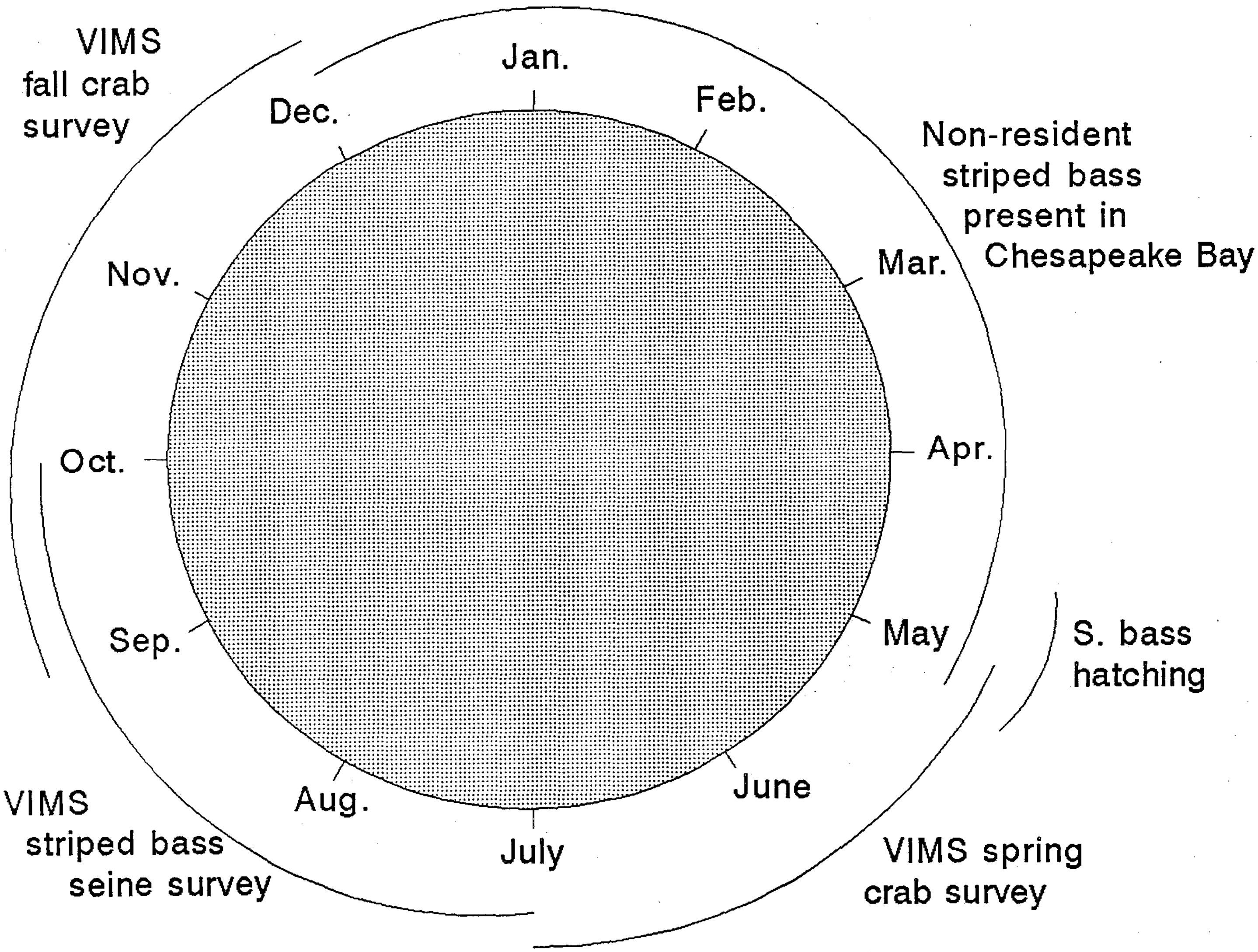


Figure 1.

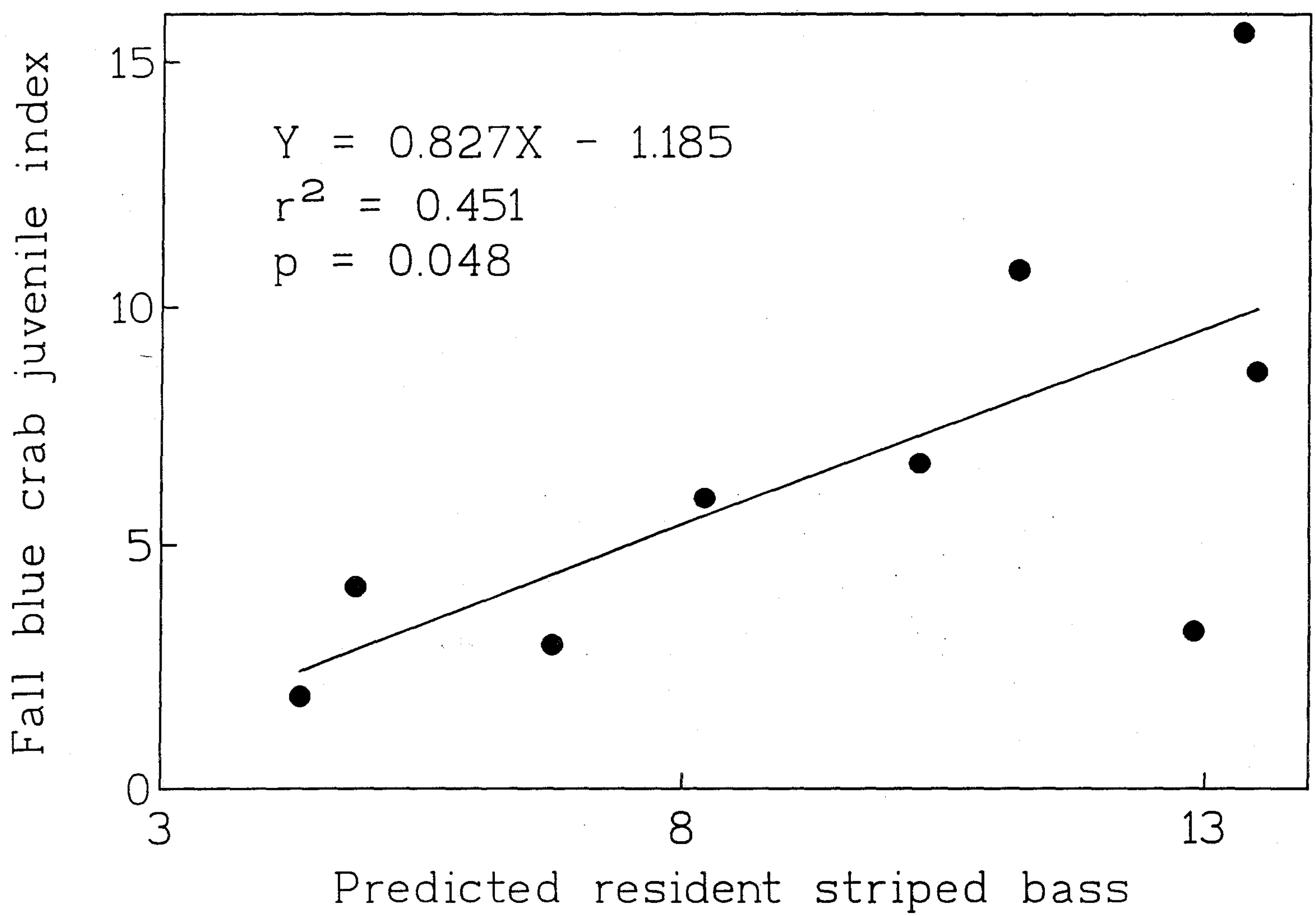

Y = 0.827X - 1.185
r2 = 0.451
p = 0.048
Fall blue crab juvenile index
0
5
10
15
3
8
13
Predicted resident striped bass

Figure 2

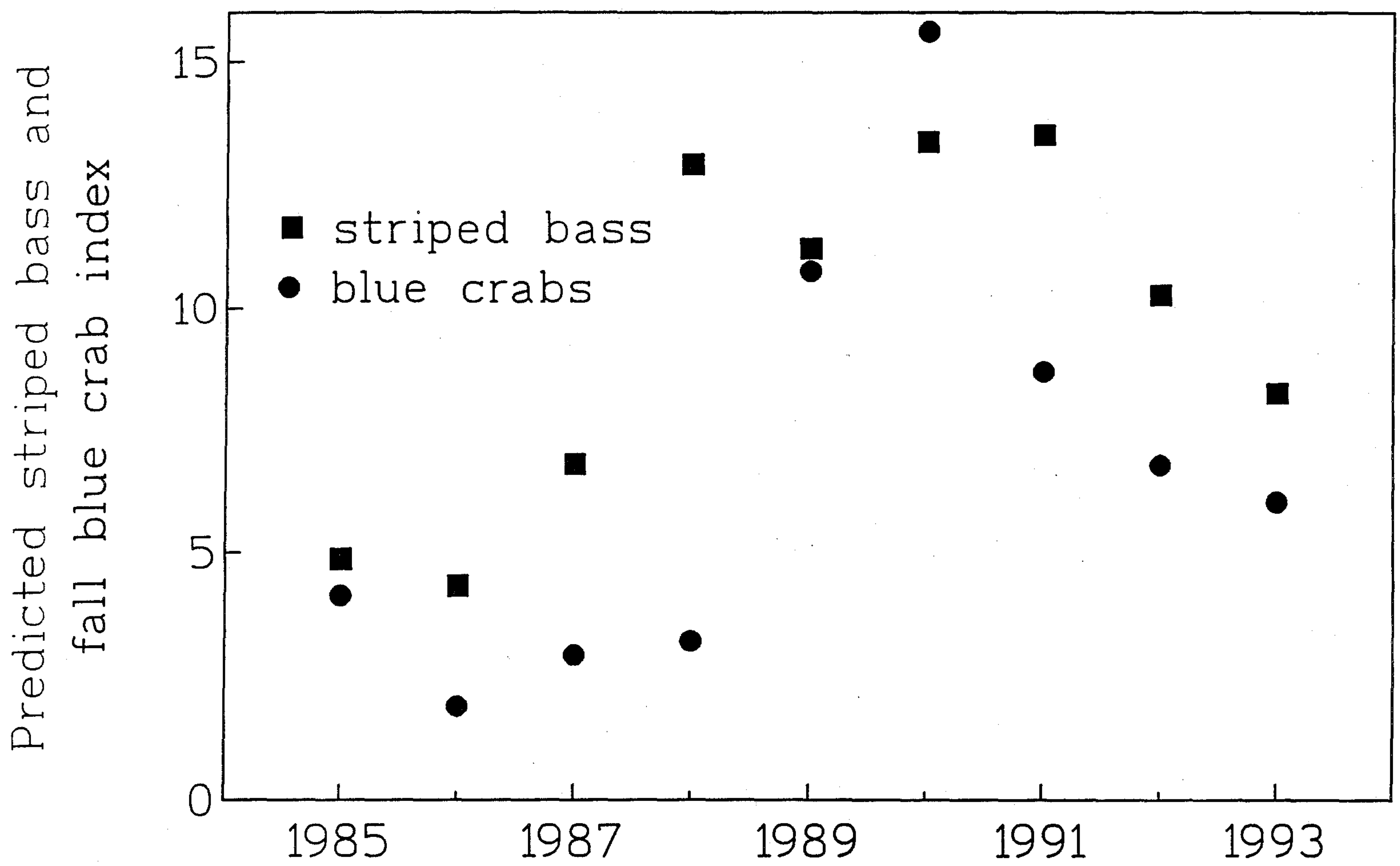

Predicted striped bass and fall blue crab index
15
10
5
0
striped bass
blue crabs
1985
1987
1989
1991
1993
Time

Figure 3

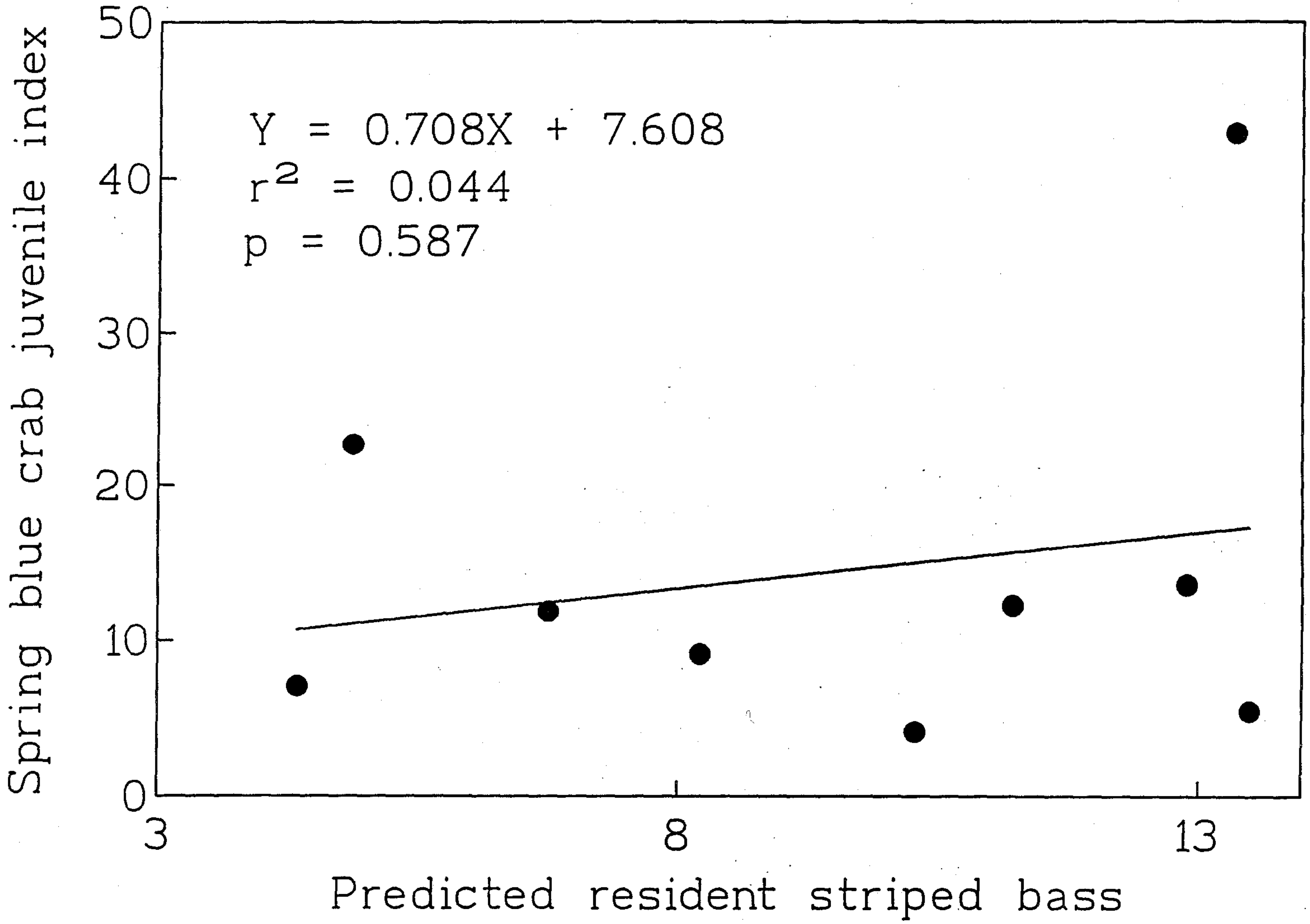
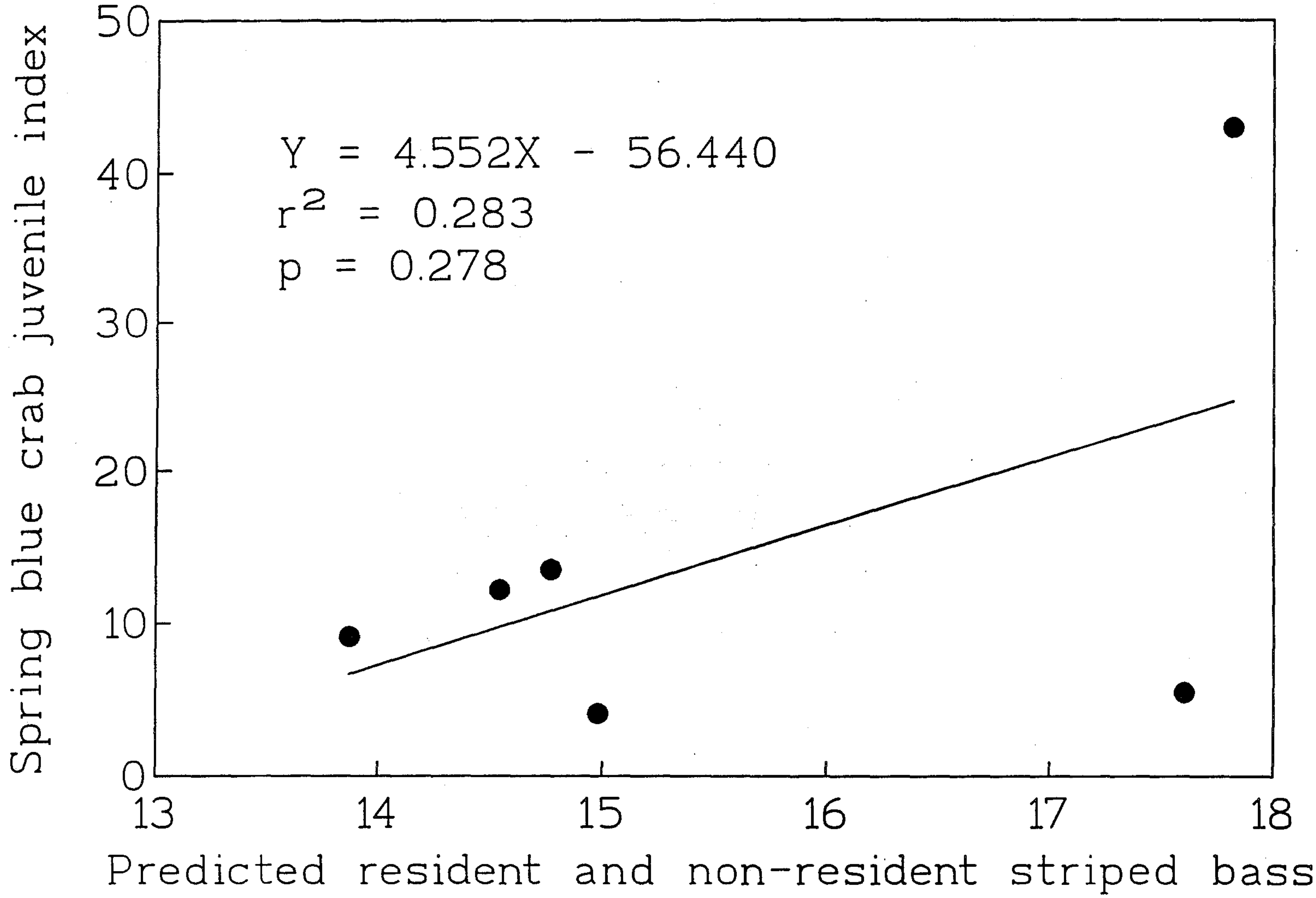
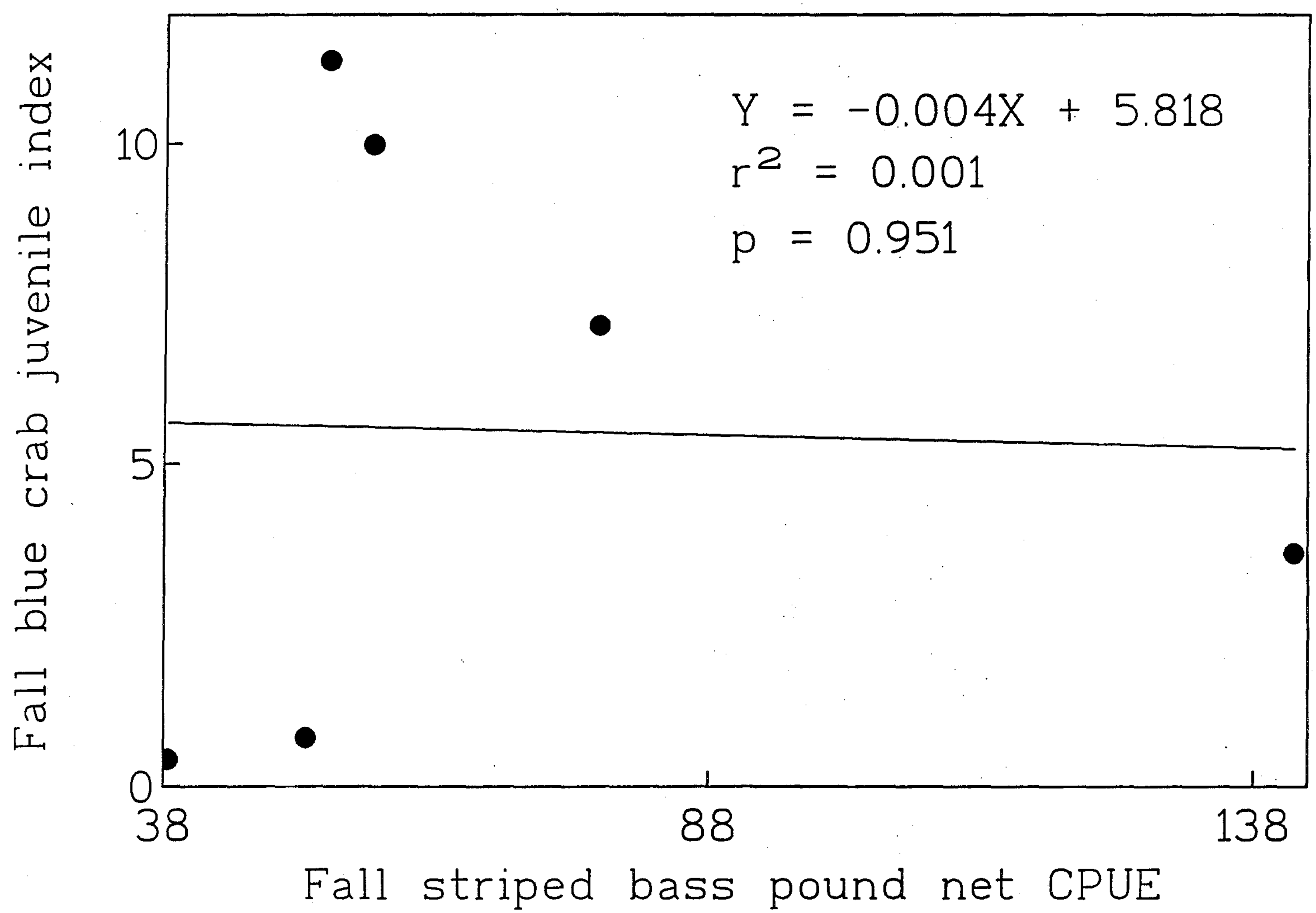

Y = 0.708X + 7.608
r2 = 0.044
p = 0.587
Spring blue crab juvenile index
50
40
30
20
10
0
3
8
13
Predicted resident striped bass

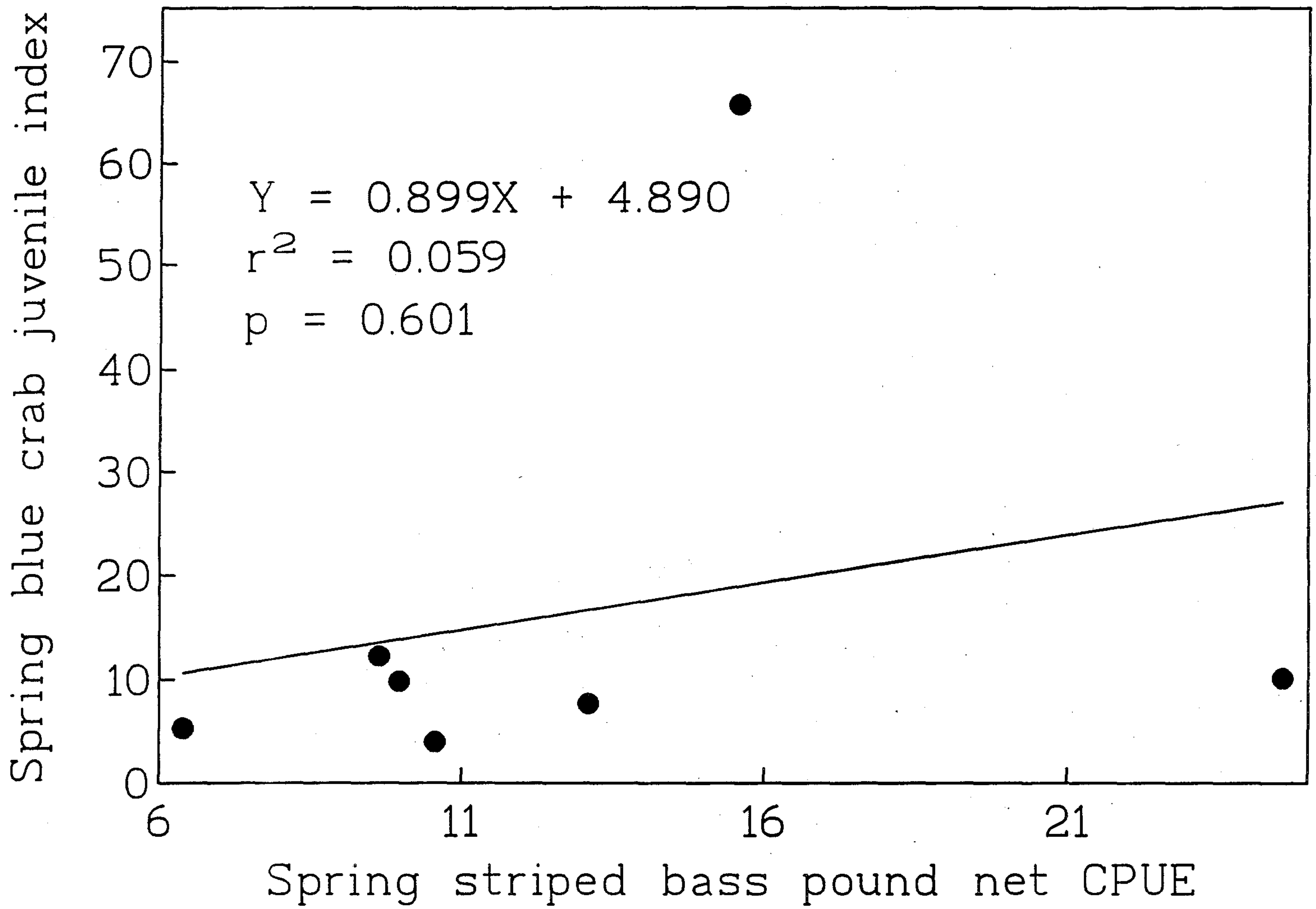
Figure 4



Y = 4.552X - 56.440
r2 = 0.283
p = 0.278
Spring blue crab juvenile index
0
10
20
30
40
50
13
14
15
16
17
18
Predicted resident and non-resident striped bass

Figure 5


Fall blue crab juvenile index
10
5
0
38
88
138
Fall striped bass pound net CPUE
Y = -0.004X + 5.818
r2 = 0.001
p = 0.951
Figure 6


Spring blue crab juvenile index
70
60
50
40
30
20
10
0
Y = 0.899X + 4.890
r2 = 0.059
p = 0.601
6
11
16
21
Spring striped bass pound net CPUE
Figure 7

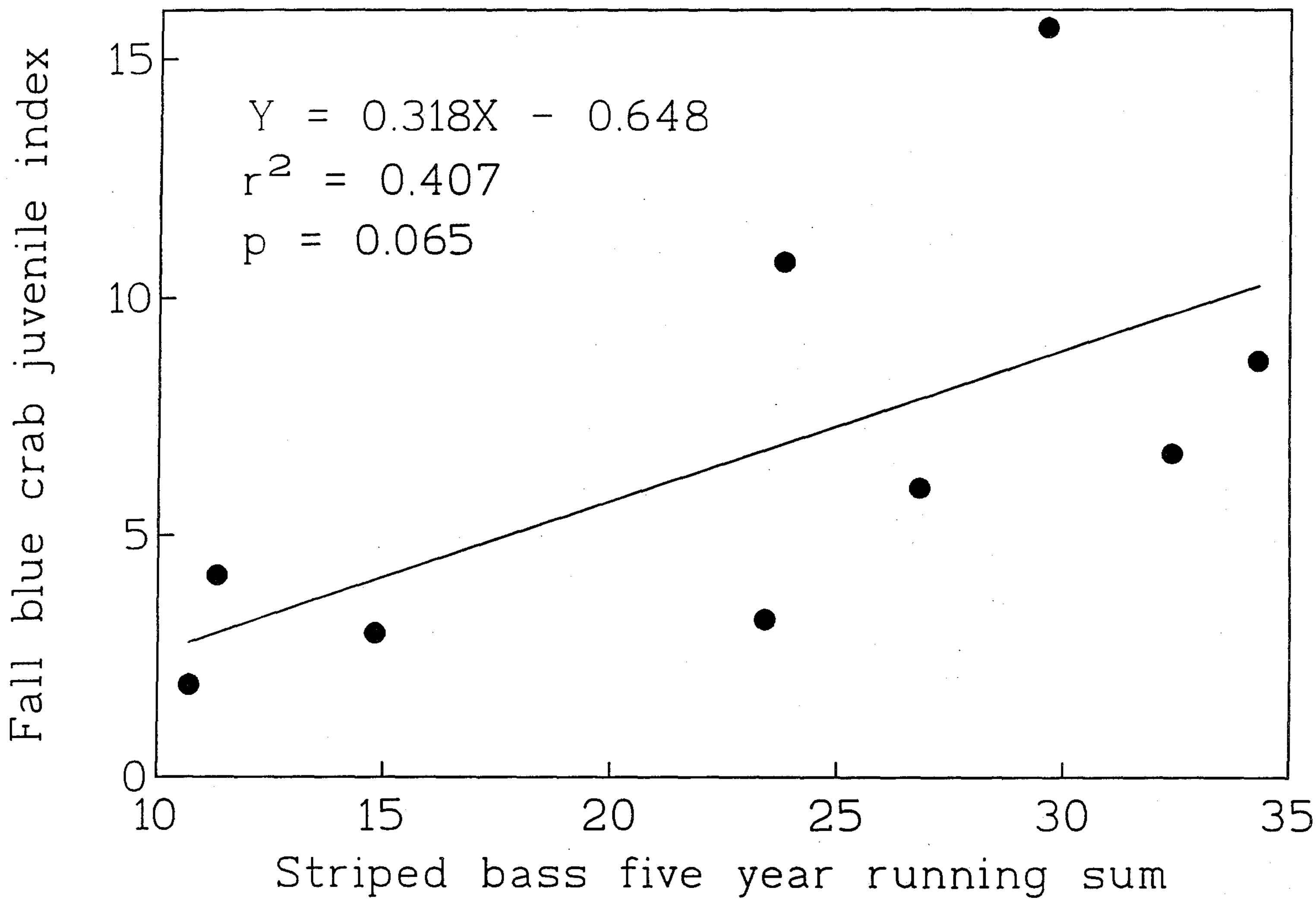

Y = 0.318X - 0.648
r2 = 0.407
p = 0.065
Fall blue crab juvenile index
Striped bass five year running sum
0
5
10
15
10
15
20
25
30
35

Figure 8

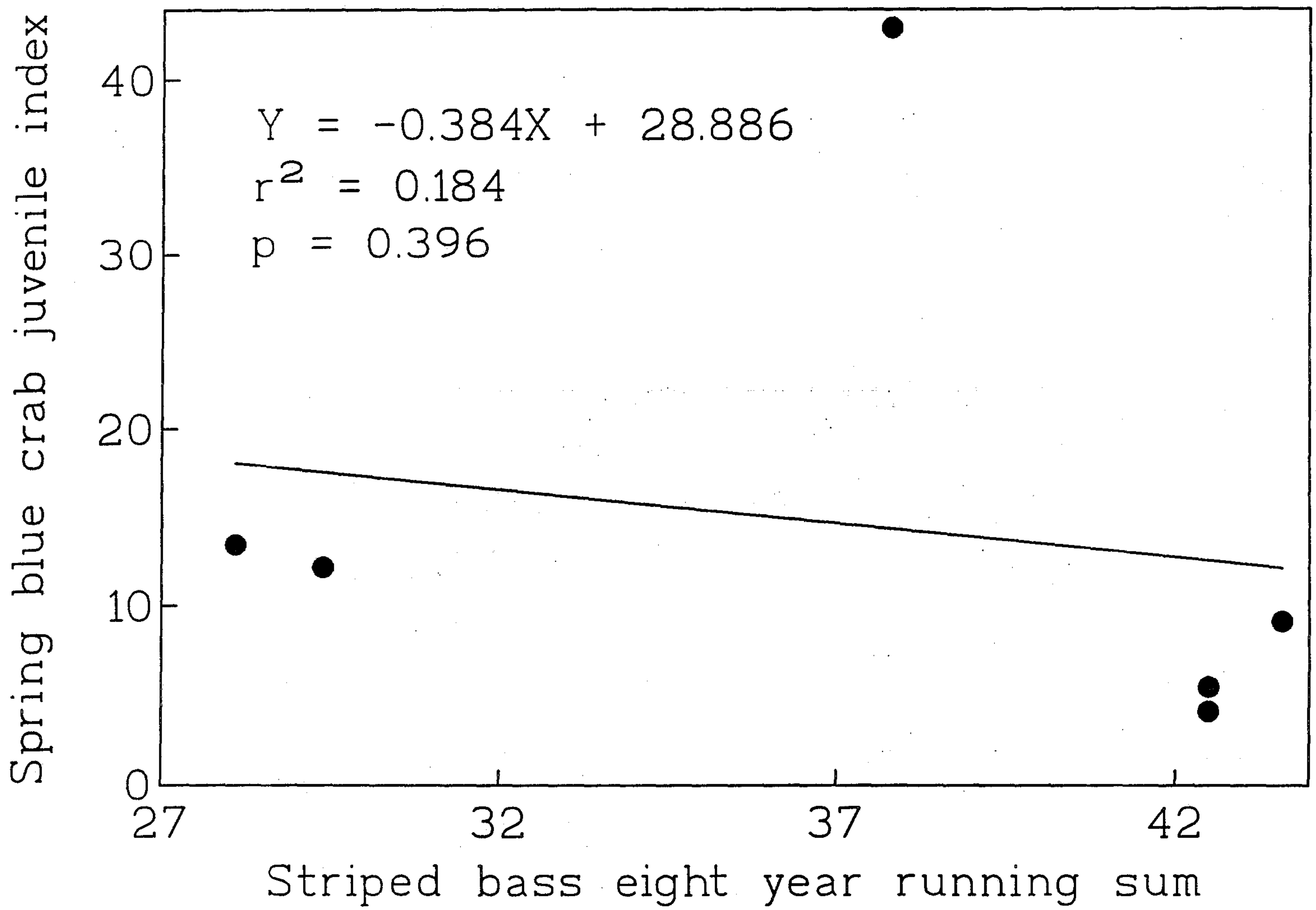

Y = -0.384X + 28.886
r2 = 0.184
p = 0.396
Spring blue crab juvenile index
40
30
20
10
0
27
32
37
42
Striped bass eight year running sum
Figure 9

Table 1.

Yr	1	2	3	4	5	6	7	8	9	10	11
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	11.3			
86	4.3		1.89	7.06	0.74	4.33	5.0	10.7		51.07	
87	6.8		2.94	11.82	0.41	4.02	10.2	14.8		38.39	10.57
88	12.9	14.8	3.22	13.46	9.88	12.28	3.5	23.4	28.1	57.04	9.64
89	11.2	14.5	10.76	12.17	7.21	9.80	9.3	23.8	29.4	77.86	9.98
90	13.4	17.8	15.62	42.97	31.46	65.82	6.3	29.6	37.8		15.55
91	13.5	17.6	8.66	5.48	11.28	7.66	3.1	34.3	42.5	52.97	13.10
92	10.3	15.0	6.72	4.14	3.60	5.33	4.6	32.4	42.5	141.75	6.40
93	8.2	13.9	5.98	9.10	8.04	10.07	12.4	26.8	43.6		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. Five year striped bass juvenile index running sum.
9. Eight year striped bass juvinile index running sum.
10. CPUE of predicted, relative, resident striped bass.
11. CPUE of predicted, relative striped bass.

Table 2.

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

Table 3.

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

Table 4.

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

Table 5.

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.

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			
88	1.97	2.75	2.36	1.86	0.61	0.03	0.06						
89		0.44	4.81	1.93	1.09	1.21	0.30	0.16	0.02				
90		2.73	2.45	3.09	3.00	2.09	1.09	0.55	0.45	0.09			
91	0.40	0.45	2.60	5.05	2.45	1.10	0.45	0.15	0.10	0.30	0.05		
92	0.12	0.29	0.48	1.40	2.36	0.88	0.31	0.24	0.10	0.17	0.07		
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