Results of long-term, seasonal sampling for *Penaeus* postlarvae at Breach Inlet, South Carolina

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Recruitment of postlarvae of commercially important penaeid shrimp has been studied in several areas in the southeastern United States, e.g. on the Atlantic coast (Bearden, 1961; Williams and Deubler, 1968; Williams, 1969; Allen et al., 1980) and the Gulf of Mexico (Baxter, 1963; George, 1962; Loesch, 1965; Christmas et al., 1966; Baxter and Renfro, 1967; Caillouet et al., 1968, 1970; Ford and St. Amant, 1971). Findings from these studies indicate that postlarvae are generally concentrated near oceanic inlets, different species are abundant at different times of the year, ingress through inlets into estuarine nursery areas is often influenced by factors such as tide and time of day, and correlations between number of postlarvae and subsequent commercial landings is often poor.

In South Carolina most published studies have examined postlarval recruitment over a one- to two-year period (Bearden, 1961; Olmi, 1986; Wenner and Beatty, 1993). Long-term sampling was conducted by Lunz[1] at several coastal sites in South Carolina in an effort to predict subsequent commercial harvest. As an extension of this work, long-term, seasonal sampling was conducted at a single site near Charleston, South Carolina, to determine relative abundance and timing of recruitment of *Penaeus* postlarvae. This study is part of a continuing effort to relate postlarval abundance to subsequent landings and to evaluate spawning success of parental stocks.

Materials and methods

Samples were collected with a 1-m diameter, 500-µm mesh plankton net fitted with a flowmeter at Breach Inlet, South Carolina (between Sullivan's Island and the Isle of Palms), from January 1975 to August 1992 (Fig. 1). Breach Inlet is an oceanic inlet with high velocity tidal currents (up to 150 cm/sec flow). The tides in South Carolina are semidiurnal and have an average range of tidal height of approximately 2 m between mean low water and mean high water. Breach Inlet was chosen as a site for intensive monitoring of recruitment because of its accessibility (boats are not required for sampling and it can be sampled in inclement weather). Preliminary studies have shown that postlarvae can be collected in consistently high numbers (several hundred per sample) at Breach Inlet, and catches are comparable to collections made in other estuaries in South Carolina (J. Whitaker, unpubl. data).

The net was deployed from a bridge over the inlet and fished near the bottom (approx. 10 m depth) for two one-hour periods during daylight flood tides. Prior to 1978, paired samples were taken twice weekly (approximately 30 minutes elapsed between samples). This effort was greatly reduced when abundance of postlarval brown shrimp, *Penaeus aztecus*, could not be correlated with commercial landings. After 1977, regular sampling involved collecting two unpaired samples per tide at one or two week intervals from late January to early August. Hydrographic information, including water temperature and salinity, were also collected during sampling (Table 1).

In addition to bottom daylight samples, consecutive samples were taken over a full tidal cycle during day and night (two surface and two bottom samples per tide) in some years during periods of high abundance to examine possible influences of tide, time of day, and location of the net on postlarval catch rates. Consecutive samples of *P. aztecus* were collected on 12–13 March 1975, 26–27 February and 30–31 March 1976, 17–18 March 1977, 24–25 February and 10–11 March 1983, 2–3 March and 2–3 April 1985, and 21 February and 3–4 March 1986 (flood tide only in 1986). Consecutive samples for *P. setiferus* were collected on 9–10 June and 16–17 July 1975, 27–28 May and 28–29 June 1976, 9–10 June 1983, and 29–30 May 1989 (flood tide only in 1989).

Plankton samples were preserved in 10% buffered formalin-seawater and sorted in the laboratory. Postlarvae were sorted to species in most instances by using characteristics identified by Pearson (1939), Williams (1959), and

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[1] Lunz, G. R. 1965. Annual report 1963–64, Bears Bluff Laboratories. Contrib. Bears Bluff Lab. No. 41, 10 p.

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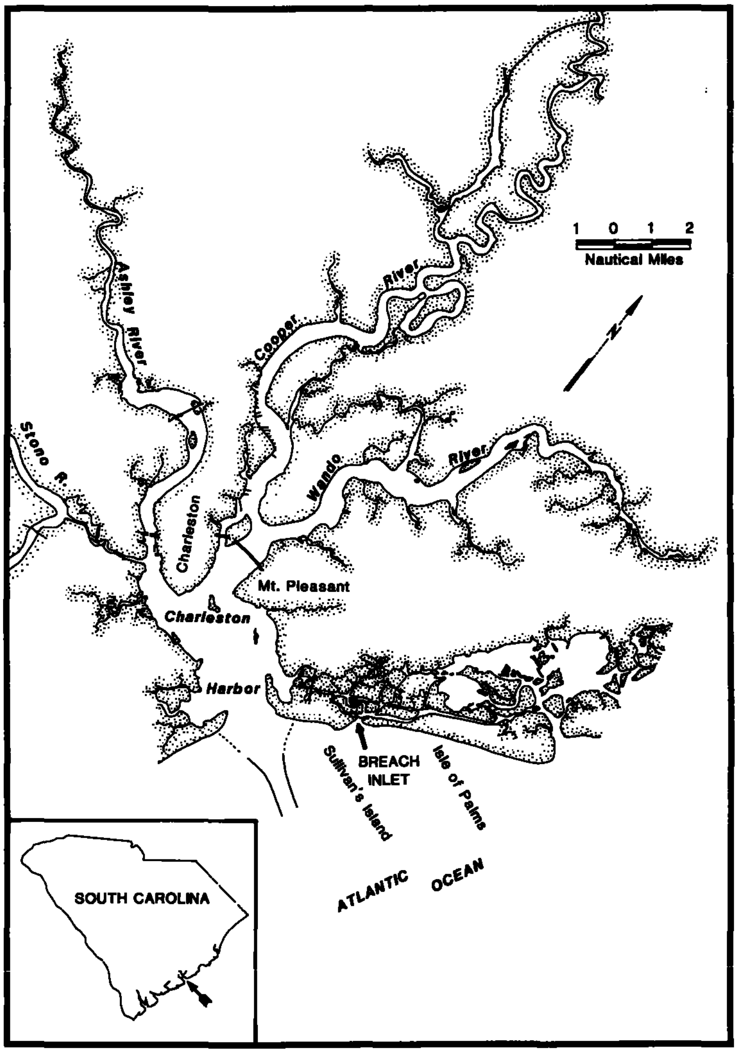

Figure 1
Map of Breach Inlet, South Carolina, site of collection of postlarval *Penaeus*.

Ringo and Zamora (1968). Postlarvae with overlapping characters were identified to genus.

Counts of postlarvae were converted to density (numbers per 1,000 m^3). Preliminary analyses revealed these data to be nonnormal and with large variation; therefore, potential effects of time of day, tidal stage, and location of nets (surface versus bottom) on ingress of postlarvae collected by consecutive sampling were tested with the nonparametric Mann-Whitney test on densities of postlarvae (flood tide only for time of day and location of nets; Siegel, 1956). The effect of lunar phase on catches made during regular sampling (daytime bottom collections made on flood tide during season of peak abundance) was tested with the nonparametric Kruskal-Wallis test on densities grouped by four lunar periods (new, full, first, or last quarter) pooled from the entire year's data (Siegel, 1956). Differences among groups were considered statistically significant at the $P \leq 0.05$ level. The above data were log-transformed to facilitate graphic representation of means and standard deviations (Figs. 2 and 3). An annual index of abundance ($\Sigma \log((\text{number}/1{,}000\text{m}^3) + 1)/\text{number of samples}$); Elliot, 1977) was calculated for each species for use in regression analysis. The index was computed from February, once densities reached 20/1,000 m^3, through April for *P. aztecus*, and from May through August for *P. setiferus*. Annual indices of postlarval abundance were regressed against annual estimates of harvest to ascertain possible relation-

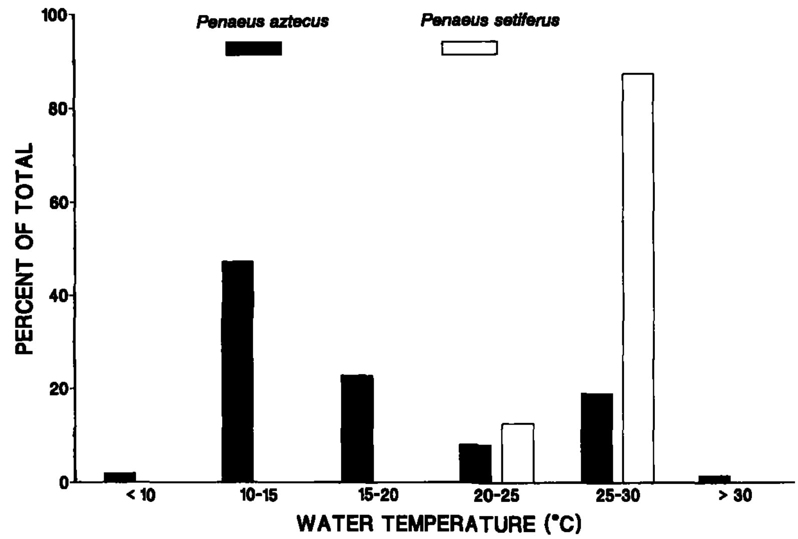

Figure 2

Distribution of catch of postlarval penaeid shrimp, *Penaeus aztecus* and *Penaeus setiferus*, over the range of water temperature observed at Breach Inlet during regular sampling.

ships.[2] Numbers of shrimp landed each year were estimated by multiplying landed weight by average grade (average number of shrimp per kg).

Results

A total of 102,109 *Penaeus* postlarvae were collected from 7 January 1975 to 3 August 1992 at Breach Inlet. Of the total catch, 68.3% were identified as brown shrimp, *P. aztecus*, 23.3% as white shrimp, *P. setiferus*, and 0.8% as pink shrimp, *P. duorarum*. The remaining 7.6% were identifed as *Penaeus* spp. The majority of the latter category were tentatively identified as *P. aztecus*, and were collected primarily from late May through July. Because *P. duorarum* postlarvae were collected in relatively low numbers and some uncertainty exists with identification, the analysis includes only *P. aztecus* and *P. setiferus*.

The majority of *P. aztecus* postlarvae were collected between February and April, when water temperature was between 10 and 20°C (the catch peaked between 12° and 16°C). *Penaeus setiferus* was collected only when temperatures exceeded 20°C; most were taken at temperatures between 25 and 30°C (peak abundance occurred in June; Fig. 2). Samples of *P. aztecus* averaged several hundred individuals in each year during times of peak ingress. However, catches of *P. setiferus* were much more variable, averaging zero in some years and several hundred in years of high abundance (Table 2).

Consecutive sampling conducted day and night on both ebb and flood tides revealed that both species

Table 1

Average and range of bottom water temperature and salinity observed at Breach Inlet, South Carolina and number of samples of *Penaeus* postlarvae collected during regular sampling, 1975–92.

Year	Temperature (°C)	Salinity (ppt)	Number of samples
1975	20.2 (9.3–29.4)	28.6 (15.0–35.0)	256
1976	19.4 (7.0–30.0)	30.7 (26.0–35.0)	236
1977	21.4 (4.9–32.1)	31.5 (21.0–36.0)	244
1978	21.2 (5.9–31.5)	29.8 (18.0–35.0)	117
1979	18.8 (6.7–28.2)	28.8 (24.0–35.0)	57
1980	15.3 (5.7–25.6)	28.8 (20.0–34.0)	34
1981	18.3 (10.9–31.0)	32.4 (25.0–36.0)	46
1982	18.9 (9.5–28.1)	28.5 (22.0–32.0)	22
1983	14.9 (8.1–26.2)	27.6 (18.0–32.0)	33
1984	23.7 (8.1–30.5)	29.0 (23.0–34.0)	63
1985	21.8 (11.3–30.7)	31.7 (26.0–36.0)	48
1986	20.8 (9.1–30.0)	31.1 (27.0–34.0)	36
1987	17.4 (8.0–29.2)	32.1 (26.0–36.0)	36
1988	19.4 (11.2–30.5)	29.1 (21.0–35.0)	38
1989	20.8 (10.5–30.6)	32.7 (26.0–36.0)	48
1990	21.3 (11.9–30.1)	31.1 (25.0–35.0)	42
1991	20.2 (10.4–29.4)	29.4 (21.0–35.0)	36
1992	21.3 (9.3–30.1)	29.1 (24.0–33.0)	34

[2] Low, R. A. 1992. Survey of the South Carolina Shrimp baiting fishery, 1991. South Carolina Marine Res. Cent. Data Rep. 9, 29 p.

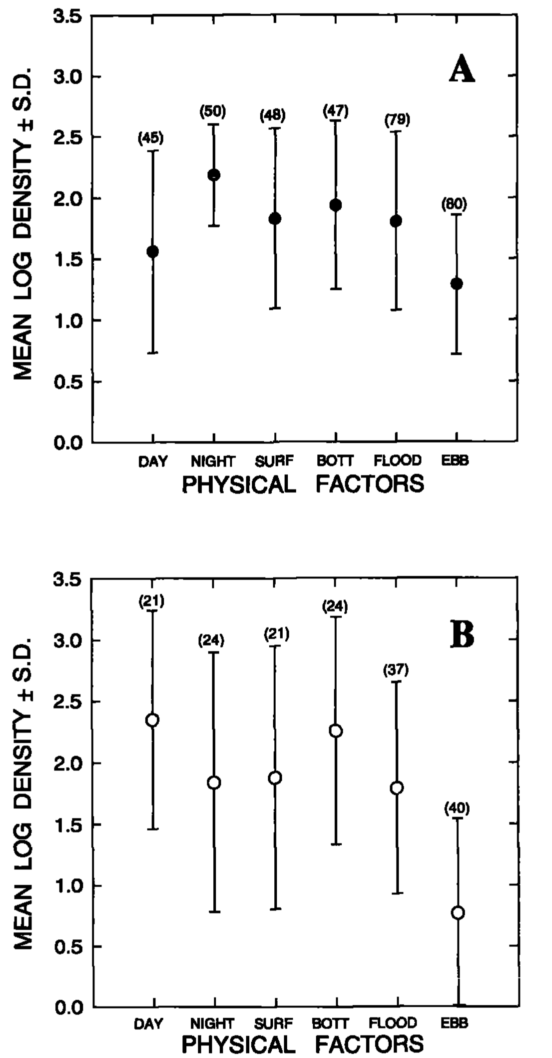

Figure 3

Mean density of postlarval penaeid shrimp (**A**) *Penaeus aztecus* and (**B**) *Penaeus setiferus* grouped by time of day, tide, and location of net at Breach Inlet, South Carolina. Samples were collected over 24-hour periods during times of peak abundance. Log Density= log((number/1,000m^3) + 1). SD=standard deviation. Numbers in parenthesis=number of samples. Surf=surface, Bott=bottom.

were significantly more abundant in samples taken during flood tides than during ebb tides ($P<0.001$; Fig. 3). Significantly more *P. aztecus* were collected at night on flood tides ($\bar{x}$=228.7/1,000m^3) than during daylight flood tides ($\bar{x}$=147.4/1,000m^3; $P<0.001$), whereas no significant difference between catches made during day ($\bar{x}$=877.9/1,000m^3) versus night ($\bar{x}$=610.2/1,000m^3) were noted for *P. setiferus* (P=0.114; Fig. 3). No significant differences in catches were noted for either species when surface and bottom collections were compared (P=0.595 for *P. aztecus*; P=0.270 for *P. setiferus*; Fig. 3).

Significant differences among catches made by regular sampling grouped by lunar phase (new moon, first quarter, full moon, last quarter) were detected for both *P. aztecus* ($P<0.0001$) and *P. setiferus* ($P<0.006$). Fewest postlarvae of both species were collected during full moon phases; *P. aztecus* were more abundant during the last quarter than at other times (Fig. 4), whereas *P. setiferus* was most abundant during the first quarter.

Results of correlation analysis revealed a low correlation (r^2=0.03; P=0.523) between annual indices of abundance of postlarval *P. aztecus* and subsequent landings. A much higher correlation was obtained for *P. setiferus* (r^2=0.79; $P<0.001$; Fig. 5). The regression equation for estimated number of *P. setiferus* landed was $Y = 40.4 + 119.0X$ (Y=estimated number landed, X=annual index of postlarval abundance).

Discussion

Our results are generally similar to observations on *Penaeus* postlarvae made by others in the southeastern United States (including the Gulf of Mexico). *Penaeus aztecus* is most abundant in springtime at water temperatures comparable to the range of temperatures observed in this study (Bearden, 1961; Williams and Deubler, 1968; Allen et al., 1980). It has been postulated that the majority of brown shrimp postlarvae recruited in the spring are produced by spawning from the previous fall (Temple and Fischer, 1967; Aldrich et al., 1968; Anderson, 1970; Whitaker[3]). Ingress begins after nearshore water temperatures approach 12°C. In contrast, *Penaeus setiferus* postlarvae are recruited in spring and summer shortly after being spawned in adjacent oceanic waters (Pearson, 1939; Lindner and Anderson, 1956). When compared to overall catches of *P. setiferus*, *P. aztecus* have often been collected in greater abundance in South Carolina (Bearden, 1961; Lunz, 1965; Olmi, 1986; Wenner and Beatty, in press) and in Texas (Baxter and Renfro, 1967).

Prior studies have shown that *P. aztecus* postlarvae are often more abundant in nighttime collections and on high (flood) tides (Caillouet et al., 1970; Duronslet et al., 1972), similar to the pattern observed in this study. This is probably due to both increased nocturnal activity and decreased gear avoidance at night

[3] Whitaker, J. D. 1982. A possible mechanism for brown shrimp postlarval recruitment. Paper presented at South Carolina Fisheries Workers Assoc. annu. meet., Clemson, SC, 24–25 Feb. 1982. Unpubl. manuscr., 3 p.

Table 2

Mean density (number per 1,000m^3), standard deviation, and number of samples collected for brown shrimp, *Penaeus aztecus*, and white shrimp, *Penaeus setiferus*, postlarvae during season of peak ingress at Breach Inlet, South Carolina 1975–92.

	P. aztecus			*P. setiferus*		
Year	Mean	SD	*N*	Mean	SD	*N*
1975	149.9	185.21	98	78.3	265.13	124
1976	119.2	184.83	100	51.7	90.65	104
1977	75.4	105.53	72	0.0	0.00	136
1978	90.1	150.80	40	0.3	1.31	53
1979	86.1	123.80	28	48.5	84.33	25
1980	209.7	144.08	20	2.6	4.17	10
1981	81.1	124.45	26	0.0	0.00	18
1982	—	—	—	9.4	18.16	10
1983	291.2	417.26	13	3.8	6.19	6
1984	125.4	192.53	10	10.5	36.33	39
1985	68.7	101.65	18	2.7	7.35	24
1986	182.7	177.05	14	4.8	19.55	20
1987	58.3	37.38	13	24.7	55.61	14
1988	69.2	112.20	14	10.8	31.55	23
1989	95.2	83.52	20	671.2	1,627.30	25
1990	336.8	348.82	18	29.5	75.82	21
1991	132.1	170.84	18	351.6	452.27	16
1992	129.7	200.25	12	326.6	1,035.87	19

(Williams and Deubler, 1968; Matthews et al., 1991). Olmi (1986) in addition to collecting more *P. aztecus* at night, also collected the majority of *P. setiferus* postlarvae at night in a tidal creek in South Carolina. These findings are in agreement with similar studies in the Gulf of Mexico, where *P. setiferus* was found to be more abundant near the surface at night in an inlet (Duronslet et al., 1972) and over a tidal flat (Caillouet et al., 1968). Wenner and Beatty (1993) collected 95% of all penaeid postlarvae at night (including a collection at a creek adjacent to Breach Inlet). In our study, no difference was detected between day and night catches of *P. setiferus*, possibly because we employed a larger net than in the other studies conducted in South Carolina in a higher-velocity tidal flow. This may have minimized avoidance of the gear by postlarvae during daylight. Additional sampling may clarify these observations.

Similar to observations made in our study, Olmi (1986) generally collected fewer postlarvae during full moon phases in South Carolina. Williams and Deubler (1968) in North Carolina and Allen et al. (1980) in the Florida Keys collected fewer *P. duorarum* at night during full moon phases than during new moon phases. Perhaps high light levels at night may delay ingress for several days, causing postlarvae to remain on offshore substrates (Matthews et al., 1991).

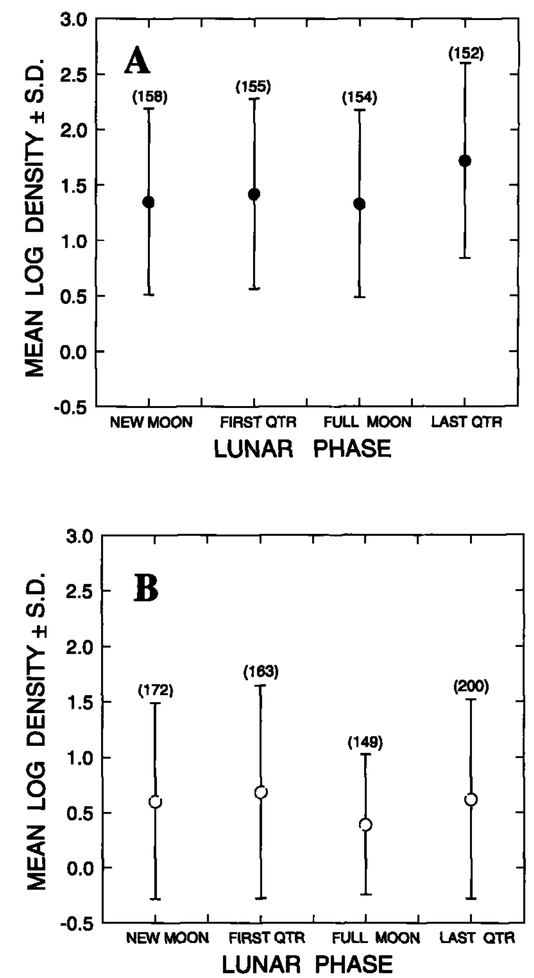

Figure 4

Mean density of postlarval penaeid shrimp (**A**) *Penaeus aztecus* and (**B**) *Penaeus setiferus* grouped by lunar phase during months of peak abundance at Breach Inlet. Samples collected near the bottom on flood tide during daylight (regular sampling). Log Density=log ((number/ 1,000 m^3) + 1). SD=standard deviation. Qtr= quarter. Numbers in parenthesis=number of samples.

Peaks in abundance of *P. setiferus* postlarvae may be related to prior spawning activity around new or full moon phases, but this relationship is uncertain at present and warrants further investigation.

A relationship between recruitment of *P. aztecus* postlarvae and subsequent commercial landings has been difficult to demonstrate (Williams, 1969; Ford and St. Amant, 1971; Baxter and Sullivan[4]). Gener-

[4] Baxter, K. N., and L. F. Sullivan. 1986. Forecasting offshore brown shrimp catch from early life history stages. *In* Proc. shrimp yield workshop. Tex. A&M Univ. Sea Grant Rep. TAMU-SG-86-10:22–36.

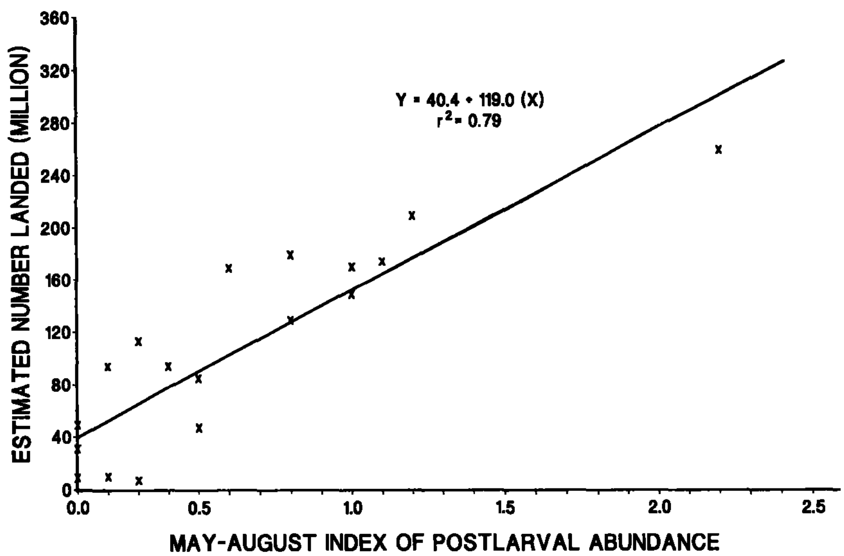

Figure 5

Plot of annual indices of abundance of postlarval white shrimp, *Penaeus setiferus*, versus estimated number of shrimp landed in the fall commercial and recreational fishery, 1975–92.

ally, environmental conditions in the nursery area, e.g. spring temperature and salinity (with related factors such as rainfall, river discharge, and meteorological conditions; Gaidry and White, 1973; Barrett and Gillespie, 1975; Zein-Elden and Renaud, 1986; Childers et al., 1990) are thought to be important influences on production. Biological factors such as predation and secondary production have also been postulated to influence yield (Hunter and Feller, 1987; Gleason and Wellington, 1988; Minello et al., 1989). Postlarval indices have been used with some success in predictive models that incorporate environmental variables and indices of juvenile shrimp abundance (Sutter and Christmas, 1983; Baxter et al., 1988). We have been unsuccessful in efforts to produce a model for brown shrimp production using data from consectutive years, although our postlarval index may be useful in the future.

Undoubtedly many factors influence the production of *P. setiferus* populations, but recent studies have demonstrated that commercial harvest of *P. setiferus* can be modeled (Lam et al., 1989) and apparent spawner-recruit relationships have been described in South Carolina (Lam et al., 1989) and in the Gulf of Mexico (Nance and Nichols, 1988; Gracia, 1991). Our study demonstrates that monitoring of *P. setiferus* postlarvae can be a reliable indicator of harvest.

Expanded sampling effort, i.e. more locations and increased numbers of samples, would perhaps yield more statistically significant results than were obtained at a single location in our study. These data do, however, represent one of the longest-term studies of postlarval penaeid recruitment to date. In addition to contributing to our overall understanding of penaeid shrimp population dynamics, our baseline monitoring effort may be useful as a management tool for predicting harvest and providing advice on optimal times for flooding coastal impoundments for extensive aquaculture.

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