# Preliminary Results from an Experimental Trap Fishery for the Spotted Spiny Lobster, *Panulirus guttatus*, in Bermuda

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## ABSTRACT

A two year experimental trap fishery commenced in April 1998 to assess the feasibility of re-establishing a commercial fishery for the spotted spiny lobster *Panulirus guttatus* following the fish pot ban of 1990. Historically, this species was caught using fish pots and reported annual landings ranged from 13,000 to almost 42,000 lobsters for the period 1975 - 1989. As no measures of directed effort for *P. guttatus* are available in the database, it is not possible to generate catch per unit effort (CPUE) data to assess changes in the fishery during this period.

The current experimental fishery tested two basic trap types, a commercially manufactured plastic crustacean trap (Fathoms Plus) and a wire mesh trap (A1) produced by the Division of Fisheries. In the first year, four commercial fishers were provided with approximately equal numbers of the two trap types to fish commercially with the provision that detailed information on trap catches was provided. In the second year, the same number of traps were used but were divided equally between three pairs of fishers. In addition, biological sampling was conducted by the authors and fishers to collect data on size structure, sex ratio and reproductive condition.

A total of 10,592 spotted spiny lobsters were caught in the first year with 64.8% taken in the Fathoms Plus traps. The CPUE values (lobsters per haul) were 1.87 (± 0.06 SE) and 1.43 (± 0.06 SE) for the Fathoms Plus and wire traps respectively. In the second year, the total catch was 9,206 lobsters with CPUE values higher in wire traps than in the Fathoms Plus, although statistical analyses showed no significant difference between the means. In addition, the fish by-catch in the Fathoms Plus traps was much less than the level in the wire traps in both years.

The highest catch rates of spotted spiny lobster were recorded in the summer months (June – August). The biological sampling revealed a male-biased sex ratio in the trap samples of approximately 10:1 (M:F) in the first year and 12.8:1 in the second year. The mean size of males (66.7 mm carapace length (CL) (± 0.06 SE)) was larger than females (60.0 mm CL (± 0.39 SE)). The presence of ovigerous females in the catches indicated that the reproductive period was from May to September with a probable peak in June-July.

KEY WORDS: Spotted spiny lobster, *Panulirus guttatus* , trap fishery, Bermuda

## INTRODUCTION

The spotted spiny lobster *Panulirus guttatus*, is known only from the western Atlantic Ocean from Bermuda, the Bahamas, the Caribbean Sea and Brazil (Williams 1984). There are few established fisheries for this species in the region although there is some small-scale harvesting of *P. guttatus* in Barbados, Dominica and Trinidad (Luckhurst and Marshalleck in press). There is also some recreational harvesting in southeast Florida (Moe 1991).

The biology of the spotted spiny lobster, known locally as the "guinea chick", was first studied by Sutcliffe (1953). Records indicate that this species has been fished commercially in Bermuda since the early 1960s but reported landings are only available from 1975 - 1989. Historically, a smaller scale version of the Antillian fish trap, used to harvest reef fishes and spiny lobster (*P. argus*), was employed to capture spotted spiny lobsters. Although a limited number of fishers specialised in harvesting *P. guttatus* over the years, the local market for this species became well-established. Field studies on the biology and the fishery for this species were conducted in Bermuda by Evans and Lockwood (1994) and Evans et al. (1996).

Following the Fish Pot Ban in Bermuda in 1990, which made the use of Antillian fish traps illegal, the Bermuda Division of Fisheries embarked on an experimental program to design and evaluate a lobster-specific trap to allow the continued harvest of spiny lobsters *P. argus* (Ward and Luckhurst 1996). The result was the establishment of a limited entry spiny lobster fishery utilising standard government-owned traps (Luckhurst 1999) which are leased for the duration of the spiny lobster season (September 1st to March 31st) each year. Following the successful implementation of this program, the Division of Fisheries addressed the issue of the more limited fishery for *P. guttatus*. After an evaluation of historical participation by fishers, the Division of Fisheries decided to work with experienced "guinea chick" fishers in order to evaluate the performance of two trap types in the experimental fishery. Standardised traps were provided to the selected fishers in about equal numbers and they were permitted to sell their catch in return for providing detailed statistics on their fishing activities.

## MATERIALS AND METHODS

The experimental "guinea chick" fishery opened in April 1998 with four participants each with an allotment of 15 traps (total 60 traps). In the second year of the experimental fishery, three partnerships were formed consisting of two fishermen per partnership. The total number of traps remained the same, but was divided into three allotments of 20 traps.

The main objective of this experimental fishery was to evaluate the efficiency of two trap types, the Fathoms Plus trap and the A1 trap. The Fathoms Plus traps are designed specifically for crustaceans (crabs and lobsters) and are used extensively in commercial fisheries, mainly in the United States. They are lightweight, oval-shaped traps made of moulded, black plastic mesh. The A1 traps are rectangular (91.4 x 121.9 x 45.7 cm) and constructed of galvanised, green vinyl-coated 3.8 cm square mesh. Both trap types have one functional funnel on the side of the trap and all funnels are fitted with an identical 10.1 cm diameter white PVC ring at the inner end. The number of *P. guttatus* and the levels of fish by-catch in each trap type were compared.

In the second year of the experimental fishery, the funnel placement on half of the A1 traps was changed to a ramp-like entrance and these traps were designated as A2 traps. This modification was made because some fishers felt that the funnel placement on the A1 trap was the cause of the lower catches experienced in the first year.

Whenever possible samples of *P. guttatus* were measured (carapace length) and the sex and reproductive condition of each individual was determined.

## RESULTS AND DISCUSSION

The Fathoms Plus trap outperformed the A1 trap (Table 1) in the first year (ANOVA, $F = 28.27$, $p < 0.001$, $\alpha = 0.05$). Although the mean CPUE for the Fathoms Plus trap in the second year was slightly lower than those of the A1 and A2 wire traps (Table 1), statistically there were no significant differences (ANOVA, $F = 2.38$, $p = 0.09$, $\alpha = 0.05$). This result suggests that the modification of the funnel entrance with a ramp-like structure did not significantly change the lobster catch rate.

Due to the variability in the levels of commitment to the experimental fishery by different participants, it was decided to further evaluate the performance of the trap types by selecting the most productive fisher, determined by total number of lobsters landed, in each of the two years. CPUE values for each trap type within each year were compared (Table 2). In 1998-1999 the mean CPUE of the Fathoms Plus trap was significantly higher than that of the A1 trap, but in 1999-2000 (Table 2) there were no significant differences between the three trap types which is consistent with the previous results (Table 1).

**Table 1.** Spotted spiny lobster experimental fishery data summary for 1998-2000.

| Season | Trap Type | Mean CPUE | SE | No. of Trap Hauls | No. of lobsters landed | Fish By-Catch (CPUE) |
|---|---|---|---|---|---|---|
| 1998-1999 | A1 | 1.43 | 0.06 | 2,844 | 3,834 | 2,782 (1.04) |
| | Fathoms Plus | 1.87 | 0.06 | 3,456 | 6,758 | 519 (0.15) |
| 1999-2000 | A1 | 3.34 | 0.17 | 759 | 2,554 | 1,420 (1.87) |
| | A2 | 3.30 | 0.20 | 733 | 2,382 | 1,348 (1.84) |
| | Fathoms Plus | 2.87 | 0.12 | 1,450 | 4,270 | 252 (0.17) |

**Table 2.** Summary of data from the most productive fisher in each of the two years of the experimental fishery. In 1998 - 1999 the fishing area was off the east end; in 1999 - 2000 the fishing area was off the south shore.

| Season | Trap Type | Mean CPUE | SE | No. of Hauls | No. of lobsters landed | Fish By-Catch (CPUE) |
|---|---|---|---|---|---|---|
| 1998-1999 | A1 | 1.67 | 0.12 | 906 | 1,278 | 1,414 (1.56) |
| | Fathoms Plus | 2.47 | 0.10 | 1,459 | 3,655 | 171 (0.12) |
| 1999-2000 | A1 | 3.16 | 0.19 | 537 | 1711 | 1,310 (2.44) |
| | A2 | 3.21 | 0.21 | 488 | 1603 | 1,259 (2.58) |
| | Fathoms Plus | 2.93 | 0.15 | 940 | 2832 | 180 (0.19) |

The data from the two most productive fishermen were also used to test for differences in CPUE values between the two years for a particular trap type. The mean CPUE for the Fathoms Plus traps in the second year was significantly greater to that in the first year ($F = 6.96$, $p = < 0.0088$, $\alpha = 0.05$) (Table 2). However, this difference was not as great as that between the two years for the A1 traps ($F = 50.00$, $p = < 0.001$, $\alpha = 0.05$) where the mean CPUE value for the A1 traps in the second year was almost twice that of the first year (Table 2). There are a number of factors which could have been responsible for these differences including trapping in different areas of the reef platform and different levels of fishers' skill and experience. The fishers believe that the "ageing" of the trap, as the fouling community develops, is an important factor affecting catching power. As the same traps were used for the two year period, both trap types developed substantial fouling communities but the effect was perhaps greater with the wire mesh traps. The fishers suggest that the black plastic mesh of the Fathoms Plus initially provided more attractive habitat for lobsters, but as the wire mesh traps became fouled by invertebrates and algae, they were frequented more by lobsters and catch rates became very similar to the Fathoms Plus.

Figure 1 shows the mean CPUE by trap type by month for the most productive fisher in each year. This figure indicates that the Fathoms Plus trap caught more lobsters in the first months of the experimental fishery but that CPUE values for both trap types converged by August 1998. Thereafter trap performance by type was similar until January 1999 when the CPUE dropped in the A1 traps. In the second year, in all trap types there was a summer peak in CPUE (Figure 1b) similar to that of the Fathoms Plus in the first year (Figure 1a). In general, monthly mean catch rates were very similar between trap types during the second year. In both years, catch rates were generally lower during the winter months.

This experimental fishery was essentially harvesting a virgin stock as no directed commercial harvest of this species had taken place since 1990. If fishing pressure is maintained at a modest level from the time that the fishery recommences, CPUE levels similar to those of the most productive fishers might be expected. If these figures are used as maximum estimates of catchability, the Division of Fisheries will be able to formulate management measures which are conservative in approach by scaling back from these maximum estimates to fishing effort levels which should be sustainable over time.

The by-catch rates were consistently lower for the Fathoms Plus traps (Tables 1 and 2). In contrast, the fish by-catch in the wire traps (A1 and A2) was markedly higher. Given these results, the Fathoms Plus trap is clearly the preferred trap type as minimising reef fish by-catch is an important fisheries management objective for the local lobster fishery.

The above results, suggest that the exclusive use of Fathoms Plus traps should be recommended when the commercial fishery for spotted spiny lobsters in Bermuda commences. The Fathoms Plus trap performs about equally as well as the wire traps (A1 and A2), which were the designs originally favoured by fishers prior to the experimental fishery, and has the lowest fish by-catch. An added benefit of selecting this trap type is the fact that the theft of Fathoms Plus traps was almost negligible during the two year experimental fishery in comparison with wire traps. Most of the participants have now come to accept that the Fathoms Plus trap is suitable for spotted spiny lobsters and the majority support its continued use.

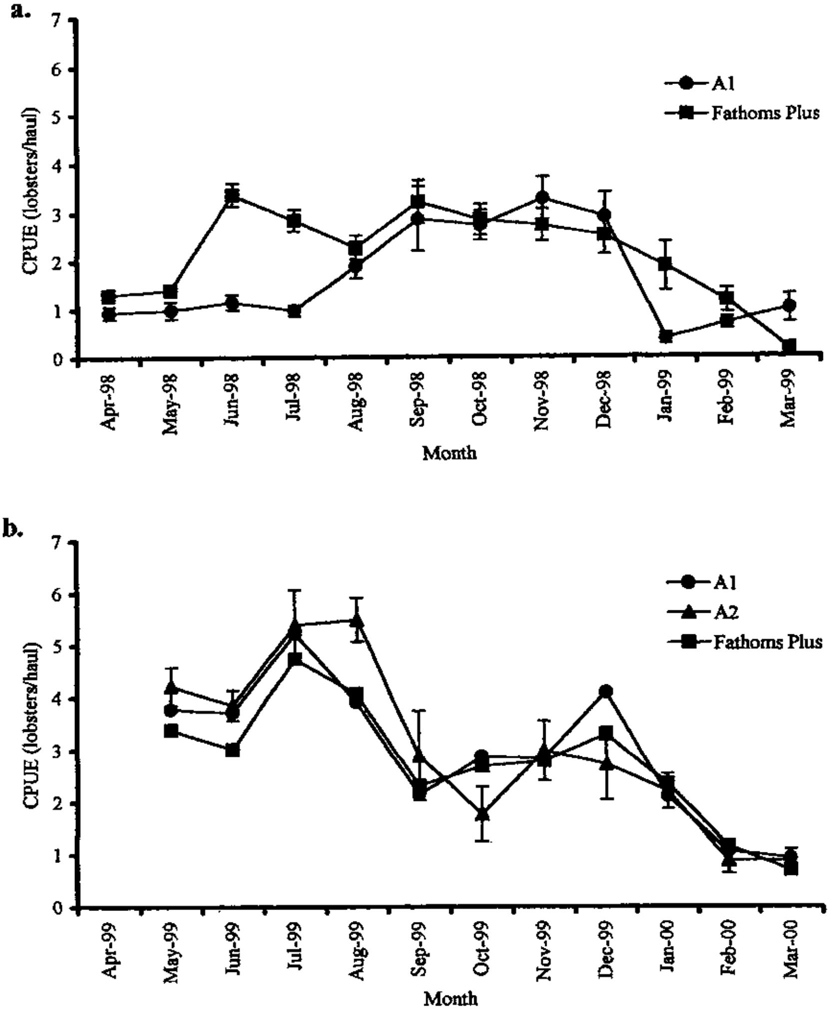

**Figure 1.** Mean CPUE ( ± SE) by month for: **a**. the most productive fisher in 1998 - 1999 and **b**. the most productive fisher in 1999 - 2000

Due to the variability in the levels of commitment to the experimental fishery by different participants, it was decided to further evaluate the performance of the trap types by selecting the most productive fisher, determined by total number of lobsters landed, in each of the two years. CPUE values for each trap type within each year were compared (Table 2). In 1998 - 1999 the mean CPUE of the Fathoms Plus trap was significantly higher than that of the A1 trap, but in 1999 - 2000 (Table 2) there were no significant differences between the three trap types which is consistent with the previous results (Table 1).

The biological sampling in both years indicated a strongly male-biased sex ratio in the trap catches. In the first year, the sample size was 1,238 (1,124 males, 114 females) for a sex ratio of approximately 10 Male: 1 Female. This finding is similar to that reported by Evans et al. (1995). The sex ratio in the second year of sampling (N = 6,112) was 12.8 Male:1 Female. If this is a true indication of the population sex ratio, then it is very important to protect females to maintain an adequate spawning stock. As a consequence, we will recommend that a commercial fishery commence with a prohibition on the possession of females in an attempt to ensure maximum reproductive output from the stock. Only eight female "guinea chick" lobsters carrying eggs were actually measured. These ranged in size from 52 to 70 mm carapace length (CL). However, the presence of ovigerous females in the catches, as recorded by the fishers' statistical forms, suggests that the reproductive period was from May to September with a probable peak in June-July.

A total of six night dives were made during the summer months to capture and sex spotted spiny lobsters to determine if the sex ratio differed from that observed in the trap catches. Unfortunately, only a small number of specimens were observed and captured (N = 16, 9 males, 7 females) and thus the sample size is inadequate to address this important issue.

The size range of lobsters sampled (N=1238) in the first year was 46-85 mm CL with the largest female measuring 75 mm CL. Mean sizes were 67.3 mm CL (± 0.16 SE) for males and 60.6 mm CL (± 0.44 SE) for females. In the second year, with a much larger sample size (N = 6,112), the size range was almost identical (47 - 85 mm CL) and the largest female was 71 mm CL. Mean sizes changed only marginally (Males = 66.5 mm CL (± 0.06 SE); Females = 58.4 mm CL (± 0.75 SE). Figure 2 shows the size frequency distribution of the lobsters sampled over the two years of the experimental fishery.

This experimental program has provided a scientific database which will be used in the formulation of a fisheries management program to allow the sustainable harvest of this small spiny lobster which will compliment the existing limited entry fishery for the spiny lobster *P. argus* in Bermuda.

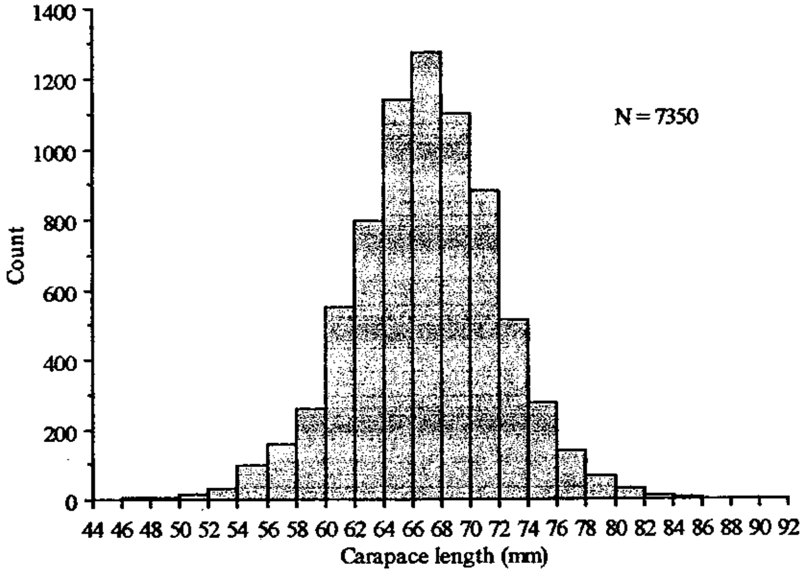

**Figure 2.** Size frequency distribution of the spotted spiny lobsters sampled over the two years of the experimental fishery

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# Regression Analysis of the Relationships Among Life-stage Abundances of Brown Shrimp (*Penaeus aztecus*) and Environmental Variables in Southern Louisiana, USA

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## ABSTRACT

Brown shrimp (*Penaeus aztecus* Ives) landings in the Gulf of Mexico display substantial interannual variability. We used regression techniques to analyze relationships among 27 years of postlarval, juvenile, and adult abundance estimates and a suite of environmental variables. Environmental variables included water temperature, salinity, turbidity, river flow rate, acres of suitable habitat, and precipitation. We used a combination of manual and stepwise model building procedures to develop annual models with offshore catch, late-juvenile, early-juvenile, and postlarval abundances as dependent variables. Environmental variables and preceding life history stages were exploratory variables. Commercial catch was described by late-juvenile abundance, water temperature, previous commercial catch, and river flow. The biological variables in the model explained 55% of the variability in offshore catch, whereas the environmental variables explained 24% of the variability. Environmental variables explained variation between each life history stage and were the only significant predictors of postlarval and juvenile abundance. The lack of biological links among early life history stages may result from environmentally-driven, density-independent relationships or biologically-driven, nonlinear relationships. We are designing an individual-based simulation model of shrimp to further explore the relationships among their early life history stages. Both the regression and simulation models are ongoing efforts. We hope the combination of statistical and individual-based simulation modeling will provide further insight into the factors that affect variability in brown shrimp recruitment.

KEY WORDS: Penaeid, brown shrimp, annual recruitment

## INTRODUCTION

Like many penaeid fisheries, brown shrimp (*Penaeus aztecus* Ives, *Farfantepenaeus aztecus* Ives) landings in the Gulf of Mexico display substantial interannual variability. Because most of the shrimp caught in the Gulf fishery are less than one year old (Caillouet and Koi 1981), brown shrimp have an essentially annual life cycle. Adults spawn offshore, larvae move toward the coast, juveniles grow within the estuaries, and adults move away from the shallow coastal zone and enter the offshore fishery. The short life cycle and intense fishing pressure should make brown shrimp one of the easiest fisheries to forecast (Matthews et al. 1994).

With the world-wide commercial importance of penaeids, there are many models which attempt to predict shrimp abundance. Although the details of these models vary geographically and by species, they exhibit several common features. Commercial catch is related to several environmental variables including temperature (Barrett and Gillespie 1973, Barrett and Ralph 1977, Hettler 1992), rainfall (Staples 1985, Staples et al. 1995), intertidal vegetation (Turner 1977), and water level in the marsh (Zimmerman and Minello 1984). Many studies that examine biological variables use juvenile abundance to predict subsequent catch (Berry and Baxter 1969, Caillouet and Baxter 1973, Barrett and Gillespie 1973). Some models use postlarval abundance to forecast catch (Delauncy et al. 1994, Matthews 1995). Fewer studies (Vance et al 1998) look for links among the earlier life history stages.

Our objective in this paper is to use regression analysis to better understand the sources of interannual variation in Louisiana's brown shrimp recruitment. Recruitment in this paper is defined as the abundance of shrimp that reach the next life stage. We are interested in the prediction of annual catch and in what regression analysis reveals about penaeid ecology. We used 28 years (1970 – 1997) of biological and environmental data related to brown shrimp recruitment in order to examine the linear relationships among successive life history stages and environmental variables.

## METHODS

We assembled a dataset that included annual values of brown shrimp abundance estimates by life stage and monthly or annual values of a suite of environmental variables. The four life stages examined were postlarval (number of shrimp/m$^3$), early juvenile (number of shrimp/10 minute trawl with six foot net), late juvenile (number of shrimp/10 minute trawl with sixteen foot net), and adult (pounds of offshore catch). Environmental variables examined water temperature, salinity, turbidity, river flow rate, precipitation, and acres of habitat > 10 ‰. Because shrimp may be affected by the environment at critical periods in the spring, annual monthly averages (for February through July) were calculated for salinity, temperature, turbidity, precipitation, and river flow. We dropped February salinity and turbidity because we had incomplete data at the beginning of the season.

The Louisiana Department of Wildlife and Fisheries (LDWF) provided postlarval and juvenile abundance estimates. A detailed description of the data collection procedures can be found in Marine Fisheries Division Field Procedures Manual (LDWF 1996). Table 1 summaries the LDWF sampling protocol for each life stage. In general, LDWF sampled weekly when the brown shrimp densities were known to be historically high. Postlarval data were collected from four major tidal passes in Barataria Bay, which functions as an index for brown shrimp recruitment. We calculated postlarval densities based on tow catch and flow meter readings. Estimates of juvenile abundance in Louisiana were obtained from six and sixteen foot otter-trawl surveys. Because of sample location and mesh size, the six foot trawl selected for smaller shrimp than the sixteen foot trawl. Hence, we used the six foot trawl data to estimate early-juvenile abundance and the sixteen foot trawl data to estimate late-juvenile abundance. The mean total length of the early juveniles was 65 mm, and the mean total length of the late juveniles was 75 mm.

**Table 1.** LDWF sampling protocol used to monitor the brown shrimp fishery in southern Louisiana.

| Stage | Gear | Mesh Size | Sampling Location |
|---|---|---|---|
| **Postlarvae** | 0.5 m plankton net | 500 micron | Tidal passes |
| **Early juvenile** | 6' trawl | 3/8 inch | Shallow marshes |
| **Late juvenile** | 16' trawl | 3/4 inch | Bays, sounds, or lakes |

We estimated adult abundance by using commercial catch data (in pounds) provided by the National Marine Fisheries Service. We also converted the annual pounds of commercial catch to annual numbers of shrimp caught. The use of numbers reduces effects of differential growth of individual shrimp during the juvenile stage when they are in the estuaries. Very similar results were obtained with numbers and pounds. We used total annual offshore heads-off catch as a dependent variable because offshore catch accounted for over 50% of the total annual recorded catch, and offshore catch was well correlated with total catch ($R^2 = 0.84$).

The LDWF provided two sets of environmental data. The first set of data was acquired in conjunction with the biological sampling of the postlarvae and juvenile abundances, and it included surface and bottom water temperature, surface and bottom salinity, and turbidity. The second set of environmental data was collected independently of the biological sampling, and included an annual estimate of the total number of acres with a salinity greater than 10 ‰, mean monthly precipitation in southern Louisiana (Source: NOAA Climatological Data), and mean monthly Mississippi River (at Tarbert Landing, Miss) and Atchafalaya River (at Simmesport, LA ) flow rates (Source: US Corps of Engineers, New Orleans District). Examples of water temperature and river flow variables are shown in Figure 1a.

We did not discriminate between surface and bottom measurements of the environmental variables because the water column in areas of data collection were generally shallow and well-mixed. In cases where the LDWF sampled salinity and temperature at the top and bottom of the water column, we deleted outliers and used simple linear regression models to compare the surface and bottom values for each life history stage (postlarval, early juvenile, and late juvenile). The salinity near the bottom explained > 90% of the variation in surface salinity, and the bottom temperature explained > 97% of the variation in surface temperature. Because brown shrimp are primarily benthic, we used the bottom values of temperature and salinity. If bottom values were not available, we substituted surface values.

We used regression analysis to explore the relationships among life history stages and environmental variables. Specifically, we created regression models to describe the interannual variation in total annual pounds of offshore catch, mean annual late-juvenile abundance, mean annual early-juvenile abundance, and mean annual postlarval abundance. In order to describe each life history stage, we used the entire suite of environmental variables plus all preceding life history stage abundances. Because commercial catch may be an indicator of spawning potential, we used last year's catch (in pounds and numbers) as possible indicators of this year's abundances.

We used a combination of manual and stepwise (automated) regression to build our models. Automated stepwise model building presented potential problems due to the loss of data because of missing values. When multiple regressions were performed using SAS stepwise regression (SAS Institute 1989), the data were limited to years that had a value for all exploratory variables. Thus, initial regressions were run on few data points ($n < 10$) and had inappropriately large correlation coefficients ($R^2 > 0.95$). We therefore used a manual model-building procedure to identify a reduced set of exploratory variables, which were then used in the stepwise procedure. First the dependent variable was correlated to each exploratory variable. A simple linear regression was run using the dependent variable and the exploratory variable with the highest single correlation. The residuals from this regression were then correlated with all of the remaining exploratory variables. A second model was built using the residuals as the dependent values and the exploratory variable with the highest correlation as the new predictor variable. We repeated this procedure until no additional predictor variables were significantly correlated to the residual from the preceding model.

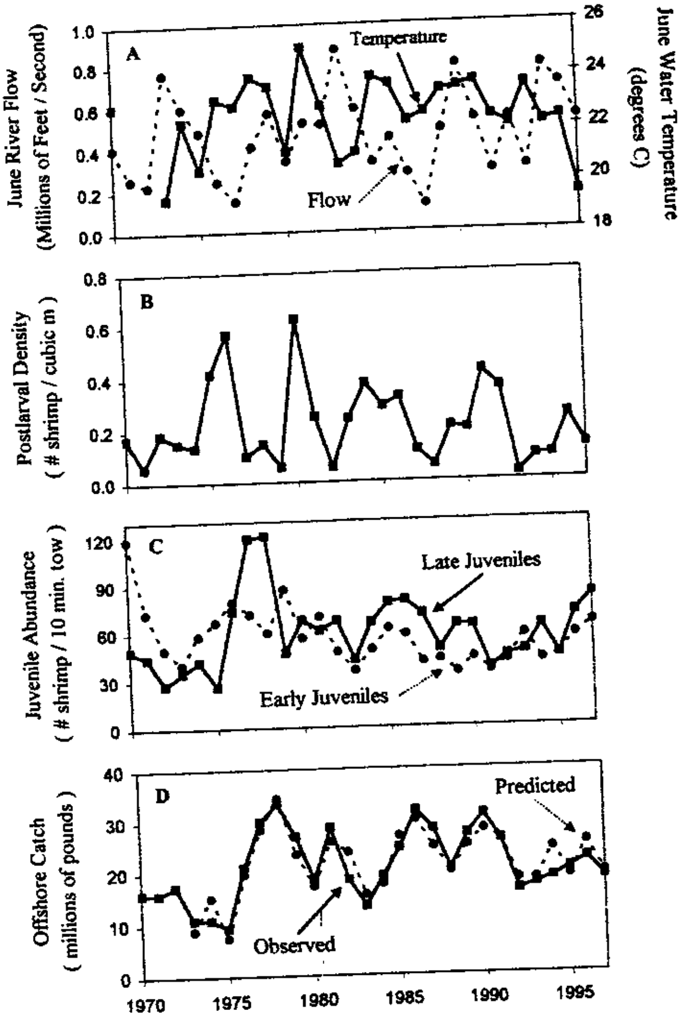

**Figure 1.** Annual values of selected environmental variables and brown shrimp life stage abundances. **1a.** June estuarine water temperature (°C) and June Atchafalaya and Mississippi River flow rates ($10^4$ cubic feet/second). **1b.** Postlarval Abundance (# of shrimp/$m^3$) **1c.** Early and Late-juvenile abundance (# of shrimp/10 minute trawl) **1d.** Offshore commercial catch (in millions of pounds).

We then preformed an automated stepwise multiple regression using the variables that were selected with the manual procedure. The stepwise process allowed the removal of predictor variables in later models. All variables that were not significant at the 0.10 level were removed one at a time from the regression equation. Removing variables changed the regression relationship because it allowed more years to be included in the analysis. We used the resulting regression equation to predict catch for each year in the study period. We report the final models which were identified by the combination of manual and stepwise model building. In an attempt to explore the contribution of environmental and biological variables, the model predicting commercial catch was subsetted into two reduced models. The first reduced model contained only biological variables, and the second reduced model contained the environmental variables.

## RESULTS

Commercial catch of brown shrimp in Louisiana was described by late-juvenile abundance, April water temperature, total estimated number of shrimp caught in Louisiana in the previous year, and June Mississippi and Atchafalaya River flow (Table 2, Figure 1d). The reduced biological model explained 55% of the variability in offshore catch, whereas the reduced environmental model explained 24% of the variability in catch.

The early life history stages were correlated with environmental variables but not with preceding life-stage abundances. Late juvenile abundance was correlated with salinity variables and with May water temperature (Table 2). All of the salinity variables, except March salinity, suggested that abundance of late juveniles was higher under saltier conditions. Early juvenile abundance was correlated with turbidity, river flow, precipitation, and salinity (Table 2). Post larval abundance was correlated with temperature in the tidal passes, salinity, precipitation, and river flow (Table 2).

## DISCUSSION

Environmental variables helped explain the variation between each life history stage and were the only significant predictors of the postlarval and juvenile abundances. In general, environmental conditions in the later months (May and June) were correlated more closely with the later life stages (late-juveniles and adults) and earlier months (February and March) were correlated more closely with the earlier life stages (postlarvae and early-juveniles). Although there were exceptions, higher shrimp abundance was generally associated with higher salinity and warmer water temperature.

**Table 2.** Final regression models from the analysis of brown shrimp life stage abundances and environmental variables. Final models are those determined from the combination of the manual and stepwise model building procedure.

| Dependent Variable | Predictor Variables (Positive or Negative Relationship) | n | $R^2$ | P |
|---|---|---|---|---|
| **Commercial Catch** | Full Model:<br>+ Late juvenile abundance<br>+ April estuarine water temperature<br>+ Number of shrimp caught last year<br>+ June river flow | 25 | 0.85 | $p < 0.0001$ |
| | Reduced Biological Model:<br>+ Late juvenile abundance<br>+ Number of Shrimp caught last year | 27 | 0.55 | $p < 0.0001$ |
| | Reduced Environmental Model:<br>+ April estuarine water temperature<br>+ June river flow | 26 | 0.24 | $p < 0.0454$ |
| **Late Juveniles** | + March estuarine salinity<br>+ June estuarine salinity<br>- Annual precipitation (in SE LA)<br>+ May estuarine water temperature<br>+ May precipitation (in SE LA)<br>- March salinity (in lower estuary) | 21 | 0.87 | $p < 0.0001$ |
| **Early Juveniles** | - June estuarine turbidity<br>- February river flow<br>- Annual precipitation (in SE LA)<br>- March salinity (in lower estuary) | 23 | 0.66 | $p < 0.0005$ |
| **Postlarvae** | + February temperature (in passes)<br>- May temperature (in passes)<br>+ March salinity (in lower estuary)<br>- February precipitation (in SE LA)<br>+ April river flow | 20 | 0.77 | $p < 0.0004$ |

As is the case with most regression analysis, correlation does not necessarily mean causation. Variables selected by the regression procedure may represent a controlling mechanism or may simply be correlated with a controlling mechanism. For example, June turbidity was selected as a significant predictor of early juvenile abundance. Turbidity might directly affect juvenile abundance by affecting predator prey relationships (Minello et al. 1987). Alternatively, turbidity may simply be correlated with a controlling mechanism, such as wind-driven events that affect postlarval transport and salinity regimes. The lagged catch variable is a second example of an uncertain controlling mechanism. Whereas last year's catch may reflect this year's spawning potential, it may also be a reflection of trends in expended effort and gear efficiency.

Caution in the interpretation of the final regression models is appropriate due to the multicollinearity among predictor variables. Collinearity can arise from covariance among related variables (e.g. salinity and precipitation) and from using several monthly values of a single environmental variable (e.g. April temperature and May temperature). Because each iteration of the selection procedure chose only one variable for inclusion, several well-correlated variables were not included in the prediction equation. For example, the selection procedure included late juvenile abundance ($r = 0.62$) but did not include annual mean turbidity ($r = 0.56$). Correlated environmental variables might help explain the inclusion of suspicious variables. For example, May temperature predicted postlarval abundance even though the postlarval abundance peak is in March and April.

Whereas environmental variables were significant predictors at all life history stages, the biological link among abundances at successive life history stages was only detected between the late-juvenile and adult abundance. Failure to document the biological links among the early life history stages could be explained in several ways. One explanation is that we have inappropriate or insufficient data to detect relationships in abundance. The juvenile abundance estimates may be inappropriate because trawl data can be qualitative rather than quantitative measures of abundance (Rozas and Minello 1997). The postlarval data stage is especially susceptible to insufficient sampling due to the difficulties in capturing pulses of immigrants. Nevertheless, we presume that because the LDWF sampling protocol captured the pattern in the late-juvenile to adult abundance, it could also capture an abundance pattern in the early to late-juvenile stage.

Assuming we have appropriate and sufficient data to detect relationships among successive life stages, the lack of biological links among early life history stages may result from environmentally-driven, density-independent relationships and density-dependent, nonlinear relationships. To explore these possibilities, we are designing an individual based model to simulate early life history stages. The simulation model begins at post-larval immigration into the estuaries and tracks individual shrimp in a spatial grid of land and water cells until the shrimp emigrate back to coastal waters. Habitat-dependent growth and mortality are recorded at each tidal cycle. Initial simulations indicate the important, but complex, role of edge habitat in affecting shrimp survival within the estuary.

Both the regression and simulation models are ongoing efforts that are still being refined. We plan to expand the regression model by adding variables associated with estuarine water levels, acres of vegetated habitat, shrimping effort, and timing of the inshore fishing season. Using a biological year (Klima et al. 1982) rather than a calendar year might also strengthen the regression relationships. After we expand the regression model, we will examine regression diagnostics and then use the same regression procedures to examine inshore shrimp catch. The pounds caught inshore and offshore are not well correlated ($r^2 = 0.22$) and may be related to a different suite of variables. We are also considering alternative analytical methods to regression, such as neural network analysis and general additive models, to explore any relationships among the early life stages. We hope the combination of statistical and individual-based simulation modeling will provide further insight into the factors that affect variability in brown shrimp recruitment.

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