Predicting White Shrimp, *Penaeus setiferus*, Abundance Based on Environmental Parameters and Previous Life Stages

HAMADY DIOP[1], WALTER R. KEITHLY, JR.[1],
RICHARD F. KAZMIERCZAK, JR.[2], and RICHARD F. SHAW[1]
[1]*Coastal Fisheries Institute*
School of the Coast and Environment
Louisiana State University
Baton Rouge, Louisiana 70803 USA
hdiop1@lsu.edu, wkeithly@lsu.edu, rshaw@lsu.edu
[2]*Center for Natural Resource Economics and Policy*
Agricultural Economics and Agribusiness
Louisiana State University AgCenter
Baton Rouge, Louisiana 70803 USA
rkazmierczak@agcenter.lsu.edu

ABSTRACT

Louisiana white shrimp, *Penaeus setiferus*, landings display substantial intra-annual and inter-annual variability. This variability reflects differential impacts of a variety of environmental and biological factors which influence growth, mortality, and subsequent survival in a given year. Accounting for shrimp stock variability in shrimp stock and related catch is one of the more frustrating problems facing fishery managers. Efforts to develop rigorous predictive models to help fishery managers to forecast landings early enough in the season to significantly aid industry have been, for the most part, unsuccessful. For predicting Louisiana white shrimp abundance and subsequent catch, we developed a recursive three-equation model in which different life stages are predicted based on ecosystem parameters such as temperature, river discharge, cumulative wetland loss, and lagged previous stage counts. Changes in environmental factors were examined and simulated to determine impacts on the different life stages and catch.

KEY WORDS: Shrimp, *Penaeus setiferus*, abundance models

Predecir Camarón Blanco, *Penaeus setiferus*, la Abundancia se Basó en Parámetros de Ecosistema y Etapas Previas de Vida de Camarón

Las capturas de camarón en Louisiana presentan una variabilidad interannual substancial. Esta variacion refleja impactos diferenciales de una variedad de factores ambientales y biológicos que influencian el crecimiento, la mortalidad y la sobrevivencia subsiguiente en un año dado. La variabilidad interannual en capturas pesqueras o captura por unidad de esfuerzo es uno de los problemas más frustrantes que enfrentan los administradores pesqueros. El esfuerzo para desarrollar modelos predictivos rigurosos para ayudar a los administradores pesqueros con el objeto de pronosticar las capturas pesqueras lo suficientemente temprano en la temporada para ayudar apreciablemente a la industria, ha sido una de los mayores fracasos. Proponemos unos modelos recursivos de tres ecuaciónes en los cuáles diferentes ciclos de vida son predecidos basados en los parámetros del ecosistema tales como el flujo del agua, la temperatura, la descarga del río, el nivel de la lluvia y las diferentes etapas de vida temprana y el habitat de los peces. Las simulaciones se realizaron para abordar problemas administrativos tales como el impacto de un aumento en el número de pasos para una etapa de vida sobre las etapas de vida subsiguientes. Tambien se predicen los impactos de los cambios ambientales sobre las diferentes etapas de vida.

PALABRAS CLAVES: Camarón, *Penaeus setiferus*, modelos

INTRODUCTION

The Gulf of Mexico generally accounts for about 70 % of the U.S. commercial production of shrimp and, among Gulf states, Louisiana is the largest contributor. The two primary species harvested in Louisiana are white shrimp, *Penaeus setiferus*, and brown shrimp, *Penaeus aztecus*. During the 1990 - 2001 period, Louisiana's commercial production of white shrimp averaged 48 million pounds (heads-on weight) while landings of brown shrimp averaged 50 million pounds (heads-on weight). The dockside value of these landings averaged $157 million annually and white shrimp production represented almost 60 % of this total. Given the large landings and relative importance of Louisiana's white shrimp fishery, it would be useful to predict the influence of changes in environmental factors on subsequent commercial catch. This serves as the overall goal of this paper.

To accomplish this goal, a recursive three-equation model in which different life stages are predicted based on environmental parameters is developed and estimated. In the first stage of the model (i.e., equation 1), monthly estimates of early juveniles are regressed against a suite of environmental variables (a more detailed description of the different life stages as well as the environmental variables used in the analysis is provided in a subsequent section of the paper). In the second stage (i.e., equation 2), monthly estimates of late juveniles are regressed against a suite of environmental variables as well as current and lagged estimates of early juveniles. Finally, in the last stage (i.e., equation 3) adult abundance, estimated by monthly industry reported white shrimp catch in Louisiana standardized by real effort (i.e., catch per unit effort, or CPUE), is regressed against a suite of environmental factors as well as current and lagged estimates of late juveniles. The period covered by the analysis was from 1970 through 1997.

Iterative substitution of equation 1 into equation 2 and then equation 2 into equation 3 allows one to examine the full impact of any specific environmental variable, even one directly affecting only the early juvenile stage, on any subsequent life stage, including adult abundance (as estimated via CPUE).

which case the hypothesized relationship would be positive. Finally, early juvenile abundance may have little relationship to water clarity but may impact catchability of early juveniles (i.e., the measurement of abundance) via escapement mechanisms (see Haas et al., 2001, for a more detailed discussion). The expected relationship in this situation would be negative. Of course, some amalgam of all the abovementioned factors may 'come into play' in determining the relationship between early juvenile abundance (or catchability) and water clarity.

Since Louisiana wetlands provide critical habitat during the early-life stages of shrimp, the hypothesized relationship between early juvenile white shrimp abundance and accumulated wetland loss is negative. Specifically, loss in wetlands is anticipated to result in a monotonic decline in abundance of shrimp in the early-life stages, *ceteris paribus*. Finally, the relationship between early juvenile abundance and GRC and FGR is unknown.

The second stage of the three-equation system, i.e., that depicting late juvenile abundance, is specified as follows:

NUMSXN(t) = g[NUMSIX(t), NUMSIX(t-1), TEMPSXN(t), SALISXN(t), TURBSXN(t), RATEC(t), LANDLOSS(t), GRC(t), FGRC(t)] (2)

where where NUMSXN(t) is the estimate of late juvenile shrimp abundance in month t, TEMPSXN denotes the water temperature (bottom) associated with late juvenile shrimp abundance, SALSXN denotes the estimated salinity associated with late juvenile shrimp abundance, TURBSXN denotes estimated water clarity associated with late juvenile shrimp abundance. Finally, the term (t) merely reflects the current period and (t-1) represents a lag of one period. Hence, NUMSIX(t-1) merely represents the estimated abundance of early juveniles lagged one period (i.e., lagged one month).

The rationale for inclusion of the environmental factors (and relationship to abundance) has been previously presented and, as such, is not repeated here. Given the fast growth rate of early juvenile shrimp, a lag of more than one period was considered unwarranted. Late juvenile abundance is expected to be positively related to current and lagged early juvenile abundance.

The final stage of the three-equation system, i.e., that depicting adult abundance, is specified as follows:

CPUE(t) = v[NUMSXN(t), NUMSXN(t-1), NUMSXN(t-2), NUMSXN(t-3), NUMSXN(t-4), NUMSXN(t-5), D(t), RATEC(t), GRC(t), FGRC(t), EFFORT (t), EFFORT(t-1), TEMPSXN(t)] (3)

The endogenous variable, CPUE(t), as previously noted, is a proxy for adult abundance and is estimated as monthly industry reported white shrimp catch in Louisiana standardized by real effort. The large number of lagged estimates of late juvenile abundance in the adult abundance equation (equation 3) reflects the fact that shrimp, while essentially an annual crop, can live for a large number of months upon entering the Gulf. The four month lag associated

Finally, the three equations depicting the different abundance stages (i.e., with late juveniles, in association with the two month period associated with movement of early juveniles to late juveniles, suggests that environmental factors occurring as much as six months previously can impact adult abundance. This six month period is thought to cover the vast majority of adult shrimp (i.e., the adult shrimp can survive up to six months). Overall, one would anticipate a positive relationship between current and lagged late juveniles and adult abundance.

One of the major tools employed by the Louisiana Department of Wildlife and Fisheries (LDWF) in its management of the white shrimp fishery (as well as the brown shrimp fishery) is through a seasonal closure of inshore waters. With respect to white shrimp, the inshore waters are opened in August and remain open throughout the remainder of the calendar year (inshore waters are closed to brown shrimp harvesting activities when white shrimp begin showing up in significant numbers). To 'capture' those months when inshore waters are open to white shrimp harvesting, a discrete variable (equal to zero for the months January through July and one for the months August through December), denoted by D(t), is included in the adult abundance equation. While opening of inshore waters for white shrimp harvesting does not directly impact adult abundance (it could indirectly influence it through fishing mortality), failure to account for the time period when inshore waters are open could result in significant model misspecification.

The variable EFFORT(t) reflects the amount of real shrimp effort exerted in the white shrimp fishery. Given the relatively fixed stock in any given month, increases in effort should, in theory, result in declining abundance (measured by CPUE) and, as such, one would hypothesize a negative relationship between effort and CPUE. Lagged effort is included in the equation in an attempt to capture the impacts of past fishing pressure on current abundance and the relationship between the two is expected to be negative.

Statistical Considerations

There are a number of statistical considerations that need to be discussed; the first of which relates to all environmental factors. Specifically, while the current level of any given environmental variable, say RATEC(t) is anticipated to directly impact the different life stages of white shrimp abundance, previous levels of the environmental factors may also directly influence abundance. As such a two month moving average was used in the construction of all environmental variables in all equations. Hence, for example, the river flow rate in July, denoted RATEC(7), actually reflects a simple two month moving average of river flow rate.

A second statistical consideration reflects the functional form to be used in estimating the equations. In general, theory provides little guidance regarding the functional relationship between the endogenous and exogenous variables in each of the equations. Preliminary analysis of the data using a Box-Cox transformation procedure (see Pindyck and Rubinfeld 1991, for discussion of the procedure) suggested that a double log model may represent the 'preferred' functional relationship for all equations. As such, all equations were estimated using a double log functional form.

early juveniles, late juveniles, and adults) bear a close conceptual relationship with each other and, as such, one would expect that there to be a correlation in the error terms across the different equations. As such, Seemingly Unrelated Regression (see Pindyck and Rubinfeld 1991, for a discussion of the procedure) was employed to increase efficiency of the estimates.

Data Sources and Description

Much of the data sources and description of the data are fully developed in Haas et al. (2001) and, hence, are not repeated here. However, elaboration regarding some of the variables as well as further description are certainly warranted.

Beginning with the endogenous variables, monthly estimates of the abundance of early juveniles is based on LDWF sampling in the shallow marshes and are equal to the number of shrimp caught per 10 minute tow using a six-foot otter trawl, averaged over all samples over all locations in a given month. Similarly, monthly estimates of late juvenile abundance is based on LDWF sampling bays, sounds and lakes and is equal to the number of shrimp per 10 minute tow using a 16-foot otter trawl, averaged over all samples over all locations in a given month. Finally, monthly estimates of adult abundance reflect monthly reported industry catches (not landings) in Louisiana (both inshore and offshore) adjusted by the real amount of shrimping effort. Effort is expressed in 24 hours of tow time (i.e., one day is equal to 24 hours of tow time) and the nominal fishing effort collected by NMFS was adjusted for variations in fishing power among different vessels at any point in time as well as changes in fishing power over time using the procedure discussed by Griffin et al.(1997). Hence, the estimate of adult abundance is equivalent to catch (in pounds) per day where a day fished is standardized for heterogeneity of the fleet and changes over time in relative fishing power of the standard vessel.

The river flow is measured in thousand of cubic feet per second in a 24 hour period. The Mississippi river flow is recorded at Tarbert landing (Mississippi) and the Atchafalaya river flow is recorded at Simmerport, Louisiana. Turbidity is reported as secchi disk depth in feet and tenths. Salinity was recorded (ppt) using a salinometer at each sampling site for the early and late juvenile stage. Finally, no information is routinely collected pertaining to accumulated wetland loss. Estimates used in the current study are based on those derived by Turner (1997) and provided to us by the author. Loss estimates provided to us by Turner are annual in nature and we made no attempt to convert them to monthly. Hence, while the estimate of accumulated wetland loss is permitted to increase from one year to the next in this study, it remains constant for all 12 months within a given year. Accumulated loss is expressed in square miles per year.

RESULTS AND DISCUSSION

Regression analysis shows that most of the environmental variables included in the various models are good predictors of abundance. As expected, the positive relationship between temperature and early juveniles is an evidence that warmer temperatures are conducive to white shrimp abundance

(Table 1). The elasticity, which indicates a percent change in a dependent variable due to a percent change in an independent variable, is about 5 for early juveniles indicating that a one percent change in temperature is associate with a five percent change in abundance. The impact lessen as shrimp grow and move offshore (Table 2).

Table 1. Results for the recursive three-equation model. Most of the reported parameters are significant at the 5% alpha level.

Label	Early Juvenile (Numsix)	Late Juvenile (Numsxn)	CPUE
Intercept	0.832	1.344	9.647*
TEMPSIX	4.988*		
SALISIX	0.044		
TURBSIX	0.124*		
RATEC	-0.699**	-0.066	-0.221*
LANDLOSS	-1.442*	-0.196*	
GR	-0.171	-0.019	0.003
FGR	-0.084	-0.002	0.019
NUMSIX		-0.008	
NUMSIX11		-0.031*	
TEMPSXN		0.730*	
SALISXN		0.348*	
TURBSXN		0.648*	
NUMSXN1			0.033
NUMSXN11			0.148*
NUMSXN12			0.152*
NUMSXN13			0.121*
NUMSXN14			-0.054*
D			0.967*
EFFORT			-0.448*
EFFORT1			-0.174*

System R^2 is 0.56
* Significant at the 5% alpha level
** Significant at the 10% alpha level

Table 2. Derived elasticities with respect to various environmental factors and effort. An elasticity is for example a percentage change in early juvenile

Label	Early Juvenile (Numsix)	Late Juvenile (Numsxn)	CPUE
Intercept			
TEMPSIX	4.988	0.113	0.045
SALISIX	0.438	0.001	0.0003
TURBSIX	0.124	0.003	0.0011
RATEC	-0.699	-0.084	-0.255
LANDLOSS	-1.441	-0.228	-0.092
GR	-0.171	-0.003	
FGR	-0.083	-0.024	
TEMPSXN		0.730	0.118
SALISXN		0.348	0.139
TURBSXN		0.648	0.259
EFFORT			-0.448

The importance of the availability and quality of wetland habitat to juvenile shrimp has been well-documented (Doi et al. (1973), Turner, 1977, Pauly and Ingles 1988). Subsequently, the results show that the loss of this essential habitat has a negative impact on the abundance of early juvenile white shrimp. A one percent increase in cumulative wetland loss leads to a 1.44 percent decrease in the amount of shrimp at the early stage of life. While this negative effect lessens as the shrimp progresses through its life stages, (-0.228% and -0.092 respectively, for the later two stages) the cumulative impact in loss in abundance has serious implications for commercial catch. To visualize these results the change in cumulative wetland loss with respect to CPUE has been simulated and plotted in figure1. As wetland loss increase over time, one can observe a downward trend in CPUE. Lastly, the pressure exerted by the fishing fleet on the total shrimp stock has the potential for decreasing the catch per unit of effort (CPUE). Results show that a one percent increase in fishing effort leads to a 0.448 percent decrease in CPUE.

Biological factors are important predictive indices for shrimp abundance since a large number of early juveniles is associated with a large number of late juveniles (Table 1). This same relationship holds between late juvenile and adult shrimp.

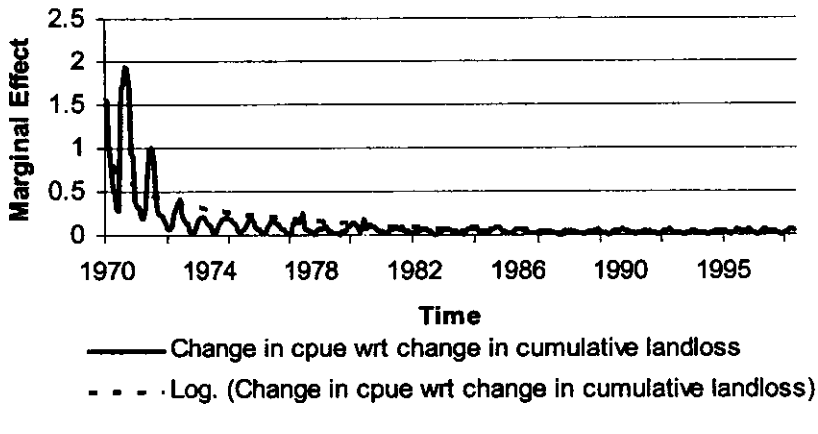

Figure 1. Impacts of cumulative wetland loss on catch per unit of effort (CPUE)

CONCLUSIONS

The goal of this paper was to develop a predictive model for white shrimp abundance based on environmental and biological factors using a recursive three-equation model. This strategy allowed the examination of full impacts of environment or biological shocks on various life stages. Overall results linked positively temperature and salinity with abundance of shrimp at its early life stages. Wetland loss over time and higher river discharge seem to lessen the abundance of shrimp. Biological factors such as the higher abundance of early juveniles predict well the late juveniles, *ceteris paribus* and similar relationship exits between the late juveniles and the CPUE.

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