Marine Resource Economics, Volume 16, pp. 51–63
Printed in the U.S.A. All rights reserved
0738-1360/00 $3.00 + .00

Alternative Cycling Strategies for Shrimp Farming in Arid Zones of Mexico: Dealing with Risk and Uncertainty

J. ANTONIO MARTINEZ
Centro de Investigaciones Biologicas del Noroeste

J. CARLOS SEIJO
Centro de Investigacion y Estudios Avanzados del Instituto Politecnico Nacional

Abstract *Northwest Mexican coastal waters have large seasonal temperature variations, high salinity, and are subject to intense solar radiation. Shrimp farms in this region have been using two annual production strategies; six- to eight-month cycle with one complete harvest and several partial harvests, or two, three- to four-month cycles with complete harvests. The preferred strategy depends on two uncertain variables; shrimp growth, which varies across the region, and market price, which varies across the season. A bioeconomic model was used to compare the economic yield of the two cycling strategies for three zones across the region, under three alternative average annual temperatures states. Simple decision theory criteria are used to show that the two-cycle strategy dominates the one-cycle strategy in the Bahia de La Paz zone. Results for central and northern Sonora are conditional on temperature.*

Key words Cycling strategy in Mexican arid zones, shrimp aquaculture.

Introduction

The problem of cycling strategy evaluation and optimization in shrimp aquaculture has usually been approached from the vantage points of economics and biology, pointing to market price and shrimp growth uncertainties (Hatch and Feng 1997). Environmental variables, such as water temperature, introduce uncertainty in biological variables, growth, and feed consumption. Dynamic bioeconomic modeling of shrimp aquaculture as a method to relate biological, environmental, and economic variables can be a useful tool when uncertainty of environmental variables introduces an important risk in the biological yields (biomass and shrimp size). In turn, these uncertain biological yields are crucial for farmers (Martinez, Seijo, and Juarez 1994) to decide upon a cycling strategy at a specific site or zone.

An appropriate cycling strategy in shrimp farming is one of the key manage-

---

J. Antonio Martinez is in the Programa de Posgrado, Centro de Investigaciones Biologicas del Noroeste S.C., A.P. 128, La Paz 23000 B.C.S., Mexico, email: amartin@cobnor.mx. J. Carlos Seijo is a professor in the Departamento de Recursos del Mar, Centro de Investigacion y Estudios Avanzados del Instituto Politecnico Nacional in Merida. A.P. 73 Cordemex Merida 97310 Yucatan, Mexico, email: jseijo@cemaes.marista.edu.mx.
We thank CONACYT for the financing, F. Magallon, G. Portillo, and Sergio Hernandez (CIBNOR) for the main biological and water temperature information and for their observations. We also thank Dr. Ellis Glazier for editing the English.

ment aspects to optimize biological and economic yield simultaneously and, therefore, to rationalize the use of the natural and economic resources involved. Shrimp farming uses important natural resources: coastal land, seawater, and aquatic biota for feeding and oxygen production in ponds. These resources need to be used as efficiently as possible because shrimp farming produces land and water pollution, which may affect other shrimp farms and activities, such as commercial and sport fishing and touristic activities. Other social implications arise when we know that these resources have alternative uses. For example, the coastal land could be used for residential or tourist activities. The healthy development of shrimp farming can produce important positive externalities, such as the spread of technological skills in workers, which could be an important factor for development of other marine species aquaculture.

Northwest Mexico is the main producing region of cultured shrimp in the country. In this region, there are two large, distinctive natural subregions. The first, in the south, is semitropical and is formed by the state of Sinaloa and the northern part of Nayarit (Saenz and Magallon 1989). This subregion accounts for 77% of national cultured shrimp production (SMARNAP-BANCOMEXT 1995). In this region, water temperature allows two or three annual production cycles. The second subregion, in the north, is arid and formed by the rim of the Gulf of California along the state of Sonora and the east coast of the Baja California Peninsula. This subregion accounts for about 17% of national production (SMARNAP-BANCOMEXT 1995).

The arid subregion is the largest, but as a transition zone between warm and cold waters, it has large seasonal variations of water temperature. In winter, the surface marine water temperature is between 16˚C and 20˚C, which is too cold for shrimp culture. Beginning in March-April, the water temperature is suitable for shrimp culture, because it rises from around 20˚C to a maximum of 30˚C in August-September. Another common characteristic in this arid subregion is the highly saline marine water. This is due to the small amount of fresh water discharge from rain and rivers and the high evaporation rate.

In this arid region, two common cycling strategies are used for farming of *Penaeus vannamei*, or white Pacific shrimp (CIBNOR-BANCOMEXT 1998). The first strategy (D_1) is to have two culture cycles at a density of around 20 postlarvae (PL) per m^2. One cycle is in spring-summer; the other in summer-autumn. The first harvest is in June-July, when the shrimp fishing period is still closed. Therefore, the shrimp supply comes solely from aquaculture. Aquaculture supply during this period is comprised primarily of small- and medium-sized shrimp (around 14g). The second harvest is in November-December, and the biological yield is better because larger shrimp are obtained (around 18g), but the supply from aquaculture must compete with the fishery, and the price can be lower.

The second cycling strategy (D_2) has one long cycle per year and from one to three partial harvests. The partial harvests have two purposes. The main one is to reduce the biological risks that are the result of pond overcrowding. Epidemics and stress from lack of oxygen can increase mortality and slow shrimp growth. The second purpose of partial harvests is to improve the farm cash flow by means of the revenue received from the sale of these harvests. The number and time of partial harvests depends mainly on how much biomass the pond can support. Experience dictates that for semi-intensive culture, the safe level of maximum biomass per ha is between 1,500 and 2,000 kg, and for semi-intensive-intensive culture it is 2,500–3,500 kg . Once these biomass levels are reached, farmers make a partial harvest of 200–500 kg/ha. A partial harvest also slightly improves the survival rate. In the D_2 strategy, seeding density is around 35 PL/m^2. The culture cycle begins in April-May and is finished in September-November, when medium- to large-sized shrimp (18–22g) are harvested. Because of larger sizes, shrimp prices are higher than those for the two-cycle strategy.

The main objective of this work is to compare the economic yield of the two cycling strategies in three zones of the arid region of northwest Mexico with different seawater temperature regimes. To relate the biological and the economic yields, a bioeconomic model was built. The biological yield depends on shrimp growth, which is heavily dependent on water temperature. Using a 17-year sea surface temperature series for each of the three zones, a probabilistic approach was used to estimate the biological yield, which permitted a probabilistic and comparative analysis of economic yield of the two cycling strategies for each of the three chosen zones.

Materials and Methods

Data

Input prices were obtained from suppliers and are in real mid-1998 US dollars. Head-on, pond-side shrimp prices for the same period came from Ocean Garden Products, Inc. (1998) and farmers. To fit the shrimp growth function, data from 1996 and 1997 culture cycles of the Northwest Center for Biological Research semi-experimental farm were used (CIBNOR 1997, 1998). The farm is located in Bahia de La Paz in the Baja California Peninsula. Data to estimate a weekly mortality rate distribution were obtained from a CIBNOR-BANCOMEXT survey of 27 farms (1998) and from a farm in central Sonora State.

Description of the Bioeconomic Model and the Decision Analysis Approach

The ultimate outcome of the bioeconomic model is the quasi-rent of the variable cost per ha and per week before taxes, and does not include financing, fixed costs, and depreciation. The probabilistic mean of the quasi-rent is the decision variable in choosing a cycling strategy. Through a biological submodel, this variable relies heavily on seawater temperature (see table 1) and a probabilistic shrimp mortality rate (see table 2). The decision analysis approach is Bayesian and was used in the aquaculture field by Martinez, Seijo, and Juarez (1996) and described by Seijo, Defeo, and Salas (1998) for use in fisheries. This approach deals with risk and uncertainty by means of building a decision table with probabilistic scenarios as columns (seawater temperatures states in our case, see table 1), and the decision options as rows (see table 3). A conditional loss table is then calculated by subtracting the highest outcome in a column (quasi-rent) from all the outcomes in the column (see table 4). The expected conditional loss by row (by cycling strategy) is calculated adding the products of each conditional loss times the probability of the corresponding scenario. The Bayesian rule recommends choosing the cycling strategy with minimum expected conditional loss.

It is assumed that operating costs correspond to a semi-intensive farm. The model includes three submodels: biological, economic, and pumping (see equations in appendix). The time unit is one week. The submodels are estimated using Excel 7.0 (Microsoft Corporation 1995) in conjunction with risk-analysis software (Decisioneering Inc. 1996).

Biological Submodel

In the biological submodel, biomass depends on shrimp weight and mortality. The weekly shrimp-growth function was estimated using Statistica 4.3 (StatSoft Inc.

Table 1
Temperature States and Probabilities of Occurrence

	Temperature States or States of Nature		
	Cold (S_1)	Average (S_2)	Warm (S_3)
Bahia de La Paz			
Annual Mean (°C)	23.5	24.3	25.3
Probability	0.31	0.56	0.13
Central Sonora			
Annual Mean (°C)	21.1	23.4	24.3
Probability	0.06	0.18	0.76
Northern Sonora			
Annual Mean (°C)	18.9	22.5	23.1
Probability	0.06	0.82	0.12

Table 2
Mortality Rate/Week Distribution

Mortality Rate	Range			Probability
Class	From	to	Midpoint	(P)
Low	0.9%	2.7%	1.8%	0.14%
Medium	2.7%	4.5%	3.6%	0.70%
High	4.5%	5.5%	5.0%	0.16%

1993). The adopted shrimp-growth function is a Von Bertalanffy equation [see appendix, equations (1) and (2)] recommended by Tian, Leung, and Hochman (1993) for *P. vannamei* and fitted with three independent variables: sea surface temperature, seeding density, and time. The growth equation includes temperature, shrimp weight in the prior week, and time as independent variables. Seeding density is fixed at 18 PL/m^2 for each of the two-cycle strategies, and at 36 PL/m^2 for the one-cycle strategy. In both strategies, the same quantity of postlarvae is cultured in a year. In northwest Mexico, when two cycles are used, the growth rate is higher (due to higher water temperatures) in the second cycle (August-November) than the first (April-July), about 1.2g vs. 0.9g/week, with a final weight of around 14g vs. 18g.

To compare economic yield from the two cycling strategies in the arid region of northwest Mexico, three coastal zones with different water temperatures were chosen. The coordinates and names of the zones as follows:

	Latitude	Longitude
Puerto Peñasco (north Sonora)	31˚18’– 31˚20’	113˚31’– 113˚30’
Estero El Rancho (central Sonora)	27˚55’– 27˚56’	110˚07’– 110˚08’
Bahia de La Paz	24˚20’– 24˚50’	110˚15’– 110˚45’

Table 3
Quasi-rent ($US) of Variable Costs/ha Per Cycling Strategy

	Temperature State or State of Nature				
	Cold (S_1)	Average (S_2)	Warm (S_3)	Expected	
p =	0.31	0.56	0.13	Value	Std. Dev.
Bahia de La Paz					
Double cycle (D_1)	6,292	11,761	15,933	10,573	1,639
Single cycle (D_2)	4,287	10,441	14,920	9,078	1,834
Central Sonora					
Double cycle (D_1)	5,399	13,179	15,131	14,214	891
Single cycle (D_2)	4,405	12,862	16,770	15,353	1,335
Northern Sonora					
Double cycle (D_1)	4,997	12,815	15,119	12,626	558
Single cycle (D_2)	4,982	14,380	17,508	14,195	685

Table 4
Conditional Losses ($US)/ha Per Cycling Strategy

	Temperature State or State of Nature			Expected
	Cold (S_1)	Average (S_2)	Warm (S_3)	Value
Bahia de La Paz				
Double cycle (D_1)	0	0	0	0
Single cycle (D_2)	2,005	1,320	1,013	1,496
Central Sonora				
Double cycle (D_1)	0	0	1,639	1,253
Single cycle (D_2)	994	317	0	144
Northern Sonora				
Double cycle (D_1)	0	1,565	2,389	1,570
Single cycle (D_2)	15	0	0	1

Bayesian decision criterion: Select the cycling strategy which provides the minimum expected value of conditional loss: Bahia de La Paz, D_1; Central Sonora, D_2; Northern Sonora, D_2.

Monthly data of sea surface temperatures of the three coastal zones came from IGOSS (1999). Seventeen years (1982–98) of monthly surface water temperature data were used for each zone to classify the years into the categories of cold (S_1), average (S_2), and warm (S_3). These categories were defined using average, annual temperature and were considered as temperature states, or formally, states of nature (S_i), in the framework of a decision theory approach (Martinez, Seijo, and Juarez 1996; Seijo, Defeo, and Salas 1998). These states of nature are defined in table 1. Probabilities of occurrence of these alternative states of nature were estimated using a probability distribution of sea surface temperature. Weekly temperature was estimated for a typical year for each of the categories based on the method of moving averages. This temperature relationship was used in the biological submodel for the two cycling strategies to estimate shrimp weight for each zone and state of nature.

To estimate biomass, a constant mortality rate per week is estimated by equation 3 (see appendix), which solves for the mortality rate from the Beverton-Holt population function [see appendix, equation (4)]. To estimate the constant mortality rate, data for initial and final populations were obtained from 21 farms in northwest Mexico (CIBNOR-BANCOMEXT 1998). A probability distribution was then estimated for mortality-rate data (see table 2) using the Monte Carlo method with 2,000 iterations (Decisioneering Inc. 1996).

In the second cycling strategy, two partial harvests are used, under the practical criterion to harvest 200–500 kg/ha (380 kg in the model) each time the biomass/ha reaches the limits (1,500–2,000 kg/ha). In both cycling strategies, the decision of when to make the final harvests is determined by the optimum harvest week, when the quasi-rent of variable costs is at a maximum. In the same way, partial harvests occur (between the limits of biomass/ha) when the quasi-rent is at a maximum.

Economic Submodel

For each zone, deterministic and probabilistic quasi-rents of the variable costs per ha per week were estimated for each of the three states of nature and the two cycling strategies in order to compare economic yield (see table 3). The quasi-rent of the variable costs is defined as the difference between revenue and the variable costs [see appendix, equation (17)]. Variable costs include feed, pumping, labor, and 10% for contingencies.

The quantity of shrimp feed per ha/week for each of the cycling strategies is calculated in the biological submodel by an estimated logistic in which biomass is the explanatory variable function [see appendix, equation (6)]. Using the Statistica 4.3 package (StatSoft Inc. 1993), we fitted the function with data from the CIBNOR semi-experimental farm culture cycles in 1996 and 1997 (CIBNOR 1997, 1998). This function permits estimation of dynamic feed conversion rate (FCR) in the biological submodel by means of equation (11) (see appendix).

Pumping Submodel

The pumping submodel estimates the hours of pumping per week/ha when using a one-meter deep pond [see appendix, equation (19)]. Two $2m^3$/sec pumps of 250 hp are commonly used for an 82-pond surface farm (100 ha total surface farm), each pump with a consumption of 186 kWh/h (CIBNOR-BANCOMEXT 1998). Ponds are filled the week before seeding. In weeks 0 and 1, there is no pumping. In weeks 2 and 3, there is a 1% water pumping to replace evaporation loss (Martinez, Villarreal, and Porchas 1995). From week 4 to harvest, pumping increases from 5% to 15%. A pump efficiency rate of 75% is used. The submodel estimates the pumping cost/ week [see appendix, equation (20)] and the cumulative pumping cost in any week [see appendix, equation (23)].

The results from the three submodels allow us to identify the optimum cycle harvest week in which quasi-rent for variable costs per ha is at a maximum. This variable is then used in the probabilistic decision-theory framework (Bayesian criterion), and risk analysis is used to compare the two cycling strategies for each zone. To create the decision table for each zone, the probability mean for the quasi-rent was obtained per strategy and state of nature. This probability mean was obtained by introducing uncertainty into the model in the form of normal probability distributions for shrimp prices and mortality rates. The normal distribution was chosen because empirical data for both variables from a 27-farm survey (CIBNOR-BANCOMEXT 1998) resembles that kind of distribution. Mortality rate and market price were considered the most important risk variables beside shrimp growth, and their probability values were generated with the Monte Carlo method using 2,000 iterations (Decisioneering Inc. 1996).

Results and Discussion

The decision tables show that under the Bayesian probabilistic rule, the two annual culture cycles (D_1) are clearly a better option in the southern zone (Bahia de La Paz, table 4), where the expected conditional loss of adopting such cycling strategy is zero against US$1,496/ha for D_2. The one-culture annual cycle with two partial harvests (D_2) with expected conditional loss of US$114/ha is a better cycling strategy option than D_1 in the central zone (loss of US$1,253/ha, see table 4). In a more conclusive way, D_2 is also a better option than D_1 in the northern zone (US$1/ha vs. US$1,570/ha, see table 4). The results suggest that the one annual culture cycle strategy is more attractive as we go from the southern to northern areas of the region.

In addition to Bayesian analysis, risk was also estimated without mathematical probabilities for states of nature. By using the maximin, minimax, and maximax criteria (Schmid 1989; FAO 1995), different degrees of management caution can be represented (Francis 1992; Cordue and Francis 1994). Maximin is a risk-averse approach that leads the decisionmaker, the farmer, to choose the cycling strategy that involves the maximum value of the observed minimum quasi-rents (see table 3). The minimax conditional loss criterion is a less cautious approach that leads the decisionmaker to chose the option (cycling strategy) that minimizes the maximum conditional loss (see table 4). The maximax criterion is used by an optimistic and risk-prone decisionmaker by choosing the option that contains the highest value of all outcomes (see table 3) (Defeo and Seijo 1999). For comparison, the main results of the Bayesian, minimax, maximin, and maximax criteria are given below:

	Best Cycling Strategy			
	Bayesian	Maximin	Minimax	Maximax
Bahia de La Paz	D_1	D_1	D_1	D_1
Central Sonora	D_2	D_1	D_1	D_2
Northern Sonora	D_2	D_1	D_2	D_2

With and without mathematical probabilities, D_1 is the best cycling strategy for Bahia de La Paz, because the Bayesian rule agrees with maximin, minimax, and maximax criteria. For the central Sonora zone, only the risk-prone criterion maximax agrees with the Bayesian criterion that D_2 is the best option. The Bayesian rule can be a way to show that the risk involved in the maximax risk-prone decision rule is a reasonable one when cycling strategy D_2 is chosen. The same can be said for the northern Sonora zone, where the Bayesian analysis can show that the risk involved in preferring D_2 (under minimax and maximax rule) can be reasonable. Bayesian analysis suggests that minimax criterion could be too cautious for the farmers of this latter zone when D_1 is considered the best option.

In cycling strategy D_1, the price for the first harvest may be higher than normal because shrimp supply from aquaculture enters the market during the off-season. Therefore, farms do not compete with supply from the fisheries. If this situation is simulated introducing a premium for the price of the first harvest in D_1 for the central and northern Sonora zones, sensitivity analysis shows that the D_2 strategy should be abandoned. The price premium for the first harvest must be higher than 15% in the northern Sonora zone and higher than 9% in the central Sonora zone. These percentages represent the increase in price which makes the quasi-rent equal for both strategies in each of the two zones. They were obtained by the trial and error method, which involves equations (12), (13), and (17) of the economic submodel (see appendix).

Concluding Remarks

Both the probabilistic (Bayesian) and the non-probabilistic analyses tend to indicate that D_1 is a better cycling strategy for the Bahia de La Paz area, whereas D_2 is a better option in the central and northern Sonora zones. This general conclusion corroborates the impression that in the arid zone of northwest Mexico, as we move from south to north, or from warm to cooler waters, the two annual shrimp culture cycle strategy (D_1) is less attractive and the one annual cycle with partial harvests (D_2) becomes a better option, if we use the water temperature regime as the unique environmental determinant for shrimp growth and assume pond-side price stability. When a price premium for the first harvest (when farmed shrimp do not compete with the fishery) is introduced for the two-cycle strategy, the Bayesian rationale suggests that farms in the northern and central Sonora zones should shift from the one-cycle to the two-cycle strategy when the increase in price is higher than 15% for northern Sonora and 9% for central Sonora.

The rationality of this general proposal seems to match the empirical experience and practice of the region's farmers. This work was started because of the interest expressed by farmers (by personal communication and workshops) when the cycling strategy issue arose, and because of the questions which arose during more than 10 years of experience of the semi-experimental farm at The Centro de Investigaciones Biológicas del Noroeste (CIBNOR). Particularly, farmers from the arid zone of the Mexican northwest coastal region reported that in some years they decided upon a preferred cycling strategy, but during the year this was changed because of unexpected variations (*i.e.*, shrimp growth and market price). After a trial and error method, some farmers reported they simply changed the cycling strategy from one year the next. Currently, research that involves cycling strategy is being conducted for the entire Mexican northwest coastal region. This work is an important contribution because it provides us with a methodology to explain the cycling strategies. A more detailed study that includes more zones of the region could be a useful tool for regional management of shrimp farming to help assure continuous supply.

Even though the analysis suggests that for the Bahia de La Paz zone the two-culture cycle strategy is clearly the best option, we are not taking into account commercial practices such as pre-cycle sale contracts with predetermined price and shrimp size. This commercial practice has the advantage of decreasing price uncertainty, and it seems to be more common for large shrimp sizes, which are more suited for export and are harvested in the annual, one-cycle strategy.

As far as we know, there are no pond-side, price-time series available in Mexico; therefore, we cannot make an empirical probability distribution to estimate price uncertainty per size and season. Farmers agree that price uncertainty is important and that prices can be higher when it is off-season for fishing. When environmental factors, such as seawater temperature, are considered, a 17-year time-series cannot be long enough to build a reliable probability distribution. Fortunately, cumulative homogeneous satellite-based data (like the data we used) will provide longer and more reliable series to build more solid distributions. Longer time series and higher-quality data are rapidly improving studies about the time patterns of oceanographic phenomena related to sea temperature as ENSO (the warming-cooling cycle "El Niño"- La Niña") and global warming. The study presented here has potential to be used for the prediction of biological and economic yield of shrimp farming in specific zones.

References

CIBNOR (in Spanish). 1997. 1996 Shrimp Culture Cycles of CIBNOR Farm Report. Unpublished report. La Paz, Mexico.

___. 1998. 1997 Shrimp Culture Cycles of CIBNOR Farm Report. Unpublished Report. La Paz, Mexico.

CIBNOR-BANCOMEXT (in Spanish). 1998. A 27 Shrimp Farm Survey in Sinaloa State. Unpublished Report. La Paz, Mexico.

Cordue, P.L., and R.I.C.C. Francis. 1994. Accuracy and Choice in Risk Estimation for Fisheries Assessment. *Canadian Journal Fisheries Aquatic Science* 51:817–29.

Decisioneering Inc. 1996. Crystal Ball Risk Analysis Package.

Defeo, O., and J.C. Seijo. 1999. Yield-mortality Models: A Precautionary Bioeconomic Approach. *Fisheries Research* 40:7–16.

Fisheries and Agriculture Organization (FAO). 1995. Precautionary Approach to Fisheries. Part 1: Guidelines on the Precautionary Approach to Capture Fisheries and Species Introductions. Technical Consultation on the Precautionary Approach to Capture Fisheries (Including Species Introduction). Lysekil, Sweden, 6–13, June. FAO Fish. Tech. Pap. No. 350, Part 1, 52 pp. Rome: FAO.

Francis, R.I.I.C. 1992. Use of Risk Analysis to Assess Fishery Management Strategies: A Case Study Using Orange Roughy (*Hoplostethus atlanticus*) on the Chatham Rise, New Zealand. *Canadian Fisheries Aquatic Science* 49:922–30.

Hatch, U., and C. Feng Tai. 1997. A Survey of Aquaculture Production Economics and Management. *Aquaculture Economics and Management* 1(1):13–27.

IGOSS. 1999. Sea Surface Temperature Data. http://ingrid.Ldgo.columbia.edu/SOURCES/.IGOSS/nmc/monthly/.sst/T + 457.5000/VALUE/10/30/98.

Martinez-Cordero, F.J, J.C. Seijo, and L. Juarez. 1994. The Bioeconomic Analysis of a *Penaeus vannamei* Hatchery in Mexico, Applying Time Distributed Delay Functions. Proceedings of the 7th Meeting of the International Institute of Fisheries, Economics and Trade (IIFET), Vol (2):115–26. Taipei, Taiwan.

___. 1996. Incorporating Risk and Uncertainty in the Feasibility Analysis of Aquacultural Projects by Means of Decision Theory. 8th Meeting of the International Institute of Fisheries, Economics and Trade (IIFET). Casablanca, Morocco.

Martinez-Cordoba, L.R., L. Villarreal, and M.A. Porchas. 1995. Culture of White Shrimp *Penaeus vannamei* in Reduced Water Exchange Ponds in Sonora Mexico. *World Aquaculture* 26(4):47–8.

Microsoft Corporation. 1995. Excel Spreadsheet Program, v. 7.0.

Ocean Garden Products, Inc. 1998. Comportamiento del Mercado de Camaron. Various issues.

Saenz, P.G., and F. Magallon (in Spanish). 1989. Analysis of Shrimp Farming Possibilities in the Mexican Pacific Rim. Instituto Nacional de la Pesca, Serie Documentos de Trabajo, Año 1, No. 7, 25 pp., September. Mexico City, Mexico.

Schmid, A.A. 1989. *Benefit-Cost Analysis: A Political Economy Approach*. 354 pp. Boulder: Westview Press.

Seijo, J.C., O. Defeo, and S. Salas. 1998. *Fisheries Bioeconomics: Theory, Modeling and Management*. FAO Fisheries Technical Paper 368:176 pp. Rome.

SMARNAP-BANCOMEXT (in Spanish). 1995. Business Opportunity: Shrimp *Penaeus vannamei*, Shrimp 100 Hectare Farm. National International Trade Bank. Mexico City, Mexico.

StatSoft, Inc. 1993. Statistica 4.3 Software Package.

Tian, X., P. Leung, and E. Hochman. 1993. Shrimp Growth Functions and Their Economic Implications. *Aquacultural Engineering* 12:81–96.

Appendix

Biological Submodel Equations

Equations of Shrimp Mortality and Growth

$$W_t = W_\infty\left[1 - e^{-(c+bT_t+dW_{t-1})(ta-t_o)}\right]^3 \quad (1)$$

$$W_t = 23.3\left[1 - e^{-(0.01626+0.0004*T_t+0.0026*W_{t-1})*(ta-(-17.6)}\right]^3 \quad (2)$$

$$P = (0.00)\ (0.73)\ (0.81)\ (0.0003)\ (0.0041)$$

Regression coefficient, $R = 0.98$

$$M = \left[\ln(No) - \ln(N_t)\right]/tp \quad (3)$$

where:

W_t = shrimp weight at week t (g)
W_∞ = shrimp asymptotic weight (g), [S_1, 20], [S_2, 23], [S_3, 24]
B. de La Paz, annual average temperature (˚C); S_1 = 23.5, S_2 = 24.3, S_3 = 25.3
Central Sonora, annual average temperature (˚C); S_1 = 21.1, S_2 = 23.4, S_3 = 24.3
North Sonora, annual average temperature (˚C); S_1 = 18.9, S_2 = 22.5, S_3 = 23.1
T_t = Seawater temperature average at week t
W_{t-1} = shrimp weight in previous week (g)
ta = shrimp age (weeks)
t_0 = theoretical age at which $W = 0$
P = value or significance level for the estimated coefficients
R = regression coefficient c, b, and d are constants.
M = constant weekly mortality rate
N_o = shrimp initial population (organisms)
N_t = shrimp population at week t (organisms)
tp = weeks in pond

Biomass and Feed Equations per ha/week

$$N_t = N_0 e^{-Mt} \tag{4}$$

$$B_t = N_t(W_t) \tag{5}$$

$$Qf_{t,d} = Q_{\infty,d}\left[1 - e^{(-0.00153)B_{t,d}}\right] \tag{6}$$

where seeding density = d[18,36]

$$Qfcum_{t,d} = \sum_{t=0}^{t} Qf_{t,d} \tag{7}$$

$$QfC_{t,d} = Qf_{t,d}Pfd \tag{8}$$

$$QfCD_{t,d} = QfC_{t,d}/(1 + dw)^t \tag{9}$$

$$QfCDcum_{t,d} = \sum_{t=0}^{t} QfCD_{t,d} \tag{10}$$

$$FCR_{t,d} = Qfcum_{t,d}/B_{t,d} - B_{0,d} \tag{11}$$

where:

N_t = shrimp population at week t (organisms)
N_0 = shrimp initial population (organisms)
M = constant mortality rate/week
B_t = biomass at week t for seeding density d (kg)
$B_{0,d}$ = biomass at week 0 for seeding density d (kg)
$Qf_{t,d}$ = quantity of feed at week t for seeding density d (kg)
$Q_{\infty,d}$ = maximum observed quantity of feed/week in one ha pond for seeding density d
$Qfcum_{t,d}$ = cumulative quantity of feed from week 0 to week t (kg) for seeding density d
$QfC_{t,d}$ = cost of feed at week t for seeding density d (US$/ha)
Pfd = feed price (US$/kg)
$QfCD_{t,d}$ = discounted feed cost at week t for seeding density d (US$/ha)
dw = discount rate per week
$QfCDcum_{t,d}$ = cumulative discounted feed cost from week 0 to week t (US$/ha) for seeding density d
$FCR_{t,d}$ = feed conversion rate at week t for seeding density d (kg of feed/kg of shrimp)

Economic Submodel Equations

$$VB_t = B_t \Pr Shmp_t \tag{12}$$

$$VBD_t = VB_t/(1 + dw)^t \tag{13}$$

$$OC_t = Cpc + Fcum_t + Pucum_t + Lcum_t + Cgcum_t \tag{14}$$

$$OCD_t = OC_t/(1 + dw)^t \tag{15}$$

$$OCDcum_t = \sum_{t=0}^{t} OCD_t \tag{16}$$

$$NDY_t = VBD_t - OCDcum_t \tag{17}$$

where:

VB_t	= biomass value at week *t* (US$)
B_t	= shrimp biomass at week *t*
$PrShmp_t$	= shrimp price at week *t*
VBD_t	= discounted biomass value at week *t*
dw	= discount rate/week
OC_t	= operating cost at week *t* (kg)
Cpc	= cycle seed cost (US$)
$Fcum_t$	= cumulative fertilizer cost at week *t* (US$)
$Pucum_t$	= cumulative pumping cost at week *t* (US$) [see equation (23)]
$Cgcum_t$	= cumulative contingency cost at week *t* (US$)
$Lcum_t$	= cumulative labor cost at week *t* (US$)
OCD_t	= discounted operating cost at week *t* (US$)
$OCDcum_t$	= cumulative discounted operating cost from week 1 to week *t* (US$)
NDY_t	= discounted net income at week *t*, or quasi-rent at week *t* per ha (US$)

Pumping Submodel Equations (Water Exchange/ha)

$$P_t = FV * ER_t \tag{18}$$

$$PhW_t = Ef * FV * P_t \tag{19}$$

$$Pu_t = En * PhW_t * PkWh \tag{20}$$

$$Phcum_t = \sum_{t=0}^{t} PhW_t \tag{21}$$

$$kWhcum_t = En * Phcum_t \tag{22}$$

$$Pucum_t = PkWh * kWhcum_t \tag{23}$$

where:

P_t = pumped water per day at time t (m^3/ha)
FV = full capacity volume of water in 1 ha at 1 m deep (m^3/ha)
ER_t = pumping rate per day at time t (%/day)
Ph_t = hours of pumping per day at time t (hours/day/ha)
Ef = pump efficiency rate
PhW_t = hours of pumping per week at time t (hours/week/ha)
Pu_t = pumping cost per week at time t (US$/week/ha)
En = kWh per hour of pump operation (kWh/hour)
$PkWh$ = kWh price (US$/kWh)
$Phcum_t$ = cumulative pumping hours at time t (hours/ha)
$kWhcum_t$ = cumulative kWh for pumping at time t (kWh/ha)
$Pucum_t$ = cumulative pumping cost at week t (US$/ha)