Identifying Risk Factors Affecting Weather- and Disease-Related Losses in the U.S. Farm-Raised Catfish Industry

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Two double-limit tobit models are used to identify significant risk factors that most affect farm-raised catfish losses from weather-related events and from disease outbreaks. Results of the weather loss model indicate that the variables for operator education level, number of ponds, pond water depth, production management strategy, past experience with severe losses from low oxygen levels from off-farm power outages, past experience with severe losses from diseases, and being in the South are statistically significant. Results of the disease loss model indicate that the variables for operator experience and pond water depth are significant. Development of models explaining weather and disease losses through observable variables provides a better understanding of the interrelation between the loss perils and explanatory variables so management strategies can be developed to mitigate losses from identified risk factors.

Key Words: aquaculture, tobit, risk management, columnaris, enteric septicemia of catfish, weather losses

Aquaculture represents a growing sector of U.S. agriculture and the National Fisheries Institute has placed U.S. farm-raised catfish sixth on its list of Americans' most preferred fish and seafood products. Americans consumed 0.97 pounds of catfish per capita in 2006 (National Fisheries Institute 2007). The farm-raised catfish industry is the largest aquaculture industry in the United States, with 565 million pounds being processed in 2006, with a farm-gate value of $452 million (NASS 2007a). This quantity of fish was produced in 167,000 water acres located in 31 states, with 95 percent of the acreage being located in four states: Mississippi (58 percent), Arkansas (19 percent), Alabama (14 percent), and Louisiana (4 percent). Mississippi produced 313 million pounds ($241 million farm-gate value), Arkansas produced 99 million pounds ($75 million), Alabama produced 131 million pounds ($98 million), and Louisiana produced 16 million pounds ($13 million) (NASS 2007b).

Of the approximate 1,000 catfish farms in the United States, 35 percent of all operations are located in Mississippi, 17 percent in Alabama, 13 percent in Arkansas, and the remaining 35 percent distributed among 28 additional states (NASS 2006). In 2006, the average annual catfish production per operation, operation size, production, and operational sales for the four leading catfish-producing states, respectively, were the following: Mississippi—803,000 pounds, 198 acres, 4,053 lb/acre, and $618,000; Alabama—675,000 pounds, 111 acres, 6,083 lb/acre, and $506,000; Arkansas—751,515 pounds, 208 acres, 3,613 lb/acre, and $570,000; and Louisiana—561,000 pounds, 196 acres, 2,860 lb/acre, and $449,000. Direct sales to processors accounted for 98 per-

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This paper was presented as a selected paper at the Crop Insurance and Risk Management Workshop, sponsored jointly by the Northeastern Agricultural and Resource Economics Association, the Risk Management Agency, the Farm Foundation, the Food Policy Institute at Rutgers University, and Cornell University, in Rehoboth Beach, Delaware, on June 12–13, 2007. The workshop received financial support from the Northeast Regional Center for Rural Development. The views expressed in this paper are the authors' and do not necessarily represent the policies or views of the sponsoring agencies.

The authors thank two anonymous reviewers for providing many helpful comments.

cent of total sales of foodsize catfish produced in the United States (NASS 2006).

From the catfish industry perspective, risk management is critical to profitability and survival. Few risk management tools are available to U.S. aquaculture producers. In 2001, the Risk Management Agency (RMA) of the U.S. Department of Agriculture entered into a partnership with Mississippi State University's Department of Agricultural Economics to create the National Risk Management Feasibility Program for Aquaculture (NRMFPA). Their goals were not only to investigate the feasibility of developing insurance policies for numerous aquaculture species, but also to investigate development of other non-insurance risk management tools for producers (Miller et al. 2002). The work presented here focuses on the identification of observable risk factors that impact losses from weather events and disease outbreaks. Development of models explaining weather and disease losses through observable variables will provide a better understanding of the interrelation between the loss perils and explanatory variables so management strategies can be developed to mitigate losses from identified risk factors.

Characterization of relative risks facing agricultural operations is fundamental to accurately classifying and managing risk exposure on a farm (Coble et al. 2006, Shaik et al. 2006). Factors contributing to the riskiness of an operation need to be known so that mitigation of identified risk factors can be addressed. Tucker et al. (2004) characterized farm-raised catfish losses as being due primarily to infectious diseases, idiopathic diseases, bird predators, water quality, power outages, or floods. Infectious diseases are likely affected by intensification of the production system, experience of the manager, and overall stress of the production process on the fish being raised. Idiopathic diseases have no known etiology and thus the chance of their occurring is truly random but faced by producers. Locating farms in some rural areas is likely to result in those farms experiencing more power outages than they would in other locations, and locating farms in regions protected by river levees would mean that they would have a greater chance of being flooded than those located on higher ground.

Forster (2003) categorized risks to salmon culture in pens located in off-shore marine waters as being related to diseases and parasites, mechanical failures (in hatcheries), structural failures (in net pens), weather events, water quality and pollution, plankton blooms, predators, theft, and vandalism. For instance, locating a net pen in geographically different coves will result in differing tidal fluctuation characteristics and will likely result in a different risk level for each location. Likewise, disease potential is likely to differ in different cove areas because of the differing water quality, tides, and other factors that vary between locations.

Historical data is normally used to classify operations' risk levels, and the lack of such data has required innovative approaches to solve the risk classification issue. This paper puts forth a survey approach to obtain historical production and peril-specific loss data to determine risk factors affecting losses from the primary perils facing the farm-raised catfish industry. Study results will benefit producers, researchers, and others interested in mitigating risks of identified weather- and disease-related risk factors affecting aquaculture farm operations.

Catfish Perils

Catfish producers consider disease to be the major problem they face during production seasons (Miller et al. 2002, Tucker and Robinson 1990). Channel catfish diseases are caused by parasitic organisms that infect fish through viruses, bacteria, fungi, protozoan, and metazoans, and typically occur during the months of March to October, as seen in Figure 1. A study conducted by the USDA National Animal Health Monitoring Systems (NAHMS) of the Animal and Plant Health Inspection Service (APHIS) states that the three most prevalent diseases reported on catfish operations were enteric septicemia (ESC) (60.6 percent of operations), columnaris (COL) (50.4 percent), and saprolegnia (SAP, also known as winter fungus) (32.9 percent) (USDA 2003). This study also states that occurrences of these diseases tend to increase as operation size increases.

U.S. catfish losses due to disease outbreaks in 2002 are presented in Table 1, which reports the percentage of catfish operations having specified disease losses by severity level—i.e., light losses from a disease would be less than 200 pounds lost to the specified disease during 2002, moderate

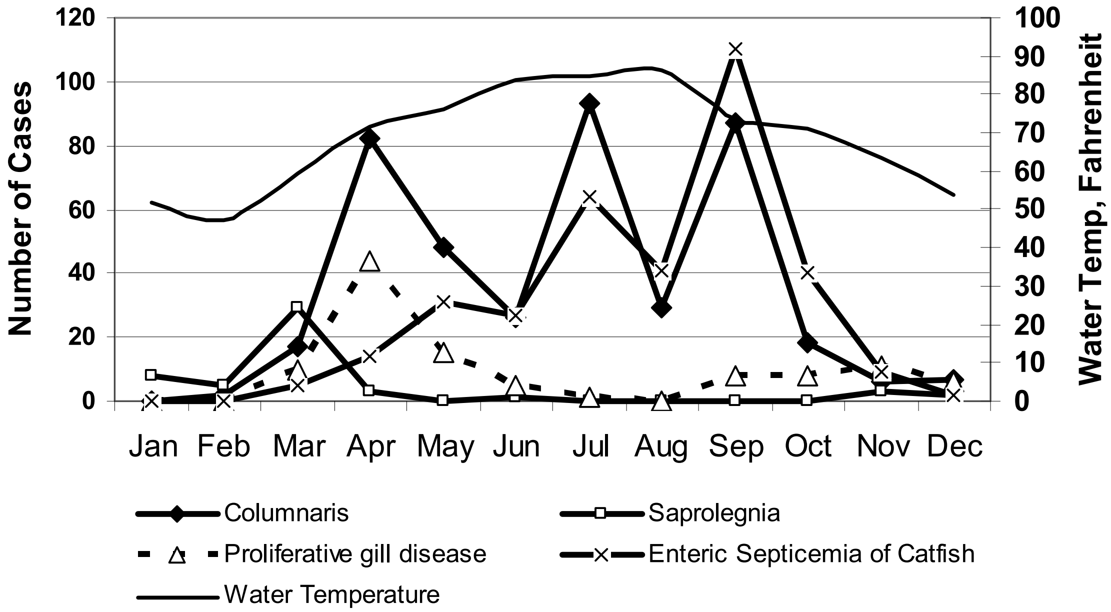

Figure 1. Seasonal Occurrence of Catfish Diseases[a]

Source: Mississippi State University (2006).

[a] As measured by the number of fish submitted and diagnosed for a specific disease by the National Warmwater Aquaculture Center in Stoneville, Mississippi, in 2006.

Table 1. Percentage of Catfish Operations Having Disease Losses Categorized as Light (< 200 pounds lost), Medium (200–2,000 pounds lost), or Severe (> 2,000 pounds lost) in 2002

	Average Loss per Outbreak (in pounds)		
Disease/Parasite Name	Light (< 200)	Moderate (200–2,000)	Severe (> than 2,000)
Enteric septicemia	50.5	39.5	10.0
Columnaris	49.0	36.5	14.5
White spot (Ich)	44.3	13.3	42.4
Proliferative gill disease	37.9	26.7	35.4
Anemia	32.3	25.9	41.8
Saprolegnia (winter fungus)	40.6	33.1	26.3
Visceral toxicosis	42.6	24.2	33.2
Trematodes	41.4	40.0	18.6
Other	22.6	41.2	36.2

Source: USDA (2003).

losses would be between 200 and 2,000 pounds lost, and severe losses would be greater than 2,000 pounds lost. For example, in 2002, 50.5 percent of all catfish operations had light (< 200 lb) losses, 39.5 percent of operations had moderate (200 to 2,000 lb) losses, and 10.0 percent of operations had severe (> 2,000 lb) losses caused by ESC. APHIS data did not indicate the frequency of these disease outbreaks nor did they provide precise measures of the magnitude of losses, especially in the severe loss case where tens of thousands of pounds of catfish could be lost but only a "> 2,000 lb" loss was recorded. At present, little research or literature exists that describes the magnitude and frequency of losses due to specified perils in aquaculture industries. One of the major contributions of the NRMFPA research has been the determination of the frequency and magnitude of fish losses for specific perils, as well as the identification of risk factors affecting these perils. Knowledge of significant risk factors based on observable farmer characteristics, production practices, physical farm characteristics, and regions of production could be useful in mitigating on-farm losses.

The National Warmwater Aquaculture Center in Stoneville, Mississippi, reports the top four catfish disease diagnoses determined by the Center during 2006 as ESC, COL, proliferative gill disease (PGD), and SAP (Mississippi State University 2006). ESC alone accounted for 10.7 percent of all submitted cases and for 56.5 percent of cases involving ESC and a second disease (up from 31.3 percent in 2005). Columnaris alone accounted for 13.7 percent of all submitted cases and for 68.4 percent of cases involving COL and a second disease (up from 49.4 percent in 2005). Proliferative gill disease accounted for 17.8 percent of cases, and SAP accounted for 8.4 percent of cases submitted. Figure 1 depicts the seasonal occurrences of these diseases.

The second-greatest loss of concern to catfish producers involves the loss of electricity, used mainly for aeration purposes (Miller et al. 2002). Aeration electricity losses can occur from accidents, power outages, and weather events. In the aftermath of Hurricanes Katrina and Rita, which affected much of the southern U.S. catfish-farming region (Alabama, Arkansas, Louisiana, and Mississippi), the topic of catfish losses due to weather-related events has gained greater attention. Catfish losses from weather-related events can include freezing of the pond, flooding, droughts, and other severe weather events such as windstorms, tornadoes, lightning, and hurricanes. Farmers cannot prevent natural weather events, but in some cases they might be able to take steps toward decreasing the impact of these events.

The research presented in this paper focuses on farm-raised catfish in a freshwater pond environment, and models identify the impacts and explanatory power of producer attributes, farm characteristics, and production region on catfish losses resulting from weather-related events and disease outbreaks. This paper's unique contributions to the literature are in the method used to obtain peril-specific aquaculture loss data, analysis of the data to identify significant risk factors that explain catfish losses, and results that allow individual farms to mitigate risks and catfish losses from disease and weather events.

U.S. Catfish Farm Survey Data

Publicly available farm-level aquaculture data are extremely sparse or non-existent. Information sources such as diagnostic labs (Mississippi State University 2006), National Agricultural Statistics Service (NASS) production data (NASS 2007a), NASS Census of Aquaculture (NASS 2006), and the National Animal Health Monitoring System (USDA 2003) surveys report summary statistics for production, acreage, and losses. Information about farm and producer risk factors is not available, but necessary in order to develop strategies to reduce losses on the farm. Faced with these challenges, the NRMFPA concluded that collecting farm-level information from a comprehensive producer survey was the most appropriate method to obtain data required to understand risk factors affecting losses and to make an estimation of frequency and magnitude of losses by specific perils.

The NRMFPA contracted with NASS headquarters to have state NASS offices survey catfish producers to obtain historical (i.e., objective) and future production/loss (i.e., subjective) information. State NASS offices have their own confidential lists of catfish producers, as they survey them on a biannual basis for the USDA Catfish Production Report (NASS 2007b). The state NASS catfish producer lists were used by the state NASS personnel to conduct the survey.

NASS conducted the Risk Management for Aquaculture Survey from July 1, 2005, through August 12, 2005, in 11 states. A total of 1,201 catfish producers within 11 states (Alabama, Arkansas, California, Florida, Georgia, Kentucky, Louisiana, Mississippi, Missouri, North Carolina, and Texas) were contacted and surveyed in person, using enumerators. If the producer met the screener question criteria, a face-to-face interview was conducted. Four hundred twenty-four producers were screened out due to discontinued use of their catfish operation or because their catfish operation was a non-profit organization (such as a research facility or for public recreation). The remaining number of producers after the screening questions was 777, with 567 completing the survey. The catfish sample is a complete enumeration of *all* catfish producers in eight of the eleven states, with a stratified random sampling taking place in the three largest production states: Mississippi, Arkansas, and Alabama.

Information was collected on farmer characteristics including the number of years the owner/manager had been producing catfish, level of education attained, age, operation ownership type, past insurance purchase, willingness to take financial risks, household income, market value of assets, and percentage of investment that is borrowed. Production practice information obtained included the production strategy in use, number of water acres used in food fish production, number of fish stocked, whether the catfish are feed fed, pounds of catfish produced, and number of employees.

Information collected on physical farm characteristics included the furthest distance between the most remote pond group from the management headquarters, shortest distance between any ponds and another catfish operation, average age of the ponds, average water depth of ponds, number of catfish ponds in an operation, frequency of reworking ponds, and the primary water source. On-farm equipment information was collected and included the number of back-up electrical generators, the amount of electrical horsepower for fixed aeration purposes, and the number of tractor-powered paddlewheels for mobile aeration purposes.

Information collected on catfish loss events included the number of times in the prior ten years the producer had incurred a loss of more than 5 percent of the expected total annual production, specific information on the three largest catfish loss events over the last ten years of operation and associated cause of loss (the specific peril), expected production during each loss year associated with the specific peril, and size of fish dying. The producer had a checklist of perils to choose from, as well as an "other" category. Future subjective loss estimates were also obtained.

Empirical Discrete Choice Tobit Model

A double-limit tobit model is used to explain the ratio of catfish losses from weather-related events and from disease outbreaks to expected production in two separate models by evaluating observable operational risk factors that include producer and farm characteristics and production practices. The ratio of catfish losses to expected production was calculated from survey responses to questions concerning the three largest historical losses a producer had experienced in the last ten years, the specific cause of loss, and the expected production during the year that losses occurred.

The dependent variable in each model was the ratio of catfish losses due to weather-related events or the amount of catfish losses from catfish diseases to the expected production during the loss years (Coble et al. 2006), and thus the values of the variable are censored and must fall between zero and one. As many perils affecting catfish production are relatively rare events, the dependent variable was expected to contain a significant fraction of observations that would be zero. Since the dependent variable is bounded between zero and one, the tobit model is used instead of the ordinary least squares (OLS) model, and the assumptions of the tobit model as stated by Greene are maintained (Greene 2003). Thus, the double-limit tobit model is appropriate for analyzing our data as the values cannot assume values above the upper limit or below the lower limit, as presented by Heckman (1979), McDonald and Moffit (1980), and Gould, Saupe, and Klemme (1989).

The double-limit tobit model is expressed as follows:

$$(1) \qquad Y_i^* = \beta' x_i + u_i$$
$$Y_i = 0 \quad \text{if} \quad Y_i^* \leq 0$$
$$Y_i = Y_i^* \quad \text{if} \quad 0 \leq Y_i^* \leq 1$$
$$Y_i = 1 \quad \text{if} \quad Y_i^* \geq 1,$$

where Y_i* represents the ratio of catfish losses resulting from disease- or weather-related events to expected production in the loss years. The effect of dependent data censoring that the tobit model addresses is that there is an observed portion of the data and a latent or unobserved portion of the data. In our case, we are creating a historical loss ratio from two variables, and all data is observable.

The log-likelihood function for the estimation of the double-limit tobit censored regression model is

$$(2)\qquad \ln L = \sum_{y=L_i} \ln \Phi\left[\frac{y_i - x_i\beta}{\sigma}\right] + \sum_{L_i<y<R_i} \ln \frac{1}{\sigma}\phi\left[\frac{y_i - x_i\beta}{\sigma}\right] + \sum_{y_i=R_i} \ln\left[1-\Phi\left(\frac{R_i - x_i\beta}{\sigma}\right)\right],$$

where L is the left (lower) and R is the right (upper) bound of the observed portion of the dependent data. The three parts of equation (2) correspond to a regression for the observed data and probabilities for the latent observations below and above the observed data (Greene 2003). The censored tobit model is a type of truncated distribution model where a part of the untruncated distribution is above or below the bounds of the observed data. In our case the untruncated portion of the dependent variable lies between zero and one.

The Statistical Analysis System's (SAS) qualitative and limited dependent variable model (proc QLIM) was used to analyze equation (2), the censored endogenous variables (*WeatherLR* and *DiseaseLR*), with a lower bound of zero and an upper bound of one. The dependent variable y_i is the ratio of catfish losses due to weather and disease occurrences to the expected production, and x_i represents a vector of risk factors that could affect this ratio of losses.

The following equation was used to estimate the risk factors' effect on the ratio of losses caused by weather and disease occurrences:

$$(3)\qquad Y_i^* = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + u_i ,$$

where x_i represents the various vectors of risk factors that could affect Y_i^*, β represents the parameters of unknown coefficients, and u_i represents the normally distributed error term with zero mean and constant variance.

The dependent variable, y_i, represents either *WeatherLR*, the ratio of catfish losses due to all weather-related events (freezing of the pond, flood, drought, windstorm, tornado, lightning, or hurricane) to the expected production during the loss years, or *DiseaseLR*, the ratio of catfish losses due to diseases [COL, ESC, channel catfish virus (CCV), PGD, "Ich" (*Ichthyophthirius* or white spot disease), and SAP] to the expected production during the loss years. For each model, the dependent variable was the summation of losses by loss categories, i.e., from itemized weather- or disease-related events stated above, from the three largest loss events from the prior ten years of production divided by the summation of the expected production during the same three loss years. This average loss was divided by the number of years in which the loss events could have occurred—that is, from the ten-year period in question—to obtain an annual loss percentage for weather- and disease-related losses, and was used in the tobit model regressions. Thus, there is one aggregated loss ratio for each observation used in the weather- and disease-loss models.

The vector x_i represents a set of explanatory variables, with education of the manager (X_1), number of ponds on an operation scaled down by dividing the actual number of ponds on the operation by ten (X_2), and pond water depth (X_3) as common explanatory variables for the *WeatherLR* and *DiseaseLR* models. The education variable is a dummy variable representing a high-school education level (= 1) or beyond this level (= 0). Added explanatory variables used in the weather loss model (*WeatherLR*) are the following: a dummy variable for the type of production system in use, where 1 equals multiple-batch production system and 0 equals single-batch production system (X_4); a dummy variable indicating whether a historical loss (within the last ten years and greater than 5 percent of on-farm inventory) from low oxygen levels due to an electrical power outage had occurred on the farm, where 1 means it had and 0(X_5) means it had not; a dummy variable indicating whether a historical COL and/or ESC disease event had occurred, where 1 means it had and 0(X_6) means it had not; and a regional dummy variable that grouped the larger catfish-producing states of Alabama, Arkansas, Louisiana, and Mississippi together (equals 1) or states outside this region [equals 0 (X_7)]. Additional continuous explanatory variables used in the disease loss model (*DiseaseLR*) are the number of years the manager has been producing catfish (X_8) and pond age (X_9).

Tobit model coefficients cannot be interpreted as traditional regression coefficients, and marginal effect interpretations for each variable are of more interest. The marginal effect of an explanatory variable is the partial derivative of the event probability with respect to a specific explanatory variable and indicates how much the event's probability changes when the specific explanatory variable changes by one unit (Greene 2003), and for the observed data can be stated as

$$(4) \qquad \frac{\partial E[y_i | x_i]}{\partial x_i} = \beta \Phi \left(\frac{\beta' x_i}{\sigma} \right).$$

However, estimation of the marginal effect for a dummy variable having a zero or one choice is different than for the continuous variable marginal effect of equation (4). Most standard procedures in econometric software packages do not distinguish between the marginal effect of a continuous variable and a dummy variable, and thus additional programming is required to obtain the latter. If the calculation of the marginal effect for a continuous variable is used for dummy variables having zero/one choices, then an erroneous marginal effect is the result (Gould, Saupe, and Klemme 1989). The determination of the dummy variable marginal effect must take into account the cumulative distribution function (cdf) of the regression divided by sigma for the dummy variable valued at zero and again for the dummy variable valued at one. Subtracting the cdf/sigma value at zero from the cdf/sigma valued at one and multiplying this difference by the initially calculated dummy variable coefficient will provide the dummy variable's marginal effect (Greene 2003, Gould, Saupe, and Klemme 1989).

Perils and Model Risk Factors

In the weather loss model the dependent variable (*WeatherLR*) represents the ratio of catfish losses from weather-related events to expected production during the loss years. Weather events causing catfish losses used in this analysis are freezing of the pond surface, flooding, droughts, windstorms, tornadoes, lightning, and hurricanes. Explanatory variables used in the analysis are manager/operator educational level, number of ponds on an operation, pond water depth (feet), a pond production system dummy variable (single- or multiple-batch), presence of past large losses (> 5 percent) from oxygen depletions due to electrical breakdown from off-farm causes (dummy variable), presence of past large losses from columnaris (COL) and/or enteric septicemia (ESC) disease (dummy variable), and a regional dummy variable (*South*). Table 2 lists the explanatory variables used in this model and our initial thoughts on the expected parameter signs for the weather model.

The parameter sign on the education level of the manager/operator variable is expected to be negative, i.e., post high school education would reduce catfish losses occurring from weather events. The number of catfish ponds on an operation could have a positive or negative sign, depending on the nature of the weather event. If the weather event is freezing of ponds, there would be a high percentage of ponds affected, so the parameter sign would be positive. In the case of intense, local weather events, such as tornadoes, the increased number of ponds could act as a diversification measure, and have a negative sign, or provide a larger target for the tornado path to hit, in which case an overall positive sign would be expected.

We expect the variable for average pond water depth to have a negative sign, indicating an inverse relationship with weather-related losses. As pond depth increases, catfish losses would decrease from weather-related events such as windstorms, droughts, and freezing of ponds. We expect a positive sign on the production system type, indicating that the multiple-batch production system would increase production losses compared to the single-batch production system. Even with its production deficiencies, the multiple-batch production system is more commonly used than the single-batch system because it is more effective in providing on-flavor fish for sale to the processor than the single-batch production system, which may not have any ponds with on-flavor harvest-sized fish available at some times during the 12-month calendar year.

We could expect a positive or a negative parameter sign for the dummy variable indicating past large losses (> 5 percent) from oxygen depletions due to electrical breakdown from off-

Table 2. Weather and Disease Loss Model Explanatory Variables and Expected Parameter Sign

Variable Name	Explanation	Expected Parameter Sign [a]
WEATHER LOSS MODEL		
Education	High school or less = 1, high school or more = 0	(-)
Number of ponds	Number of ponds on an operation (divided by 10)	(+)
Pond water depth	Average water depth (feet) of catfish ponds	(-)
Production system	Production system type where multiple batch = 1 and single batch plus modular = 0	(+)
LoxygenD	One of three largest historical losses from oxygen depletion = 1, otherwise = 0	(-)
Lcolumnaris_escD	One of three largest historical losses from columnaris and/or enteric septicemia of catfish = 1, otherwise = 0	(-)
South	Regional production from southern states of Mississippi, Alabama, Arkansas, and Louisiana = 1, otherwise all other U.S. catfish producing states = 0	(-)
DISEASE LOSS MODEL		
Experience	Number of years respondent has produced catfish	(-)
Education	As described above	(-)
Number of ponds	As described above	(+)
Pond age	Average age of ponds on operation	(-)
Pond water depth	As described above	(-)

[a] The expected sign on the parameter estimate represents our initial understanding of the positive or negative relationship among the independent variables and their explanatory effect on the dependent variable, i.e., weather- or disease-related losses.

farm causes. A positive parameter sign might indicate that it happened before and might happen again, and a negative parameter sign might indicate that producers, having had such a loss event, might have taken steps to safeguard against such future losses, such as by purchasing on-farm generators or additional diesel-powered aerators. Overall, we would expect a negative sign because we think producers who stay in business have learned from their past experiences and would have taken steps to ensure against losses from off-farm electrical breakdown events.

We would expect a negative parameter sign on the dummy variable indicating that past large losses from COL and/or ESC diseases had occurred because, as mentioned for the previous variable, operators who remain in business must learn from the past. In the case of these diseases, they are ubiquitous during the fall and spring, and the farmer can increase surveillance of the ponds for earlier detection of the diseases so that medicated feed can be initiated sooner and thus mitigate losses. We expect a negative sign on the regional dummy variable *South*, indicating that operations located in the southern states of Mississippi, Arkansas, Alabama, and Louisiana would have fewer weather-related losses than operations in other areas of the United States.

In the disease loss model, the dependent variable (*DiseaseLR*) represents the ratio of catfish losses due to diseases that typically occur on catfish operations during spring, summer, and fall months to the expected production during the loss years. The disease perils included in the dependent variable are losses from columnaris (COL), enteric septicemia (ESC), channel catfish virus (CCVD), proliferative gill disease (PGD), "Ich" (*Ichthyophthirius)* or white spot disease, and saprolegnia (SAP). Explanatory variables used in the analysis include operator experience (number of years producing catfish), operator education level attained, number of ponds on an operation, average pond age (years), and average pond water depth (feet). Table 2 lists the explanatory variables used in the disease loss model and their expected signs.

The number of years producing catfish represents an experience variable and is expected to have an inverse relationship to losses. As the number of years producing catfish increases, losses due to diseases should decrease due to experience/knowledge of early disease identification and quick action on appropriate preventative or mitigating management. The highest level of formal education completed should also have an inverse relationship with losses. Conceptually, more levels of formal education completed should be associated with fewer disease losses because of educational knowledge gained on catfish diseases.

The number of catfish ponds on an operation is expected to have a positive relationship with disease-related losses because, as the number of ponds on an operation increases, effective management of all ponds in the limited time frame required for disease remediation becomes more difficult to achieve, though hiring and training of the appropriate number of staff could overcome this difficulty.

We expect a negative coefficient sign for the pond age variable because new ponds seem to increase the PGD disease incidence, while pond age does not appear to increase disease incidence effects from the more common and lethal ESC and COL diseases; thus, we would anticipate a negative sign, as this latter effect is expected to be greater than the former effect. The expected pond depth variable sign could be positive or negative as pond depth diminishes over time, as levee soil erodes from wave action and soil is deposited on the pond bottom. This increase in the pond bottom's height takes up needed water volume inside the pond structure and reduces the total fish living area. This could stress fish, making them more susceptible to diseases and their spread; an expected positive variable sign on pond water depth would result. On the other hand, there is a trend among producers toward building deeper ponds, which would provide longer periods of adequate fish living space; and in this case, the variable for average water depth of ponds is expected to have a negative sign, indicating an inverse relationship with catfish losses.

Table 3 presents the descriptive statistics for the weather and disease model variables. The summary statistics for the ratio of catfish losses due to weather-related events and expected production finds that overall 0.0023 or 0.23 percent of annual losses on a farm are from events such as freezing of the pond, flooding, droughts, windstorms, tornadoes, lightning, and hurricanes. The ratio of catfish loss from diseases (ESC, COL, CCV, PGD, winter fungus) and expected production is 0.0053, or 0.53 percent of annual losses, and is greater than losses from weather-related events, which is in accordance with the literature, which states that diseases are the primary category of catfish losses (Tucker et al. 2004).

Results and Discussion

Weather Loss Model

Results of the weather loss model (*WeatherLR*) indicate that all beta coefficients were significant (Table 4). Expected beta coefficient signs for the education, number of ponds, *LoxygenD*, *Lcolumnaris_escD*, and *South* variables were in accord with model results. However, expected and estimated beta coefficient signs differed for the pond water depth and production system variables; these two differences will be discussed below when marginal effect implications for each variable are discussed.

There are direct relationships between all variable marginal effects and catfish losses when weather events occur. The parameter sign on the education level of the manager/operator variable was expected to be negative, and is, but the marginal effect sign is positive. The education dummy variable had a marginal effect value of 0.002, or stated another way, the achievement of an educational degree past the high school level increased by 0.2 percent the amount of catfish losses when a large weather loss event occurred. A plausible explanation to this finding is that a post high school education degree would not be as valuable to a producer in handling weather event effects on catfish survival as would gaining additional experience from on-farm work in this area during the time it would take to achieve the additional

Table 3. Descriptive Statistics of the Data Used in the Weather and Disease Loss Models

Variable Name	*N* [a]	Mean	Std. Dev.	Min.	Max.
WEATHER LOSS MODEL					
WeatherLR	553	0.0023	0.0150	0	0.10
Education	553	0.4896	0.6360	0	1.00
Number of ponds [b]	553	19.946	65.397	1.0	713.0
Pond water depth	553	5.4878	2.7710	0.4	20.5
Production system	553	0.8004	0.5085	0	1.00
LoxygenD	553	0.3078	0.5872	0	1.00
Lcolumnaris_escD	553	0.1774	0.4861	0	1.00
South	553	0.6941	0.5863	0	1.00
DISEASE LOSS MODEL					
DiseaseLR	551	0.0053	0.0183	0	0.1
Experience	551	13.7	11.4448	1.0	54.0
Education	551	0.489	0.6344	0	1.0
Number of ponds [b]	551	19.4	65.1736	1	713
Pond age	551	11.8	10.0595	1.0	50.0
Pond water depth	551	5.5	2.7738	0.4	20.5

[a] The overall number of user responses was 567, but in running the two models some observations were not used in one or the other models, thus the difference in *N* observations reported here and the overall number of useable surveys obtained.
[b] Variable scaling—the number of ponds variable was divided by ten.

degree. In fact, there are few, if any, advanced aquacultural educational programs that would provide any practical management to address weather threats to catfish survival and production.

The positive marginal effect for the number of ponds variable can be interpreted as the addition of ten ponds resulting in a 0.0012, or 0.12 percent, increase in fish losses when weather loss events occur. Because of the diversity of weather events included in the *WeatherLR* dependent variable (ratio of fish loss from freezing of pond, flood, drought, windstorm, tornado, lightning, or hurricane to expected production), an explanation of regional or localized weather event effects must be considered. For instance, freezing, flood, drought, or hurricane weather events might cover a large area and affect most ponds on an operation equally, while windstorms, tornadoes, or lightning events might affect a more localized area and not necessarily affect all ponds. One could argue that increasing the number of ponds could possibly have a diversification effect, and this would be especially true for weather events that have more localized effects, but not for weather events having equal impacts over larger farm areas. From the survey database, the perils of flood, drought, and freezing of ponds were much more prevalent causes of fish losses than were losses from windstorm, tornado, lightning, or hurricane weather events, making it likely that the marginal effect result is justified.

Pond water depth had a positive marginal effect on fish losses from weather events. A one-foot decrease (increase) in pond depth would result in a 0.003, or 0.3 percent, decrease (increase) in catfish losses from weather-related events. A typical catfish pond in the southern region (Alabama, Arkansas, Louisiana, and Mississippi) has

Table 4. Tobit Regression Results and Marginal Effects for the Weather Loss Model

Parameters	Estimates	T value	Pr > |t|	Marginal Effects
Intercept	-0.069139	-3.36	< 0.0008	
Education	-0.037043	-2.73	0.0062	0.00200
Number of ponds	0.002184	2.69	0.0072	0.00012
Pond water depth	0.057646	2.79	0.0053	0.00326
Production system	-0.026180	-2.03	0.0423	0.00098
LoxygenD	-0.058429	-3.45	0.0006	0.00195
Lcolumnaris_escD	-0.056249	-2.18	0.0293	0.00558
South	-0.072495	-4.80	< 0.0001	0.00676
Sigma	0.073476			
Log likelihood	-33.10936			
AIC	84.21872			
Schwarz criterion	127.37498			

Note: The dependent variable of the weather loss model is the annualized ratio of catfish losses from weather-related events to expected production during the loss years, and includes losses from freezing of pond surfaces, flooding, droughts, lightning, windstorms, tornadoes, and hurricanes.

an average depth of 5.5 feet, typically with a shallow-end depth of four to five feet and a deeper-end depth of six to seven feet. Producers follow varying water management strategies. The recommended water management follows a "6-4" rule, which suggests allowing pond water levels to fall six inches, which occurs from evaporation, and then to refill with only four inches of water, which leaves two inches of freeboard. This procedure allows for rainfall replenishment without spillover, as opposed to refilling to the standpipe brim and having spillover from the next rain event. Thus, reducing the pond depth by 0.5 feet, i.e., about six inches, would fit into the "6-4" rule with existing ponds and recommended water management practices. Weather-related losses could thus be reduced by this management strategy. However, the reader will see in the disease-related loss model discussion that follows that the pond depth coefficient sign has the opposite sign (negative), and this variable's potentially confusing results will be addressed more in that section.

The production system (*Psystem*) beta coefficient was significant, with a positive marginal effect indicating that weather-related losses increased by 0.00098, or 0.098 percent, with the multiple-batch production system. Diversification benefits from the multiple-batch production system may explain this result. A single-batch pond hit hard by a weather event would be a complete loss of foodsize fish for the production year from that pond, while a multiple-batch pond loss would represent only a fraction of the total annual foodsize fish production. This is because the latter system has the pond stocked with two to four size classes of fish, and this year's foodsize fish loss would represent a weight loss less than that of having all uniformly harvest-sized fish lost in the single-batch system pond. As mentioned earlier, the multiple-batch production system also aids in the sale of fish, as any multiple-batch pond that is on-flavor would have some harvest-sized fish available for harvest (harvest nets allow smaller fish to escape while larger fish are caught and removed), while the single-batch system has only one time period to harvest foodsize fish.

The dummy variables for past experience of losing fish to low oxygen levels from off-farm electrical outages (*LoxygenD*) and losing fish from the Columnaris and ESC diseases (*Lcolumnaris_escD*) had significant, beta coefficient signs. Marginal effects for these dummy variables were positive, indicating that past experiences increased the likelihood of losses from weather fish loss events. Having had the past experience of losses from the COL and ESC diseases (*Lcolumnaris_escD*) would increase weather-related losses by 0.0058 (0.58 percent), while having losses from oxygen depletions due to off-farm electrical breakdowns would increase losses by 0.00195, or 0.195 percent. Experiences gained by producers from past loss events may have resulted in improved crisis management and better allowed weather loss event mitigation, but the marginal effects signs indicate otherwise, specifically that persistent difficulties remain in effectively managing against these perils in the face of weather events.

The *South* regional dummy variable was significant as well. Approximately 95 percent of all farm-raised catfish are produced in the four states constituting the southern region, as conditions favor production in these states. Presumably, weather events are not so damaging to catfish production in this region that the other favorable elements related to successful catfish farming are overshadowed. However, the positive marginal effect for this variable indicates a 0.0068, or 0.68 percent, increase in fish lost from weather events for catfish farms located in the south-central region of the United States.

Disease Loss Model

Results of the disease loss model (*DiseaseLR*) indicate that operator experience and pond water depth are significant with negative beta coefficients (Table 5). This implies that the more operator experience—that is, the longer a producer has been producing catfish—the greater the reduction in disease-related catfish losses. Each additional year of operator experience resulted in a 0.00015, or 0.015 percent, decrease in the catfish losses from disease-related events. Connected to experience is education, but the education level variable is not significant, indicating that experience on the farm reduces disease risks better than formal education level attained. Education in our survey was measured in grade or degree level achieved and is not a particularly good measure of on-farm competence or experience. Thus, the lack of significance in education level is not surprising.

The pond water depth variable is significant and has a negative beta coefficient and marginal effect, which indicates that an increase in pond depth results in a decrease in disease-related catfish loss. A one-foot increase in pond water depth is associated with a 0.00114, or 0.11 percent, decrease in the amount of catfish losses from disease-related events. As discussed earlier, increasing pond depth could be problematic in the short term because of the fixed nature of the pond standpipe and levee height, but these items could be addressed in the long run when ponds are renovated or new ponds built. In fact, many catfish producers in the eastern region of Mississippi and western region of Alabama have been using deeper ponds for a number of years. These producers initially began this practice because of the difficulty and expense of obtaining water to fill and maintain water levels, as the groundwater is relatively deep and costly to pump compared to the Mississippi River Delta regions of Mississippi, Arkansas, and Louisiana. Records for east Mississippi producers indicate greater production per water surface area compared to Delta region farms, which may be an indicator of reduced mortality, but data on differences in mortality from each region are not available to analyze and compare.

The negative signs on the pond water depth variable and marginal effect in the disease model are in contrast to the positive coefficient sign and marginal effect for the same variable in the weather-related loss event model discussed earlier. The opposing responses lead one to question which result is correct and meaningful. Referring to the weather-related loss and disease loss models, the marginal effects for the pond depth variables are 0.00326 and -0.00114, respectively, and the former model appears to represent a greater magnitude in change. However, the ease in changing pond water level and the magnitude of losses from weather and diseases should be considered. Pond water levels can be reduced in the short run without any capital costs, but increasing pond water levels beyond current levee heights (or pond bottom level) will require substantial capital (Laughlin and Hanson 2001). Secondly, disease losses are greater in overall magnitude than weather-event losses in the U.S. catfish industry. Thus, it could be that the average producer would be better off making pond water depth changes in line with the disease loss model, i.e., adopting long-term measures to increase pond water depth, rather than making pond water depth decisions in line with reducing weather loss chances (decreasing pond depth).

Table 5. Tobit Regression Results and Marginal Effects for the Disease Loss Model

Parameters	Estimates	t value	Pr > |t|	Marginal Effects
Intercept	0.01160	2.58	0.00980	
Experience	-0.00059	-2.54	0.01100	-0.00015
Education	0.00411	-1.46	0.14420	0.00002
Number of ponds	-0.00004	-.029	0.77160	0.00001
Pond age	-0.00047	-1.62	0.10560	-0.00012
Pond water depth	-0.00437	-4.06	< 0.0001	-0.00114
Sigma	0.03507			
Log likelihood	199.269			
AIC	-384.538			
Schwarz criterion	-350.970			

Note: The dependent variable of the disease loss model is the annualized ratio of catfish losses from disease-related events to the expected production during the loss years and includes losses from specific diseases, including Columnaris (COL), enteric septicemia (ESC), channel catfish virus (CCV), proliferative gill disease (PGD), Saprolegnia (SAP), and "Ich" or white spot disease.

The pond age variable coefficient is not significant, but, along with the marginal effect, is negative. It was initially expected that increased pond age would increase fish losses as there are many diseases that could be affected by pond bottom soil buildup over time, which would reduce fish living space, stress fish, and cause mortalities. However, that is not the case, as the negative marginal effect indicates that increased pond age results in lower disease-related catfish losses. Of additional note is the lack of significance in the number of ponds variable in the disease loss model, though the marginal effect sign was positive.

Conclusions

In conclusion, results of this research provide information on observable risk factors that can assist producers in the U.S. farm-raised catfish industry to mitigate catfish losses due to weather-related events and disease outbreaks and provide more in-depth knowledge of catfish production to researchers not directly involved in this enterprise. Disease losses on U.S. catfish farm operations are of greater economic magnitude than losses related to weather events, although in 2005 catfish farm damages and catfish losses from Hurricanes Katrina and Rita were greater than from any prior large storm events. Education, farm/pond characteristics (number of ponds and pond depth), production management strategy, past experiences with large losses from electrical outages or disease losses, and being located in the southern catfish-producing states had an effect on the ratio of catfish losses from weather-related events to expected production. Experience and pond depth were significant variables, with negative coefficient and marginal effect signs in the disease loss model. This model indicated that the amount of catfish losses due to disease outbreaks could be reduced by operating catfish farms with experienced managers/workers and increasing pond depth when renovating or building new ponds.

References

Coble, K.H., T.R. Hanson, S.H. Sempier, S. Shaik, and J.C. Miller. 2006. "Investigating the Feasibility of Livestock Disease Insurance: A Case Study in U.S. Aquaculture." In S.R. Koontz, D.L. Hoag, D.D. Thilmany, J.W. Green, and J.L. Grannis, eds., *The Economics of Livestock Disease Insurance: Concepts, Issues and International Case Studies.* Cambridge: CABI Publishing.

Forster, J. 2003. "Industry Profile: The U.S. Farmed Salmon Industry." National Risk Management Feasibility Program for Aquaculture, Mississippi State University, Starkville, MS.

Gould, B.W., W.E. Saupe, and R.M. Klemme. 1989. "Conservation Tillage: The Role of Farm and Operator Characteristics and the Perception of Soil Erosion." *Land Economics* 65(2): 167–182.

Greene, W.H. 2003. *Econometric Analysis* (5th ed.). New York: Macmillan Publishing Company.

Heckman, J.J. 1979. "Sample Selection Bias as a Specification Error." *Econometrica* 47(1): 153–162.

Laughlin, D.H., and T.R. Hanson. 2001. "Construction Costs for Catfish Ponds for Ad Valorem Taxation Purposes." AEC Staff Report No. 2001-03, Department of Agricultural Economics, Mississippi State University, Mississippi State, MS.

McDonald, J.F., and R.A. Moffit. 1980. "The Uses of Tobit Analysis." *The Review of Economics and Statistics* 62(2): 318–321.

Miller, J.C., J.E. Lee, T.R. Hanson, and K.H. Coble. 2002. "2002 National Risk Management of Aquaculture Workshop Summary Report." Department of Agricultural Economics Information Report No. 2002-023, Mississippi State University, Starkville, MS.

Mississippi State University. 2006. "2006 CVM [College of Veterinary Medicine] Aquatic Diagnostic Laboratory Summary." Thad Cochran National Warmwater Aquaculture Center, College of Veterinary Medicine, Mississippi State University, Stoneville, MS.

NASS [*see* National Agricultural Statistics Service].

National Agricultural Statistics Service (NASS). 2006. "Census of Aquaculture (2005)." NASS, U.S. Department of Agriculture, Washington, D.C.

____. 2007a. "Catfish Processing." Agricultural Statistics Board, NASS, U.S. Department of Agriculture, Washington, D.C.

____. 2007b. "Catfish Production." Agricultural Statistics Board, NASS, U.S. Department of Agriculture, Washington, D.C.

National Fisheries Institute. 2007. "Top 10 U.S. Consumption by Species Chart." Available at http://www.aboutseafood.com/media/top10.cfm.

Shaik, S., B.J. Barnett, K.H. Coble, J.C. Miller, and T.R. Hanson. 2006. "Insurability Conditions and Livestock Disease Insurance." In S.R. Koontz, D.L. Hoag, D.D. Thilmany, J.W. Green, and J.L. Grannis, eds., *The Economics of Livestock Disease Insurance: Concepts, Issues and International Case Studies*. Cambridge: CABI Publishing.

Tucker, C., J. Avery, C. Engle, and A. Goodwin. 2004. "Industry Profile: Pond-Raised Channel Catfish." National Risk Management Feasibility Program for Aquaculture, Mississippi State University, Starkville, MS.

Tucker, C.S., and E.H. Robinson. 1990. *Channel Catfish Farming Handbook*. New York, NY: Van Nostrand Reinhold (digital duplication of the original by Kluwer Academic Publishers, Boston, MA, 2002).

U.S. Department of Agriculture. 2003. "NAHMS Catfish 2003 Part II: Reference of Foodsize Catfish Health and Production Practices in the United States." Animal and Plant Health Inspection Service (APHIS), National Animal Health Monitoring System, U.S. Department of Agriculture, Washington, D.C.