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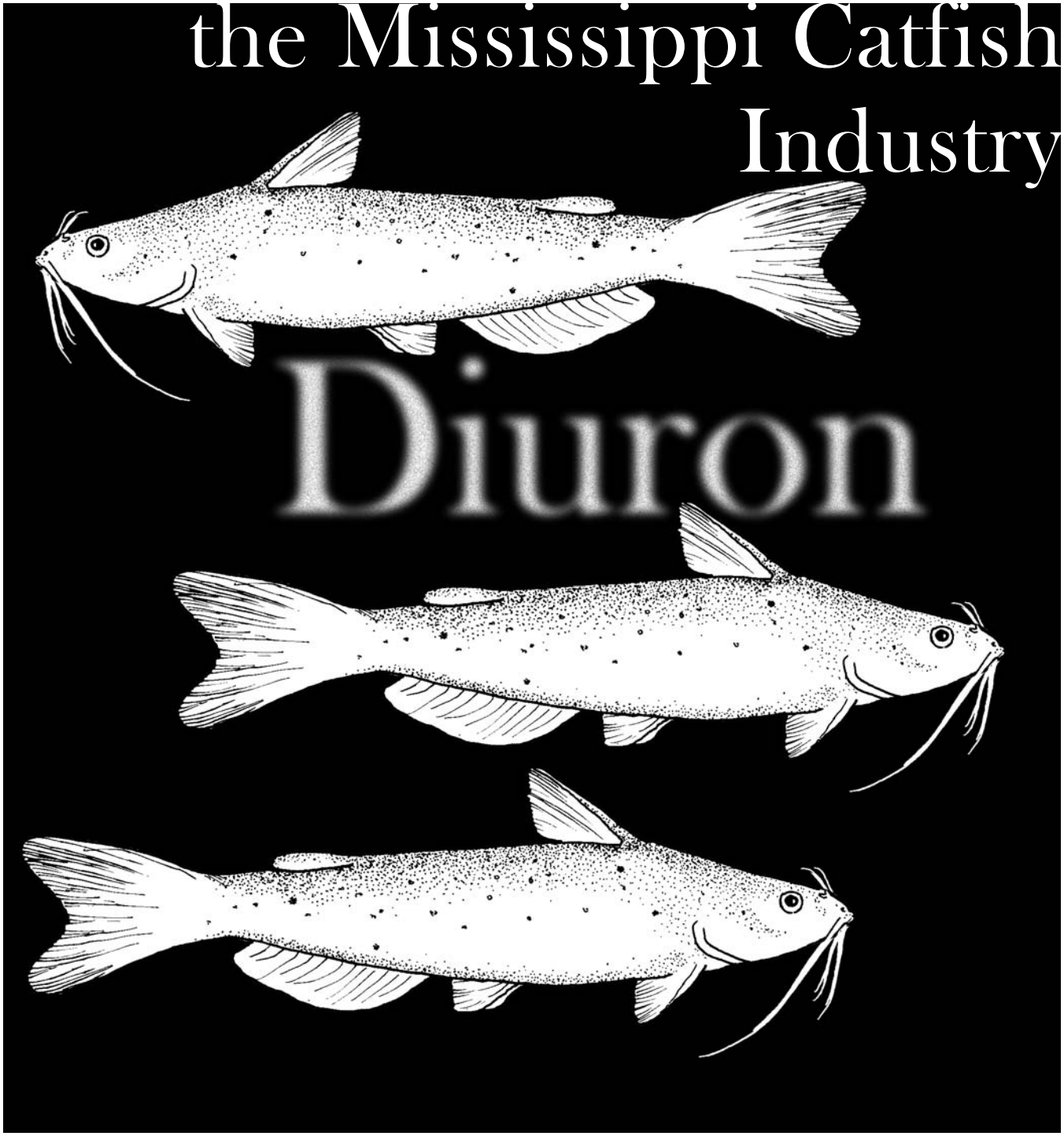
Impact of Diuron Usage on the Mississippi Catfish Industry



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Impact of Diuron Usage on the Mississippi Catfish Industry

ABSTRACT

Pond-raised channel catfish frequently develop undesirable off-flavors when naturally occurring odorous substances are absorbed from the water. When off-flavor is detected in food-sized catfish, harvest is canceled until proper flavor returns. The costs associated with delayed harvest are serious economic burdens to catfish farmers. In April 1999, the U.S. Environmental Protection Agency (EPA) granted a 1-year Section 18 Emergency Exemption allowing applications of the herbicide diuron for control of flavor problems in pond-raised channel catfish. Diuron reduces the incidence of off-flavor in catfish by suppressing the growth of blue-green algae, the most common cause of flavor problems. Catfish farmers were surveyed and processor "flavor-check" records were analyzed to determine the economic impact of diuron to the Mississippi catfish industry in 1999. Results of the farmer survey indicated a **statistically significant (α = 0.15) reduction** in per-pond occurrences of off-flavor when comparisons were made between the 1999 and 1998 production years and between the 1999 and 1997 production years. Flavor quality control records obtained from catfish processors for 1997, 1998, and 1999 were compared, and a **statistically significant (α = 0.05) lower** percentage of off-flavor occurrences was noted for 1999. When the benefits of reduced off-flavor costs to the industry were compared with the estimated costs of diuron usage, benefits outweighed costs by 43 to 1 when comparing 1999 with 1998 and 37 to 1 when comparing 1999 with 1997, indicating economic justification for diuron's use. Many factors could have affected the reported reduction in off-flavor losses, but the use of diuron in 1999 was the most important change in management from prior years and was probably the major factor responsible for the decrease in off-flavor costs to the Mississippi catfish industry.

EXECUTIVE SUMMARY

Development of undesirable off-flavors in pond-raised channel catfish can delay fish harvests and create a severe economic burden for producers and processors. Off-flavors can come from a variety of sources, but most flavor problems in catfish are caused by odorous substances synthesized by blue-green algae. Although many schemes have been proposed for managing flavor problems in fish, most approaches are ineffective, not cost-effective, or not practical under commercial fish culture conditions. Now, the only way to control off-flavors is to use algicides to eliminate odor-producing blue-green algae. In a 1999 Section 18 Emergency Exemption, the EPA allowed applications of diuron, a herbicide shown to suppress the growth of blue-green algae in catfish ponds.

The purpose of this study was to analyze the effectiveness of diuron in reducing off-flavor occurrences and to determine the economic impact of its use during the 1999 production year in Mississippi. To analyze diuron use patterns and effectiveness, information was obtained from participants in the Mississippi catfish industry (farmers, processors, manufacturers, and diuron distributors) through mail surveys, telephone conversations, or processing plant visits. The survey resulted in responses from 37% of all catfish producers, representing 48% of all food-fish production acres and 36% of all catfish production in 1999. Regional differences in response rate and food-fish production acreage were considered in analyzing data and extrapolating survey results to statewide estimates.

Survey results showed that approximately 13 tons of diuron were applied to 36,300 acres of Mississippi catfish ponds in 1999 at a cost of $155,450. Two diuron products were available to farmers: Nautilus Aquatic Herbicide (Griffin, Inc.) and Diuron 80 Herbicide (Drexel). Farmers purchased more Nautilus Aquatic than Diuron 80. Treated acreage was approximately 43% of all food-fish acreage in the state. Average diuron treatment frequency was 5.1 applications per pond, less than the permitted nine applications per pond, indicating

that fish flavor quality improved before the complete treatment regimen was needed. Survey respondents reported some fish loss due to treatment-related water quality problems (mainly reduced dissolved oxygen levels), but losses were estimated to be only $51,500 for the entire state and could not conclusively be separated from water quality problems that normally occur in catfish ponds.

Survey results indicated that occurrence of off-flavor on a per-pond basis was significantly lower in 1999 than 1998 or 1997. Off-flavor caused an extra 5.8 grow-out days per acre of food-fish production (500,000 total days) in 1999. However, the 1999 delay was 10% lower than that in 1998 and 16% lower than 1997. Aggregate Mississippi costs for flavor-related delays in fish harvest included additional operational expenses, value of fish mortality, fish sampling transportation costs, and opportunity cost.

Based on farmers' estimates of additional feed, labor, and other operating expenses, the cost of flavor-related harvest delays was estimated to be $6.8 million in 1999. That added cost was down from about $10.5 million in 1998 and about $11.4 million in 1997. Delay-related fish loss (caused by disease, poor water quality, and bird predation) was estimated to be $6.5 million in 1999, $10.6 million in 1998, and $9.1 million in 1997. Costs to transport fish for processor-conducted off-flavor tests were estimated to be $214,600 in 1999, $246,200 in 1998, and $202,900 in 1997. In the full accounting of off-flavor related costs, a 9% opportunity cost was charged on the total costs of off-flavor harvest delays to account for foregone revenues. The estimated total cost for these items was $14.7 million for 1999 – $8.5 million lower than 1998 ($23.2 million total) and $8 million lower than 1997 ($22.7 million total).

A benefit-to-cost (B/C) analysis was conducted for diuron usage in the Mississippi catfish industry in 1999. Benefits were derived from the difference in off-flavor aggregate costs to the Mississippi catfish industry between 1998 and 1999 and between 1997 and 1999. For this analysis, costs were considered the sum of total diuron purchases plus the fish mortality caused by diuron use. The B/C ratio for diuron usage was 42.5 for 1999 compared with 1998, and the ratio was 36.5 for 1999 compared with 1997. Benefits of diuron usage far outweighed costs of diuron usage, indicating economic justification for its use in catfish ponds.

In a second part of this study, catfish processors volunteered records of flavor quality testing for 1997, 1998, and 1999. The incidence of samples declared off-flavor was significantly lower ($\alpha = 0.05$) in 1999. From April 26 to December 31, 1999, 43% of the samples submitted to the plants were deemed off-flavor. Over the same period in 1997 and 1998, 52% of the samples submitted were off-flavor. The processor records support the results of the farmer survey and indicate that diuron significantly reduced the impact of off-flavor on Mississippi catfish producers.

BACKGROUND

Off-flavor is a major problem in the catfish farming industry. Since 1980, off-flavor has been identified as one of the most serious problems facing the catfish industry because of its high occurrence rate, potentially damaging effect on consumer confidence, and lack of available control measures (Sindelar et al. 1987).

Most flavor problems in Mississippi pond-cultured catfish are caused by 2-methylisoborneol, a musty-smelling compound synthesized by blue-green algae (van der Ploeg et al. 1992; Tucker 2000). Flavor problems caused by blue-green algae occur in episodes that coincide with the appearance and eventual disappearance of odor-producing species in the phytoplankton community. Populations of odor-producing blue-green algae are most common during the warmest months, but the length of time that fish remain off-flavor varies considerably. Research conducted by van der Ploeg and Tucker (1993) found an average of 115 additional grow-out days passed before catfish harvest could occur because of off-flavor, and there was a range of 27 to 344 additional grow-out days for the 10 ponds in the study. Tucker et al. (2001) reported an average of 80 days beyond an acceptable harvest-sized fish because of off-flavor, and there was a range of 17 to 286 additional grow-out days in their 18-pond experiment. The unknown duration of an off-flavor episode is the underlying problem and has enormous implications to the catfish industry.

To prevent the negative consequences that would occur if off-flavored fish were marketed, catfish processors require farmers to bring fish samples in for a flavor check 1 week before a planned harvest to obtain tentative approval for purchase (van der Ploeg 1992). Fish are checked again the day before harvest and on the day of harvest to be certain that off-flavor has not developed since the initial check. A final sample is taken from the

transport truck at the processing plant before fish are unloaded. An off-flavor result at any sample point will cancel the harvest until further tests confirm fish are on-flavor. Delayed harvest can be expensive to the farmer because of resulting additional input costs, potential fish mortality, and reduced sales events (Sindelar et al. 1987). Disruption of cash flow is another serious problem resulting from delayed harvests, especially when the duration of the delay cannot be known with any degree of certainty. Additional production costs can be offset by additional weight gained by the fish during the holdover period, but as fish get larger, feed conversion rate becomes less efficient. It becomes a question of increased fish value compared with additional production costs (variable and fixed). If fish grow too large, the processing plant may not accept them or may pay a lower price. Holding fish over the winter and spring subjects fish to additional disease periods with increased probability of fish losses.

Keenum and Waldrop (1988) estimated that off-flavor increased catfish production costs by $0.018 to $0.054 per pound depending on the severity of the marketing constraint. Another Waldrop study simulated the effects of off-flavor preventing harvests for 4 weeks, 8 weeks, and 16 weeks with resulting additional per-pound production costs of $0.005, $0.029, and $0.045, respectively (Coats, Dillard, and Waldrop 1989). Engle et al. (1995) estimated flavor-delayed harvests to increase catfish production costs by $0.023 to $0.11 per pound when cash flow considerations were included. Based on these estimates, the Mississippi catfish industry spent approximately $6.5 million to $31.1 million in increased production costs because of off-flavor in 1999. Increased production costs in the entire U.S. catfish industry would have ranged from $9.8 to $46.7 million.

Management of algae-derived off-flavors has been an elusive goal because the catfish pond environment strongly favors the presence of blue-green algae. The most common management practice involves delaying harvest until the odor-producing algae naturally disappear from the community and fish have the opportunity to purge the odorous compound from their flesh. This is an uncertain practice because changes in plankton community structure cannot be predicted and the process of purging may require variable lengths of time. Larger farms with many ponds can probably manage off-flavor episodes by skipping harvest of the affected pond and harvesting fish from a pond with harvest-sized fish of acceptable flavor. However, this practice is not feasible on smaller farms with fewer ponds. Thus, production and receipts on smaller farms can be more directly affected by off-flavor episodes. In addition, leaving fish in ponds past their desired harvest date is an economic burden on all producers – despite farm size – because growth of the subsequent crop is postponed and fish that should have been harvested may be lost to disease.

In an attempt to avoid the burdens of delayed fish harvest due to unacceptable flavor quality, many producers attempt to eliminate odor-producing algae from ponds by using copper sulfate or other copper-based products. Copper-based algicides – the only family of algicides currently registered for use in catfish ponds – have a long history of safe use in drinking water supplies, natural waters, and aquaculture ponds. However, copper-based algicides are not ideal for blue-green algae control in fishponds because the toxicity of copper products to algae and fish is controlled in a complex and poorly understood fashion by several water chemistry variables (Tucker 2000). A consistently effective and safe treatment regimen for copper-based algicides is, therefore, not available.

Diuron is a substituted urea herbicide used for selective preemergence or early postemergence control of seedling grasses and broad-leaved weeds in certain croplands. Diuron is a broad-spectrum herbicide with a 40-year history of safe use in terrestrial soils. The chemical is known to have algicidal properties at low concentrations (Badon 1995) and has several other characteristics that make it attractive as an algicidal candidate for off-flavor management (Tucker and Leard 1999). These characteristics include a wide margin of safety between algicidal concentrations and concentrations toxic to fish and humans, freedom from complex interactions with other water chemistry variables, and lack of long-term persistence in the pond environment because the chemical is decomposed by natural microbiological activity. In addition, Novigen Sciences, Inc., conducted a dietary exposure assessment that included projected diuron use in commercial catfish ponds and found that the lifetime cancer risk for the overall U.S. population is negligible (Kidwell 1999). They also reported that combined chronic exposure estimates for linuron, propanil, and diuron are also well below the chronic Rfd (reference dose for chronic oral exposure) – even when assuming worst-case assumptions such as tolerance-level residues and 100% crop treated for many commodities. Their conclusion was that there were no chronic toxicological concerns from potential diuron residues in foods. Until the 1999 EPA exemption, diuron use in the catfish industry was not allowed due to lack of established safe catfish tolerance and application levels.

OBJECTIVES

Survey of Catfish Farmers

The first step in assessing the economic impact and effectiveness of using diuron to reduce off-flavor problems was a survey of Mississippi catfish farmers. This survey was designed to collect information on 1999 diuron usage, farmer-rated effectiveness, catfish production (acreage, quantity harvested), off-flavor occurrences, and costs associated with prevented harvests. Production information for 1997 and 1998, when diuron was not permitted, was also collected for comparison to 1999 data. There were four specific objectives of the Mississippi diuron farmer survey.

Estimate the cost of off-flavor to the Mississippi catfish industry from 1997 to 1999 by estimating four variables:

- number of delayed harvest days caused by off-flavor;
- additional operating expenses incurred due to delayed harvests;
- fish mortality during the off-flavor period; and
- transportation costs incurred to have off-flavor tests conducted.

Determine the diuron usage in Mississippi in 1999 by estimating six variables:

- number of food-fish water acres treated;
- diuron application frequency;
- quantity of diuron applied;
- cost of diuron used;
- problems with diuron usage; and
- specific diuron product purchased.

Measure the effectiveness of diuron use in reducing off-flavor by estimating three variables:

- percentages of diuron-treated ponds with off-flavor;
- numbers of off-flavor occurrences in 1999 and comparisons to nondiuron years 1998 and 1997; and
- farmer-rated effectiveness of diuron.

Compare the benefits and costs of diuron usage between 1999 and prior years by estimating three variables:

- total value of off-flavor costs to the Mississippi catfish industry for each year;
- difference in off-flavor cost to the industry in 1999 and earlier nondiuron years; and
- total costs associated with diuron usage in 1999.

Catfish Processor Records

Individual catfish processing firms in Mississippi were contacted, and information concerning flavor test records was analyzed for 1997, 1998, and 1999. The specific objective of the processor portion of the study was to compare daily flavor test results over a 3-year period to determine any statistical differences associated with the diuron period (1999) and two earlier periods (1998 and 1997) when diuron use was not permitted. Additionally, processor off-flavor records were independent of farmer diuron survey responses and provided an objective analysis that would be valuable in weighing the objectivity of the farmer-completed survey results and conclusions.

METHODS

Survey of Catfish Farmers

A mail survey was sent to all participants attending one of the two diuron workshops held in Greenville or Mayhew, Mississippi, during spring 1999. The workshops were conducted by the National Warmwater Aquaculture Center (NWAC). Producer attendance was mandatory for catfish farmers seeking to be certified in diuron usage for catfish production. Large farmer turnout at these workshops indicated farmer interest in diuron.

To encourage farmer participation in the survey, advanced notice of the pending survey was published in the September and October 1999 issues of *The Catfish Journal*, a service publication to the catfish industry. Furthermore, a cover letter and endorsement letters were sent out with the survey stressing the importance and need for all farmers to complete the survey. Endorsement letters were provided by Ed Robinson, coordinator of the NWAC; Robert McCarty, director of the Mississippi Department of Agriculture and Commerce; and Sterling Withers, president of the Catfish Farmers of Mississippi.

On October 29, 1999, 725 surveys were mailed out. A second mailing was done for farmers who did not respond to the first survey on November 23, 1999. Completing the survey was voluntary, and farmers were told in the cover letter that all information provided would be treated anonymously and confidentially with only totaled summary results being reported.

There were 11 questions in the diuron survey (Appendix I). The first three questions measured the magnitude of the off-flavor problem to catfish farmers in Mississippi. Other questions sought information about farm size, production, and off-flavor occurrences in 1997-99. Additional questions sought information about the frequency of off-flavor occurrences and the distance farmers carried fish samples to have them tested for off-flavor.

In order for farmers to respond to questions that would quantify off-flavor occurrences, an off-flavor definition was provided in the survey:

> *An off-flavor occurrence is counted when a fish sample from a pond was rejected by a processing plant because fish were deemed off-flavor. Additionally, when you brought a second (third, fourth, fifth, etc.) fish sample from the SAME pond to a processing plant and it was also rejected because of off-flavor, COUNT these occurrences as ADDITIONAL off-flavor episodes. In other words, each rejected fish sample from a pond would count as an off-flavor occurrence.*

This definition counts consecutive off-flavor samples from the same pond as separate episodes and was chosen so farmer and processor records would be analogous for possible future comparison. Defining an off-flavor occurrence in this manner had major implications to the results of this study. Fish from an off-flavor population were sampled repeatedly until the population became on-flavor again, and each off-flavor fish sample was defined as representing a separate off-flavor incident. Therefore, a strong bias is introduced that emphasizes off-flavor occurrences over on-flavor occurrences. The nature of survey data and processor records is such that defining events in this manner is unavoidable, but it should be noted that it does emphasize failures of a treatment over its successes. For example, assume that a farmer has three ponds being treated with diuron. Immediately after the treatment, he samples fish from all three ponds. If two samples were deemed on-flavor and one sample off-flavor, the treatment success rate is 66%. As the farmer resamples fish from the one off-flavor population, each sample is now defined as a separate off-flavor occurrence. If seven more samples (one sample per day) are submitted to the processor, and only the last sample is deemed on-flavor, there are now three total on-flavor occurrences and seven off-flavor occurrences, or a 70% off-flavor prevalence in diuron-treated ponds. The point is that repeated sampling produces separate data points and actually dilutes the success of diuron because successful uses are sampled much less frequently than unsuccessful uses. Implications of this unavoidable bias will be discussed further in the results section concerning off-flavor occurrences at the farm and processor level.

Several questions requested information concerning farmer use of diuron in 1999. Specifically, the questions asked farmers about the number of pond acres treated with diuron, the months when treatments were applied, number of off-flavor occurrences in

diuron-treated ponds, number of treatments per pond, and any water-quality-related problems created from diuron use. Information concerning diuron-treated acreage from the survey was used to estimate the total number of food-fish pond acres treated in Mississippi. A weighting procedure was used to extrapolate survey findings to the state level. Total 1999 Mississippi food-fish acres (from the Mississippi Agricultural Statistics Service [MASS], 1999) was multiplied by the ratio of diuron-treated acres to total food-fish acres (treated plus untreated acres) as reported in the surveys. Such a weighting procedure seems appropriate as the large number of surveys mailed out – even when returned surveys by nonproducers were removed – indicate every catfish farm in Mississippi received a survey and regional representation was good. This weighting was also used in calculating the diuron usage rates of the eastern and Delta regions as well.

Another question sought to determine the duration of off-flavor periods, additional operating costs during these periods, and the value of fish mortality occurring during these periods. The total number of additional production days caused by flavor-related delays in catfish harvest during 1997, 1998, and 1999 was calculated by multiplying three variables: (1) the average number of additional grow-out days; (2) the average number of food-fish ponds per operation; and (3) the number of Mississippi catfish operations (MASS 1999).

Farmers were asked to estimate additional costs they paid for feed, labor, and other expenses during these periods of prevented harvesting. Also, farmers were asked to estimate the value of their fish losses caused by disease, low dissolved oxygen, and bird predation during these harvest delays. Aggregation of additional operating costs and fish losses to the state level was conducted by summing survey-reported costs or losses, dividing that sum by survey-reported catfish acreage, and then multiplying that result by the total number of food-fish acres in Mississippi.

Also, flavor-related costs and fish loss values reported in the survey were subjected to an outlier identification scheme to identify unrealistic responses; any unrealistic observations were removed from the estimation process. The outlier identification scheme used past per-pound off-flavor estimates calculated by Engle and Pounds (1995), Keenum and Waldrop (1988), and Coats et al. (1989). According to this scheme, acceptable flavor-related costs range from $0.018 to $0.11 per pound of catfish produced. Any observation with flavor-induced costs greater than $0.11 per pound was removed from the data set for these questions. A second criterion was established to refine the data set further. It rejected cost-analysis observations when respondents failed to provide information on production acres or pounds harvested; this information was necessary for extrapolation to state levels.

Another question asked the farmer to rank the effectiveness of diuron in lowering the number of off-flavor occurrences on their farm in 1999. A 1-10 scale was used for this question: 1 = completely ineffective, 5 = no difference, and 10 = completely effective. A final question asked farmers to give their comments about diuron, its effectiveness, or its impact on catfish profitability.

Catfish Processor Records

Fifteen catfish processors in Mississippi were contacted and asked about the availability of daily flavor-check results for fish submitted for processing in 1997, 1998, and 1999. Four of the larger catfish processors had sufficient records to cover the requested 3-year period. Flavor-check results were collected by visiting each firm and entering the total number of samples submitted for flavor-checks and the number of samples deemed off-flavor into a computer database. Data from the participating plants were combined into a single data set, and statistical tests of differences were conducted over similar annual periods.

Diuron was approved for use on April 26, 1999, and was available for use for the remainder of the calendar year. Because off-flavor is seasonal, comparisons between years were conducted on similar periods (April 26 to December 31) each year. Furthermore, the 1997 and 1998 processor flavor-check data were combined into a single data set so that Student's t-test could be used to determine differences between the combined 1997-1998 data set and the 1999 data set. The daily off-flavor percentage of fish sampled at the four processors was the variable being tested over the stated periods.

Government Agencies

Catfish production statistics and pond acreage, available from the Mississippi and National Agricultural Statistics Services (USDA 1999), were used to determine statewide estimates from sample results. As off-flavor is only a problem to farms raising harvest-sized fish or food fish (not fingerlings or broodstock), only reported food-fish acres were used in weighting sample results to obtain state-level estimates. This is a reasonable assumption because farmers would not likely add diuron treatment costs to nonfood-fish production when flavor acceptance has no bearing on their products. For 1999, there were 86,000 acres of food-fish production in Mississippi; 1998, 84,000 acres; and 1997, 82,600 acres (NASS, MASS, various months). Of the 1999 food-fish acreage, 80,000 acres were in the Delta region of northwest Mississippi, while 6,000 acres were in east Mississippi.

RESULTS: DIURON USAGE SURVEY

Descriptive Statistics of the Farmer Diuron Usage Survey

All 725 diuron workshop attendees were sent surveys, resulting in a 34% overall return rate. While low, this response rate was expected because the mailing list contained multiple people from the same farm, as well as people who were not food-fish producers (Table 1). On the first page of the survey, each respondent was asked to check a box if another person (manager, owner, etc.) would be filling out a survey for that farm. If so, that respondent was asked to return his or her copy of the survey uncompleted. Another question allowed respondents to identify themselves as nonproducers. Nonproducers were individuals who were out of business, fingerling producers, bankers, feed suppliers, or industry consultants who did not produce food fish. Once these two respondent categories were excluded, 143 of the 244 returned surveys were usable. USDA-NASS reported 390 Mississippi catfish farmers in 1999. Thus, 37% of all Mississippi catfish farmers responded to this survey in a manner that was usable (i.e., all questions were answered and within realistic bounds).

Catfish production data from the survey were compared to state levels of production (Table 2). The pounds of catfish harvested by survey respondents represented 36% of all food-sized catfish production in Mississippi. Acreage reported in the survey represented 48% of the total Mississippi food-fish acreage.

Responses to the survey were subdivided into Delta and eastern regions (Table 3). Analysis of the data in this study was conducted on a state level as well as for the eastern and Delta regions of Mississippi because production, management, and farm size in these two regions differ dramatically. Responses to the survey represented 46% of the total food-fish pond acreage in the Delta and 69% of food-fish pond acreage in the eastern region.

Further subdivision of the responses by county districts as defined by MASS show the percent of responses from each district (Table 4). There were more individual survey responses from eastern Mississippi than from the Delta, but more pond acreage was represented by Delta survey respondents. District 40 includes the counties that are the heart of the Delta catfish industry, where more than 87% of the Mississippi catfish industry is located (USDA-NASS, 1999). The

Table 1. Descriptive statistics for the Mississippi catfish farmer diuron mail survey, 1999.

Surveys sent out [1]	725
Returned surveys	244
Return rate	34%
Usable surveys	143
Percent surveys usable [2]	59%
Percent of Mississippi catfish farms responding [3]	37%

[1]Approximately 335 of these recipients turned out to be nonproducers or multiple representatives of the same farm. A question was included on the survey to account for these potential duplicates.
[2]The percent of usable surveys was calculated by dividing the total number of usable surveys into the number of all returned surveys. Returned surveys also included surveys with incomplete data, duplicate farm recipients, or other nonproducer categories.
[3]USDA-NASS reported 390 Mississippi catfish farmers in 1999. This number is used in calculating the percent of Mississippi catfish farmers responding to the survey.

Table 2. Comparison of diuron survey production and acreage to Mississippi state levels, 1999.

Variable	Survey	State	Survey as a percent of state total
Number of catfish operations	143	390	36.7
Pounds harvested	132,557,000	370,000,000	35.8
Food-fish production acreage	41,266	86,000	48.0

survey represented District 40 well; 39% of all usable surveys (representing 42% of all Mississippi catfish acres) came from this district.

Eastern Mississippi catfish production is centralized in District 60, which includes Noxubee, Lowndes, and Chickasaw counties. Survey responses from this district represented 54% of all usable surveys and 5% of all Mississippi catfish production. Because of the differences in overall pond acreage in the Delta and eastern Mississippi regions, the survey responses were analyzed as a whole and by region.

Table 3. Mississippi catfish farmer diuron mail survey responses by region, 1999.

Region	Survey responses returned		Acreage represented by responses		
	Number	Percent of all usable surveys	Number of food-fish acres	Percent of total MS food-fish acres [1]	Percent of regional MS food-fish acres [2]
Delta	65	45.5	37,136	43.2	46.4
East MS	78	54.5	4,130	4.8	68.8
TOTAL	**143**	**100.0**	**41,266**	**48.0**	**–**

[1]USDA-NASS reported 105,000 catfish water surface acres in 1999 with 86,000 acres in food-fish production and 19,000 acres in broodstock and fingerling production.
[2]MASS estimated that there are approximately 80,000 water surface acres of food-fish production in the Delta and approximately 6,000 acres in east Mississippi.

Table 4. Mississippi catfish farmer diuron mail survey responses by district and county, 1999.

County	Survey responses returned		Acreage represented by responses	
	Number	Percent of all usable surveys	Number of food-fish acres	Percent of total MS food-fish acres [1]
Bolivar	4	2.8	1,134	
Other Counties	3	2.1	111	
District 10 Total	7	4.9	1,245	1.4
Humphreys	18	12.6	7,541	
Leflore	4	2.8	5,492	
Sharkey	3	2.1	2,545	
Sunflower	20	14.0	13,458	
Washington	5	3.5	4,435	
Yazoo	6	4.2	2,270	
District 40 Total	56	39.2	35,741	41.6
Chickasaw	5	3.5	227	
Lowndes	6	4.2	519	
Noxubee	60	42.0	3,066	
Other Counties	6	4.2	300	
District 60 Total	77	53.9	4,112	4.8
Other Districts	3	2.1	168	0.2
TOTAL	**143**	**100.0**	**41,266**	**48.0**

[1]There were 86,000 water surface acres for food-fish production in Mississippi in 1999 (USDA-NASS 1999). Acreage from a single operation was accredited to the county in which the farm headquarters was located. If fewer than three responses came from one county or more than 60% of the acreage in the county came from one respondent, the results were combined into an “Other” category.

Number of Days Delayed

In 1999, the reduction in the average number of harvest days that were delayed by off-flavor problems was statistically significant ($\alpha = 0.15$) (Table 5). Flavor-delayed days per pond per operation per year were 31% fewer in 1999 than in 1998; there was a 38% reduction when 1999 was compared with 1997. The total number of additional production days resulting from flavor-related delays in catfish harvesting during 1999, 1998, and 1997 was estimated from survey responses. Mississippi's catfish industry lost an enormous number of production days – approximately 500,000 days in 1999. Compared with 1998, there was a reduction of approximately 10% in the total number of additional grow-out days required before harvesting could occur in 1999. The number of extra grow-out days was reduced by approximately 16% in 1999 compared with the number in 1997.

Additional Operating Expenses

Table 6 presents detailed cost estimates for additional feed, labor, and other costs of maintaining fish during periods when fish harvest was delayed by off-flavor episodes. These additional operating expenses were less for 1999, when diuron was available, than for 1998 and 1997, when diuron was not available for farmer use. Feed, labor, and other expenses due to flavor-prolonged harvests were $45 to $49 per acre less in 1999 ($79 per acre per year) than in 1998 ($125 per acre per year) and in 1997 ($137 per acre per year), respectively. Mississippi's aggregated annual operating costs accrued when off-flavor episodes delayed catfish harvest were estimated to be approximately $6.8 million in 1999, $10.5 million in 1998, and $11.4 million in 1997 (Table 7). Additional operating costs caused by delayed harvests in 1999 were 34% less than 1998 costs and 41% less than 1997 costs.

Fish Mortality during Delays

Catfish losses from disease, low dissolved oxygen, and bird predation during the off-flavor-induced harvest delay period were less in 1999 ($76 per acre per year) than in 1998 ($127 per acre per year) and in 1997 ($111 per acre per year) (Table 8). Significant ($\alpha = 0.15$) differences occurred between the 1999 total fish loss value compared with 1998 and 1997. Disease was the most expensive loss category for all 3 years, followed by poor water quality. Most disease mortality occurs in

Table 5. Number of days in Mississippi when catfish harvests were prevented because of the presence of off-flavor, 1999.[1]

Variables	1999	1998	1997
Average number of off-flavor days (per pond per operation per year)	48a (n = 105 farmers)	63b (n = 94 farmers)	66b (n = 85 farmers)
Average number of ponds per farm	25.5	25.0	25.0
Number of catfish operations	405	346	349
Total number of additional grow-out days required before harvesting could occur	**495,720**	**544,950**	**575,850**

[1]Letters (a and b) represent significant differences at the $\alpha = 0.15$ level; same letters represent no significant difference and different letters represent significant differences.

Table 6. Mississippi catfish operating expenses for feed, labor, and other costs incurred during additional grow-out days caused when off-flavor prevented prompt harvesting of food-sized fish, 1999.[1]

Expense item	1999 (n = 50 farmers)	1998 (n = 51 farmers)	1997 (n = 48 farmers)
	$/A	*$/A*	*$/A*
Feed	58a	76a	79a
Labor	4a	13b	18b
Other	17a	36a	40a
TOTAL	**79a**	**125a**	**137a**

[1]Letters (a and b) represent significant differences at the $\alpha = 0.05$ level; same letters represent no significant difference and different letters represent significant differences.

Table 7. Aggregate Mississippi catfish farming operating expenses for feed, labor, and other costs incurred during additional grow-out days caused when off-flavor prevented prompt harvesting of food-sized fish, 1999.

Expense item	1999	1998	1997
	$/year	*$/year*	*$/year*
Feed	5,000,000	6,400,000	6,600,000
Labor	400,000	1,100,000	1,500,000
Other	1,400,000	3,000,000	3,300,000
TOTAL	**6,800,000**	**10,500,000**	**11,400,000**

Table 8. Average per-acre value of Mississippi catfish losses due to diseases, poor water quality, and bird predation during additional grow-out days caused when off-flavor prevented prompt harvesting of food-sized fish, 1999.[1]

Loss category	1999 (n = 62 farmers)	1998 (n = 52 farmers)	1997 (n = 51 farmers)
	$/A	*$/A*	*$/A*
Disease	46a	67a	61a
Poor water quality	19a	47b	38b
Bird predation	11a	13a	12a
TOTAL	**76a**	**127b**	**111b**

[1]Letters (a and b) represent significant differences at the $\alpha = 0.15$ level; same letters represent no significant difference and different letters represent significant differences.

Table 9. Aggregate Mississippi catfish losses due to diseases, poor water quality, and bird predation during additional grow-out days caused when off-flavor prevented prompt harvesting of food-sized fish, 1999.

Loss category	1999	1998	1997
	$/year	*$/year*	*$/year*
Disease	4,000,000	5,600,000	5,000,000
Poor water quality	1,600,000	3,900,000	3,100,000
Bird predation	900,000	1,100,000	1,000,000
TOTAL	**6,500,000**	**10,600,000**	**9,100,000**

the fall and spring; when off-flavor prevents harvest during these seasons, the risks of losing fish increases. Aggregate catfish losses from disease, poor water quality, and bird predation during the off-flavor period were estimated to be $6.5 million in 1999, $10.6 million in 1998, and $9.1 million in 1997 (Table 9). Reduction in catfish mortality levels by harvesting fish on time may be the greatest economic benefit of diuron usage.

Transportation Cost of Off-flavor Tests

Another aspect of the off-flavor problem is the direct cost paid by producers to transport fish samples for flavor testing at the processing plant. The survey included a series of questions to determine the overall transportation expense for individual farmers to sample fish before harvesting. Individual farm results were then extrapolated to the Mississippi state level.

Survey results indicated that the average number of fish samples required before a pond could be harvested was approximately eight in 1999, 13 in 1998, and 14 in 1997 (Table 10). The transportation cost calculation used the round-trip distance to the processor from the farm, the number of samples needed before a pond could be harvested, and the average number of pond samples taken to the processor each trip. The average 1999 round-trip mileage was 73.1 miles per trip, which was 5.6 and 6.3 miles further than in 1998 and 1997, respectively (Table 10). Total off-flavor sample transportation miles were calculated to be greatest in 1997 and fewest in 1999. Total estimated off-flavor sample transportation costs for the state of Mississippi were estimated to be approximately $215,000 in 1999 or $2.49 per food-fish acre; $246,000 in 1998 or $2.93 per acre; and $304,000 in 1997 or $3.67 per acre.

A regional comparison of Mississippi's 1999 annual fish sampling transportation costs found that the average cost per acre was much lower in the Delta ($1.48 per acre) than in eastern Mississippi ($4.87 per acre) (Table 11). Notably, the average number of samples taken to the processor before being declared on-flavor was higher in the Delta (10.4 samples per pond) than in east Mississippi (6.6 samples). However, the eastern farmers did not take as many fish samples per trip and had to travel 20 additional miles per trip than the Delta farmers.

Total Cost of Off-flavor

The total estimated costs of off-flavor to the Mississippi catfish industry for 1997, 1998, and 1999 are summarized in Table 12. Costs include additional operating expenses, value of fish lost, sampling transportation costs, and an opportunity cost for delayed sales income. The 1999 cost of off-flavor to Mississippi farmers was approximately $14.7 million, which is a 37% decrease from 1998 and a 35% decrease from 1997. Off-flavor-related costs were approximately $23.2 million in 1998 and approximately $22.7 million

Table 10. Estimated transportation costs associated with off-flavor sampling at the processing plant for Mississippi catfish producers, 1999.[1]

Variable	1999	1998	1997
Number of ponds harvested	5,194	5,406	5,186
Average number of catfish sampled before fish could be harvested	8.1	12.5	13.6
Average number of ponds sampled per trip	4.3	5.5	4.7
Round-trip distance from farm to processing plant	73.1	66.8	67.5
Total annual transportation miles	715,214	820,729	1,012,925
Total fish sampling transportation cost for flavor checking	$214,564	$246,219	$303,878
Annual sampling transportation cost per food-fish acre of production	$2.49	$2.93	$3.67

[1]The formula for calculating the amount of Mississippi catfish farmers expenses for fish sampled is ((((Number of ponds harvested * Average number of fish samples before harvesting could occur) / (Average number of ponds being sampled per trip to the processing plant)) * (Average round-trip distance in miles from the farm to the processor plant)) * ($0.30 per mile of transport).

Table 11. Estimated transportation costs associated with off-flavor sampling at the processing plant for Delta and eastern Mississippi catfish farmers, 1999.

Variable	Delta	East Mississippi
Number of harvested acres[1]	56,800	3,960
Average pond size	11.9	9.8
Number of ponds harvested	4,773	404
Average number of catfish sampled before fish could be harvested	10.4	6.6
Average number of ponds sampled per trip	7.3	2.3
Round-trip distance from farm to processor	58	84
Total annual transportation miles	394,403	97,401
Total fish sampling transportation costs for flavor checking	$118,322	$29,220
Annual sampling transportation expense per food-fish acre	$1.48	$4.87

[1]The number of acres harvested was estimated by multiplying the number of food-fish acres in each region by the percent of total ponds harvested per year as calculated from survey results. In the Delta, 71% of 80,000 food-fish acres were harvested in 1999. In eastern Mississippi, 66% of 6,000 food-fish acres were harvested in 1999.

in 1997. Although many factors could have affected the reported reduction in off-flavor losses, the use of diuron in 1999 was the most important change in management from prior years. Therefore, diuron use was probably the major factor responsible for the decrease in off-flavor costs to the Mississippi catfish industry. Additionally, the survey results did not discriminate between algae-related off-flavors and other flavor problems. Diuron is a herbicide and only effective against algae-related flavor problems. Thus, the effectiveness of diuron is underestimated when results are based on "total" off-flavor problems, rather than restricting the analysis to algae-related off-flavors.

Table 12. Aggregate off-flavor costs to the Mississippi catfish industry, 1997-1999.[1]

Cost category	1999	1998	1997
	$/year	*$/year*	*$/year*
Operating expenses	6,800,000	10,500,000	11,400,000
Catfish mortality	6,500,000	10,600,000	9,100,000
Fish sampling transportation	200,000	200,000	300,000
SUBTOTAL	**13,500,000**	**21,300,000**	**20,800,000**
Opportunity cost [2]	1,200,000	1,900,000	1,900,000
TOTAL	**14,700,000**	**23,200,000**	**22,700,000**

[1]Costs include additional operational expenses, value of lost fish, off-flavor fish sampling transportation costs, and an opportunity cost caused when off-flavor prevented prompt harvesting of catfish.
[2]An opportunity charge of 9% is a proxy for missed harvest events and delayed cash income and the potential use of the money elsewhere during the delay period caused by off-flavor.

Amount of Diuron Used

Determining the amount and cost of diuron usage in the Mississippi catfish industry in 1999 was another primary objective of the farmer survey. Diuron was approved for nine weekly pond applications at 0.5 ounce of diuron product per acre-foot of water. Farmers did not always use the full nine applications (Figure 1). Eastern Mississippi catfish farmers used an average of 4.6 weekly applications, and Delta farmers used 5.8 applications per pond (Table 13). However, nine applications per pond was the most common application rate, although the overall average was lower.

Farmers applied approximately 13 tons of diuron to 36,322 acres of food-fish ponds during 1999, which is approximately 43% of all catfish acreage in Mississippi (Table 13). Most farmers applied diuron to fewer than 100 acres of food-fish ponds on their farms in 1999 (Figure 2). Early usage of diuron may have been reduced because the Section 18 Emergency Exemption was not granted until late in the spring, in which case the farmer would have weighed diuron use benefits against dissolved oxygen problems. If diuron had been approved earlier in the year, farmers may have applied diuron earlier in the spring to lessen the chance of dissolved oxygen problems after application.

It is estimated that almost 12 tons of diuron product were applied in 1999 in the Delta region and just over 1 ton in the eastern part of the state (Table 13). These quantities represented diuron treatment for 41% and 59% of all food-fish pond acreage in the Delta and eastern regions of Mississippi, respectively. Total expenditures to purchase these amounts of diuron were calculated to be $143,000 for the Delta and $12,000 for the eastern region. In all, the Mississippi catfish industry spent approximately $155,000 on diuron use in 1999.

Problems from Diuron Usage

Applications of any herbicide, including diuron, to eutrophic aquaculture ponds will suppress plant growth, resulting in reduced rates of oxygen production and ammonia assimilation, both of which may lead to water quality deterioration that can stress fish. When farmers were asked if they had any adverse water quality results from diuron usage, 21% indicated they had some water quality problems after applying diuron. Caution must be exercised when evaluating these responses because oxygen and ammonia problems are common in ponds during summer, even when no algicides are applied. So, it is impossible to differentiate between problems that were caused by diuron use and those that would have occurred regardless of diuron use. Thus, the following results, when extrapolated to the state level, represent the "worst-case" scenario, with actual fish losses exclusively linked to diuron usage falling somewhere between zero and the calculated maximum.

In the Delta region, 26% of the farmers who used diuron reported oxygen or ammonia problems. The average reported loss per affected Delta farm was 1,833 pounds of food fish, or 0.14 pound of fish per acre treated with diuron. In the eastern region of

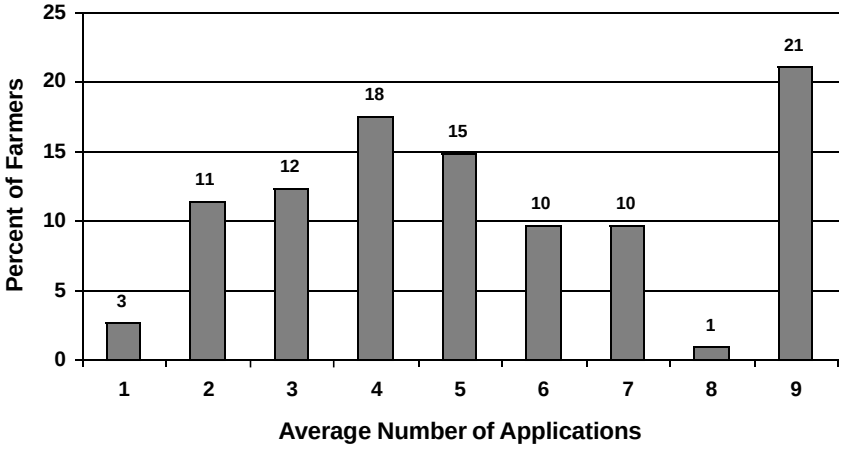

Figure 1. Average number of diuron applications for Mississippi catfish farmers in 1999.

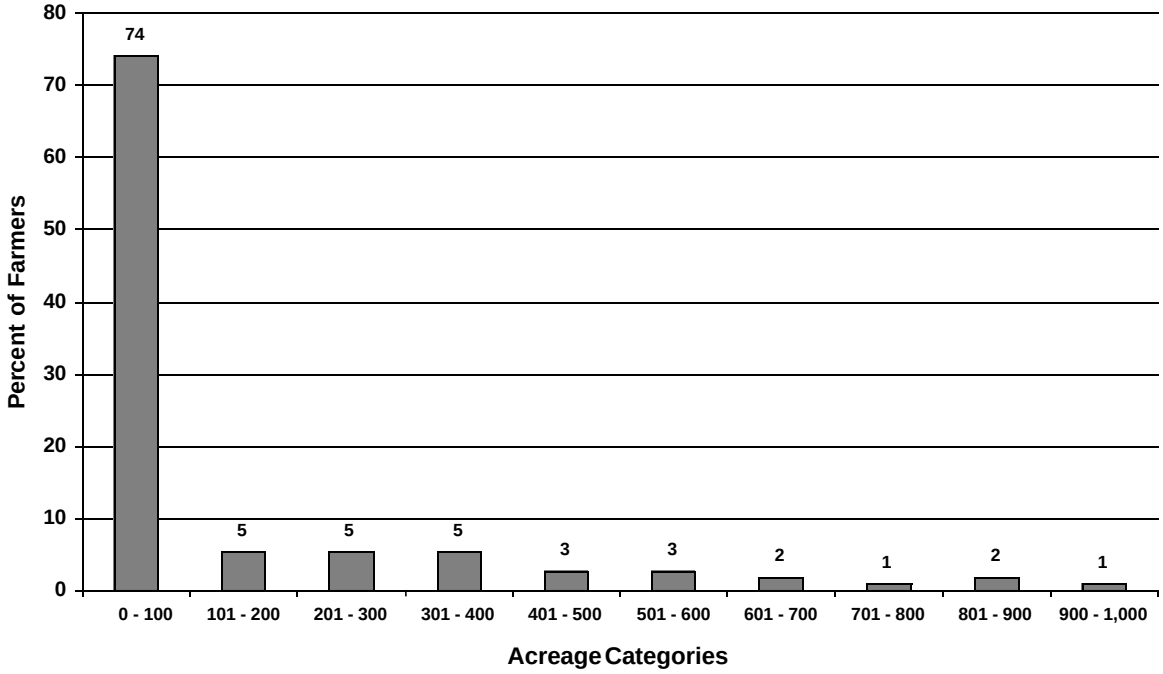

Figure 2. Catfish acreage treated with diuron in 1999.

Mississippi, 18% of the farmers reported problems after diuron use. These problems caused east Mississippi farmers to lose an average of 750 pounds of food fish per affected farm, or 4.2 pounds of catfish per diuron-treated acre. For the entire state, there were approximately 1,292 pounds of fish lost per affected farm, or 1.97 pounds lost per food-fish acre treated with diuron. Losses of fish due to diuron-related water quality deterioration in the eastern portion of the state were extrapolated to be valued at approximately $11,000; in the Delta, approximately $40,000. The combined state-level loss totaled $51,000 for an estimated loss of 68,112 pounds of food-sized catfish (Table 13).

Total Cost of Diuron Usage

The combined cost of diuron products applied in Mississippi for 1999, along with the value of lost fish resulting directly from diuron usage, is presented in

Table 13. Quantity and cost of diuron used, and value of fish lost from diuron usage in the eastern region, Delta region, and all of Mississippi, 1999.[1]

Variable	East Mississippi	Delta	All of Mississippi
Acres treated with diuron	3,530	32,802	36,332
Average number of treatments per pond	4.57	5.83	5.10
Tons of diuron product applied	1.01	11.94	12.95
Total cost of diuron product applied	$12,109	$143,331	$155,440
Value of fish lost due to diuron usage [2]	$11,208	$39,876	$51,084
Total cost of diuron use in Mississippi in 1999	**$23,317**	**$183,207**	**$206,524**

[1]This information is based on 86,000 food-fish acres of catfish in Mississippi in 1999 (USDA-NASS 1999) – 80,000 acres in the Delta and 6,000 acres in eastern Mississippi. A weighting factor using the ratio of survey acres treated with diuron to all acres reported in the survey was applied to all Mississippi food-fish acres to obtain state levels of diuron usage. Additional assumptions in this estimation procedure used an average of 4-foot-deep ponds, a 0.5-ounce diuron treatment per acre-foot, and a diuron cost of $24 per 4-pound bag.
[2]These values are based on a farm-level price of $0.75 per pound. Oxygen and ammonia problems are common during summer in ponds, even when no algicides are applied. Thus, it is impossible to differentiate between problems caused by diuron use and those that would have occurred regardless of diuron use. Therefore, the estimated values of fish lost due to diuron usage represent the "worst-case" scenario, with actual fish losses exclusively linked to diuron usage falling somewhere between zero and the calculated maximum.

Table 13. The cost for the Delta ($183,207) was approximately five times greater than for eastern Mississippi ($23,317). However, Delta costs were for approximately 10 times more diuron-treated acres than those in the eastern region.

Diuron Product Purchases

Two diuron products were available for catfish producers to purchase: Diuron 80 Herbicide from the Drexel Company and Nautilus Aquatic Herbicide from the Griffin Company. Twenty-two percent of the farmers purchased both products, 47% purchased the Nautilus Aquatic Herbicide product, and 31% purchased the Drexel product (Table 14).

Table 14. Percent of Mississippi catfish farmers who purchased specific diuron products, 1999.

Product	Number of responses	Percent
Diuron 80 Herbicide (Drexel)	33	31
Nautilus Aquatic Herbicide (Griffin)	51	47
Both	24	22
TOTAL	**108**	**100**

Effectiveness of Diuron in Reducing Off-flavor

Percentage of Treated Ponds with Off-flavor

Table 15 presents monthly percentages of off-flavor occurrences in ponds that were treated with diuron. The overall response rate for this question was low, ranging from a low of 36% of usable survey respondents for October (n = 48) to a high of 48% for August (n = 69). Most likely, these lower response rates were due to farmers not keeping records of diuron applications or not having corresponding records of off-flavor test results for these ponds. As water temperature increased in late spring and summer, there were more off-flavor occurrences and more diuron usage; more respondents answered the questions related to these months.

The percent of diuron-treated ponds with off-flavor fish was lowest in May (37%) and highest in June (56%). For every month except October, east Mississippi catfish farmers reported fewer off-flavor occurrences in diuron-treated ponds than Delta farmers reported. The number of diuron-treated ponds with off-flavor fish in east Mississippi ranged from 21% in May to 48% in October. In the Delta, the low point was 37% in October, and the high point was 58% in June.

Table 15. Percentage of diuron-treated ponds in Mississippi that were flavor tested and indicated an off-flavor presence, 1999.[1]

Month	East Mississippi	Delta	All respondents
May	21 (n = 15)	41 (n = 20)	37 (n = 35)
June	41 (n = 24)	58 (n = 26)	56 (n = 50)
July	42 (n = 27)	51 (n = 34)	50 (n = 61)
August	44 (n = 35)	49 (n = 34)	48 (n = 69)
September	46 (n = 34)	48 (n = 30)	47 (n = 64)
October	48 (n = 21)	37 (n = 27)	39 (n = 48)

[1]Survey results do not discriminate between algae-related off-flavors and other flavor problems caused by nonalgae sources. Diuron is a herbicide and is only effective against algae-related flavor problems. As such, the effectiveness of diuron is underestimated because these results are based on "total" off-flavor problems (i.e., algae and nonalgae related off-flavors), rather than restricting the analysis to algae-related off-flavors. (n = number of farmers responding.)

Comparison of Off-flavor Occurrences

The survey also asked producers to enumerate the number of off-flavor occurrences on their farms for 1997, 1998, and 1999. Tables 16, 17, and 18 present data on the number of off-flavor occurrences in all of Mississippi, the eastern region, and the Delta region, respectively.

When the total number of off-flavor occurrences from the survey sample was extrapolated to the state level, there were approximately 43,000 occurrences in 1999, 52,500 occurrences in 1998, and 52,300 occurrences in 1997 (Table 16). Based on averages for all observations, there was a significantly ($\alpha = 0.15$) lower number of off-flavor occurrences per pond in 1999 (4.5) than in 1998 (7.5) or in 1997 (7.6).

As evidenced by a lower response rate for Delta respondents, producers with larger farms and more ponds had more difficulty enumerating off-flavor occurrences than owners of the smaller catfish farms typical of east Mississippi. Only about 68% of Delta farmers responded to this question; these producers averaged 628 acres and 53 ponds per farm. On the other hand, east Mississippi farmers had a 96% response rate; they averaged 53 acres and 5 ponds per farm. This difference is probably because off-flavor occurrences on larger farms are managed by temporarily foregoing harvest in the affected pond and, alternatively, harvesting fish from another pond with on-flavor fish. This practice lessens the impact of off-flavor problems for managers of larger farms, thus making the occurrences less memorable. Frequently, managers of smaller farms with fewer ponds cannot rely on harvesting a nonaffected pond because they all may be off-flavor or there may be no harvest-sized fish available. These factors mean that off-flavor incidents affect cash flow on a small farm more quickly than on a larger farm. Thus, off-flavor occurrences may be more memorable to personnel on smaller farms.

When the data are separated into the eastern and Delta regions of Mississippi, the per-farm episodes of off-flavor are much greater in the Delta. The Delta's greater farm size most likely accounts for much of this difference. Per-pond episodes of off-flavor in the Delta for 1999 are more than double the episodes reported in east Mississippi. In east Mississippi, the annual per-pond occurrences of off-flavor were statistically lower ($\alpha = 0.05$) in 1999 than in 1998 or 1997. No detectable differences were observed between 1998 and 1997 lev-

Table 16. Total and average number of off-flavor occurrences experienced by Mississippi catfish farmers, 1999.[1]

Variable	1999	1998	1997
Total number of off-flavor occurrences	42,900 (n = 120)	52,480 (n = 98)	52,255 (n = 89)
Average number of off-flavor occurrences per farm per year	172a (n = 120)	239a (n = 95)	252a (n = 86)
Average number of off-flavor occurrences per pond per year	4.5a (n = 116)	7.5b (n = 94)	7.6b (n = 88)

[1]Letters (a and b) represent significant differences at the $\alpha = 0.15$ level; same letters represent no significant difference and different letters represent significant differences. (n = number of farmers responding.)

Table 17. Total and average number of off-flavor occurrences experienced by eastern Mississippi catfish farmers responding to the diuron survey, 1999.[1]

Variable	1999	1998	1997
Total number of off-flavor occurrences	1,105 (n = 75)	1,041 (n = 57)	981 (n = 49)
Average number of off-flavor occurrences per farm per year	14.7a (n = 75)	18.3a (n = 57)	20.0a (n = 49)
Average number of off-flavor occurrences per pond per year	2.98a (n = 72)	4.36b (n = 54)	4.48b (n = 47)

[1]Letters (a and b) represent significant differences at the $\alpha = 0.05$ level; same letters represent no significant difference and different letters represent significant differences. (n = number of farmers responding.)

els (Table 17). In the Delta, there were no significant differences in per-pond or per-farm off-flavor occurrences (Table 18).

However, according to the definition of off-flavor (see the methods section), farmers were asked to report repeated sampling of the same pond as separate occurrences. This factor introduces a strong bias toward emphasizing off-flavor occurrences over on-flavor occurrences. In other words, the repeated sampling scheme emphasizes failures of a treatment over successes. Therefore, the actual success of diuron in reducing the 1999 off-flavor rate was likely much better than that suggested by information from the farmers, as there is a masking of the chemical's success rate.

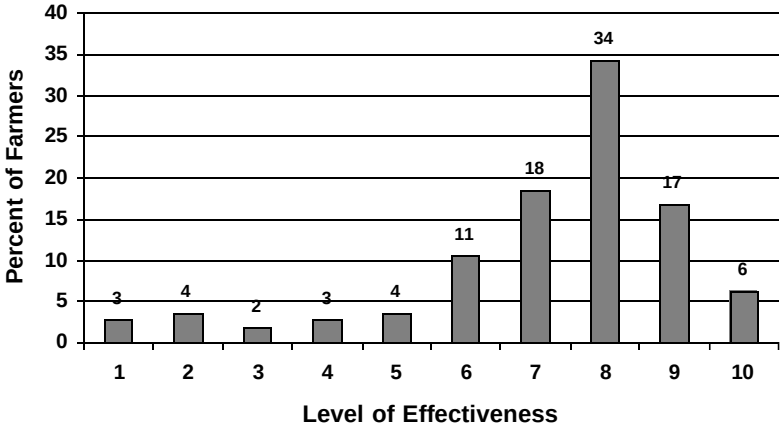

Figure 3. Diuron effectiveness rating by Mississippi catfish farmers in 1999 (rating scale: 1 = no effect to 10 = very effective).

Perceived Effectiveness of Diuron

Farmers were asked to rank the effectiveness of diuron treatments in preventing off-flavor occurrences on their farm in 1999. Figure 3 presents farmer responses. Thirty-four percent of respondents rated diuron as "very effective" (8 on a scale of 1-10). Only 16% of all respondents gave a ranking of 5 (no difference) or lower. When farmers were given a chance to comment on diuron and its effectiveness, 89% said diuron would be a good management tool to have in the catfish industry (Figure 4). Only 5% had negative comments, and 6% wanted to use the product longer before they could definitively answer this question.

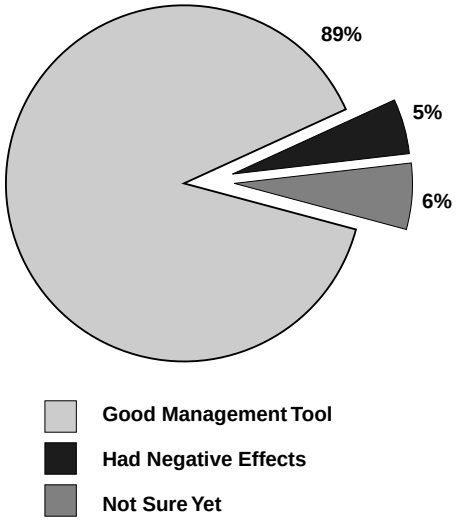

Figure 4. Mississippi catfish farmers comments on diuron in 1999.

Table 18. Total and average number of off-flavor occurrences experienced by Mississippi Delta catfish farmers responding to the diuron survey, 1999.[1]

Variable	1999	1998	1997
Total number of off-flavor occurrences	19,543 (n = 44)	22,378 (n = 40)	21,455 (n = 39)
Average number of off-flavor occurrences per farm per year	444.2a (n = 44)	559.4a (n = 40)	550.1a (n = 39)
Average number of off-flavor occurrences per pond per year	7.0a (n = 43)	10.0a (n = 39)	12.1a (n = 39)

[1]Letters (a and b) represent significant differences at the $\alpha = 0.05$ level; same letters represent no significant difference and different letters represent significant differences. (n = number of farmers responding.)

Benefit-Cost Analysis of Diuron Usage

The benefits of diuron use to the Mississippi catfish industry can be measured as the difference between the annual aggregate off-flavor costs in 1999 and the same costs for 1998 or 1997. These values have already been calculated and come directly from Table 12. The cost of diuron usage in 1999 was the value of the diuron quantity used, plus the value of any fish directly lost from diuron usage; these costs come directly from Table 13. In Table 19, the benefits, costs, and benefit-to-cost ratios are presented. The benefit-to-cost ratio (B/C) was 42.5 to 1 when comparing 1999 with 1998 and 36.5 to 1 when comparing 1999 with 1997. Whenever the B/C ratio is greater than one, the benefits outweigh the costs. In this case, the use of diuron is economically justified in its role of reducing off-flavor in the Mississippi catfish industry.

The benefit-to-cost ratio analysis is supported by the statistically significant differences between the number of off-flavor occurrences in 1999 and 1998 and between 1999 and 1997. The reduction in off-flavor occurrences on a per-pond basis was significantly (α = 0.15) lower between 1999 and 1998 and lower between 1999 and 1997 (Tables 16, 17, and 18). There was an 18% reduction in total off-flavor occurrences between 1999 and 1998 and an 18% reduction between 1999 and 1997 levels.

Table 19. Benefit-cost analysis of diuron usage in the Mississippi catfish industry in 1999.

Variable	Comparisons	
	1999 to 1998	1999 to 1997
Benefit ($/year) [1]	8,500,000	8,000,000
Cost ($/year) [2]	200,000	200,000
Benefit-to-cost ratio [3]	42.5 : 1	36.5 : 1

[1]Benefit is the reduction in off-flavor costs to the industry. Benefits from diuron usage in 1999 were estimated based on the differences between 1999 and either 1998 or 1997 expenses for aggregate additional operating expense, fish losses, and transportation costs to sample fish caused by off-flavor (from Table 12). The difference represents the reduction in flavor-associated costs to the industry due to diuron.
[2]Cost of diuron usage in 1999 includes diuron quantities purchased and the value of fish losses directly attributable to diuron usage (from Table 13).
[3]If the benefit-to-cost ratio is greater than 1, then the benefits outweigh the costs. In this case, diuron use is economically justified for use in the Mississippi catfish industry.

Results: Processor Off-flavor Records

Processing plant records of the number of total flavor checks per day and the number of off-flavor results were used to measure the relative difference in severity between years. A t-test between the mean percentage of off-flavor occurrences in 1999 compared with a combined mean of off-flavor percentages for 1997 and 1998 was statistically significant ($\alpha = 0.05$) (Table 20). The average 1999 off-flavor percentage was 43% compared with 52% for 1997 and 1998. As discussed in the methods section, the repeated sampling of the same pond when off-flavor was present tends to emphasize failure of the treatment over success and actually dilutes the success of the treatment. Therefore, the true effect of the chemical is masked, and diuron's real benefit is underestimated here. However, it is still proportionally correct when compared with earlier years. Figure 5 presents the actual daily percentages and trend lines of off-flavor results from processor records. The trend clearly shows that farmers experienced fewer off-flavor problems during the period from April 26 to December 31, 1999, when compared with the same periods in 1997 and 1998. Though many factors can account for off-flavor in any given year, the fact is that diuron was the single greatest change in catfish production management occurring in 1999 and most likely plays an important role in these yearly differences.

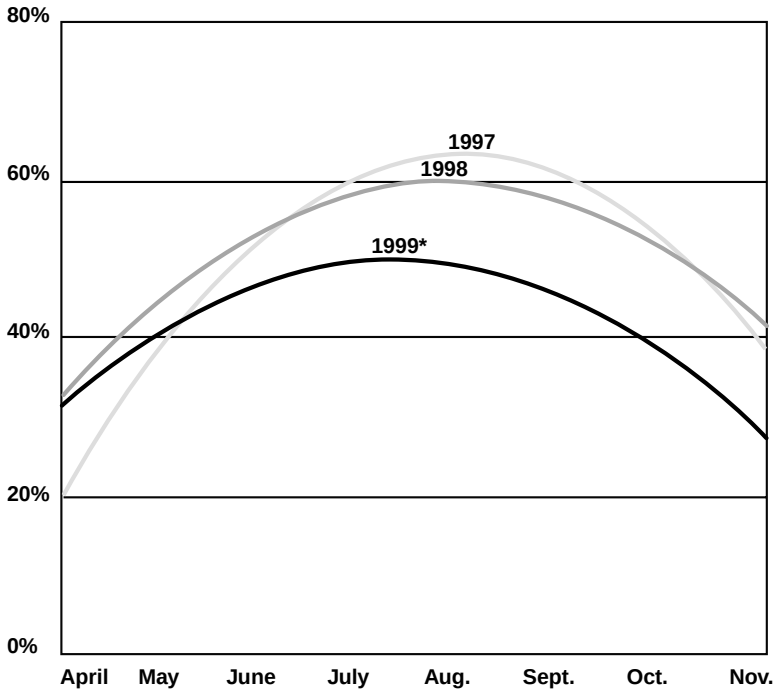

Figure 5. Percent of processor flavor checks with off-flavor, April 26 to December 31, 1997-1999 (1999 significantly different from 1997 and 1998).

Table 20. T-test [1] of mean differences in the percent of off-flavor occurring at Mississippi Delta processing plants between April 26 and December 31 in 1997 and 1998 (combined) to the same period in 1999.

Variable	1997 and 1998 combined	1999
Mean percent of off-flavor checks	52.13	43.27
Variance	1.88	1.45
Observations	462	219
T-statistic	8.5658	
T-critical one-tail	1.6480	
Probability (T<=t)	< 0.0001	

[1]Two-sample assuming unequal variances.

CONCLUSIONS

The results of this study, which is based on a comprehensive survey of catfish producers and processors, demonstrated the following findings:

- Approximately 13 tons of diuron were applied to 36,300 acres of Mississippi catfish ponds in 1999 at a cost of $155,450.
- Treated acreage was approximately 43% of all food-fish acreage in the state.
- Average diuron treatment frequency was 5.1 applications per pond – less than the permit ted nine applications per pond – indicating that fish flavor quality improved before the complete treatment regimen was needed.
- The farmer survey and processor records both showed that the occurrence of off-flavor was lower in 1999 than in either 1998 or 1997.
- Off-flavor caused an additional 500,000 days of grow-out past harvestable size in 1999, which was 10% lower than 1998 and 16% lower than 1997.
- Aggregate Mississippi operational expenses from flavor-related delays in fish harvest was $14.7 million for 1999, which was $8.5 million lower than 1998 ($23.2 million) and $8 million lower than 1997 ($22.7 million).
- The benefit-to-cost ratio for diuron usage in Mississippi was 42.5 to 1 for 1999 compared with 1998, and it was 36.5 to 1 for 1999 compared with 1997.
- Based on benefit-to-cost analysis, diuron was an effective tool in reducing the crisis of the off-flavor problem to the Mississippi catfish industry in 1999.

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APPENDIX I. FARMER SURVEY

Survey of Diuron Effectiveness in the Mississippi Catfish Industry

The Thad Cochran National Warmwater Aquaculture Center and the Bureau of Plant Industry (MS Department of Agriculture and Commerce) are sending this survey to you. Its purpose is to determine the effectiveness and economic impact of diuron in reducing off-flavor occurrences in the Mississippi catfish industry.

Your participation is voluntary, but your experience with Diuron usage in 1999 is critical in determining Diuron s effectiveness in decreasing off-flavor occurrences. We urge you to complete and send back this survey in the enclosed pre-paid envelope. Your answers will be kept anonymous and confidential; results will only be presented when combined with all other responses. The survey should take approximately 15 to 25 minutes to complete.

If you have any questions about this survey or would like additional information concerning this survey, contact Dr. Terry Hanson at (662) 325-7988.

NOTE: This survey is being sent to **ALL** Mississippi catfish farmers who attended last spring s workshops on proper Diuron usage. Thus, it is likely that the survey will go to more than one person on your farm. So, to avoid duplication, please send back only **ONE** completed survey per catfish farm.

If someone else on this farm will be filling out this survey, please check the following box and RETURN the survey in the enclosed envelope. THANK-YOU.

❑ Someone else will fill out the survey for this farm.

If you did NOT use Diuron in 1999, please explain why, i.e., fingerling farmer, out of business, too expensive, dealer - not a producer, etc., and RETURN the survey in the enclosed envelope.

_____

_____

1. In what **county** are the majority of your food fish acreage located? _____

2. Estimate your farm s total **food fish acres, number of ponds, number of ponds harvested, and total pounds harvested** for 1999, 1998 and 1997:

YEAR	Number of Acres on Farm	Number of Ponds on Farm	Number of Harvested Ponds	Pounds of Food Fish Harvested
1999				
1998				
1997				

3. In column a) below **ESTIMATE** your **TOTAL** number of off-flavor occurrences for **ALL** your ponds in 1997, 1998, and 1999 using the following definition for off-flavor.

Definition of OFF-FLAVOR: An off-flavor occurrence is counted when a fish sample from a pond was rejected by a processing plant because fish were deemed to be off-flavor. Additionally, when you brought a second, (third, fourth, fifth, etc) fish sample from the **SAME** pond to a processing plant and it was also rejected because of off-flavor, COUNT these occurrences as ADDITIONAL off-flavor episodes. In other words, each rejected fish sample from a pond would count as an off-flavor occurrence.

Additionally for columns b), c), and d), write in your 1999, 1998 and 1997 responses for:

b) the average number of fish samples required per pond before your fish could be harvested;

c) the average number of pond samples taken to the processor in a trip; and

d) the average one-way distance in miles to the processor you sold most of your fish to for each year.

Year	a) Total Number of OFF-FLAVOR Occurrences	b) Average Number of Fish Samples Required before fish could be harvested	c) Average number of pond samples taken to a processor per trip	d) Average one-way distance, in miles, to the processing plant for MOST of your sales
1999				
1998				
1997				

4. How many acres of food fish ponds on your farm were **treated** with diuron in 1999?
_____ acres

5. Which Diuron product(s) did you use? Circle a), b), or c) below.

a) Diuron 80 Herbicide (Drexel) **b)** Nautilus Aquatic Herbicide (Griffin) **c)** Both
Where did you buy your Diuron product? Name:_____ City: _____

6. Some producers began using Diuron in April and May of this year, others did not begin using Diuron until later in the summer. When Diuron treatments occurred in ponds with fish that were less than harvest size, it is likely that no off-flavor tests were conducted on these fish. Later in the summer Diuron was being applied to ponds having harvest-sized fish and fish were flavor tested when they were taken to the processing plant. This questions tries to distinguish between the number of ponds being treated with Diuron with and without flavor tests. And then the number of ponds testing positive for off-flavor and having been treated with Diuron.

In the following table write in the number of ponds treated with Diuron in 1999 for each month and whether fish from the pond were tested for off-flavor during that month.

Specifically, in column (1) write the number of ponds treated with Diuron during each month **BUT had no fish tested for off-flavor**; in column (2) write the number of ponds that were **treated with Diuron AND had fish tested for off-flavor** that month. Finally, in column (3) write the **number of ponds having fish with off-flavor and were rejected by the fish processor** for each month.

MONTH	NUMBER OF PONDS TREATED WITH DIURON:		NUMBER OF TREATED PONDS WITH OFF-FLAVOR
	But NOT Tested for off-flavor (1)	AND Tested for off-flavor (2)	(3)
March			
April			
May			
June			
July			
August			
September			
October			

7. Did you generally use the full 9 applications allowable of Diuron per pond? **Check one.**
_____ YES _____ NO

If **NO**, approximately how many Diuron applications per pond did you apply?
Approximately _____ applications per pond

8. Did you experience any severe oxygen or ammonia problems in the ponds you treated with Diuron? **Check one. _____ YES _____ NO**

If **YES**, how many pounds of fish died because of the Diuron treatment? _____ pounds

9. While off-flavor does not harm fish it can prevent harvesting. During this off-flavor period when no harvesting can occur, fish may be susceptible to **diseases, low oxygen levels, or bird predation**; additionally **more feed, labor, and other costs are incurred** to keep fish at an acceptable harvest size. Consider these sources of loss and additional costs in answering the following questions.

a) How many days, weeks, OR months did your typical **off-flavor period** of **NO harvesting** last for each year?

1999	**1998**	**1997**
_____ days, OR	_____ days, OR	_____ days, OR
_____ weeks, OR	_____ weeks, OR	_____ weeks, OR
_____ months	_____ months	_____ months

b) Estimate the **ADDITIONAL** costs **you paid** for the following items **BECAUSE off-Flavor PREVENTED** fish from being harvested for some period of each year:

	1999	**1998**	**1997**
Additional Feed Fed	$ _____	$ _____	$ _____
Additional Labor Used	$ _____	$ _____	$ _____
Additional OTHER Operating Costs Incurred	$ _____	$ _____	$ _____

c) Estimate the **DOLLAR LOSS** from **food fish deaths BECAUSE** fish were held longer than necessary **BECAUSE** of off-flavor for some period of each year:

	1999	**1998**	**1997**
Diseases	$ _____	$ _____	$ _____
Low Dissolved Oxygen	$ _____	$ _____	$ _____
Bird Predation	$ _____	$ _____	$ _____

10. How effective do you think diuron was to you in lowering the number of off-flavor occurrences on your farm in 1999?

To answer this question, use the 1 to 10 scale as follows: One (1) would correspond to Diuron being completely ineffective (no use at all). Increasing numbers represent increased effectiveness of Diuron in reducing off-flavor occurrences. Ten (10) would mean that Diuron completely prevented all off-flavor incidences.

Circle **ONE** number below, which reflects your experiences with the effectiveness of Diuron usage in reducing off-flavor occurrences on your farm.

1	2	3	4	5	6	7	8	9	10
Completely Ineffective (no use at all)				No Difference in number of off-flavor occurrences				Completely Effective (no off-flavor incidences)	

11. Do you have any comments you would like to add about Diuron, its effectiveness or its impact on catfish profitability? _____

_____

This concludes the survey. THANK YOU very much for completing this survey.
Please return this survey in the enclosed pre-paid envelope.

Mississippi State University

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