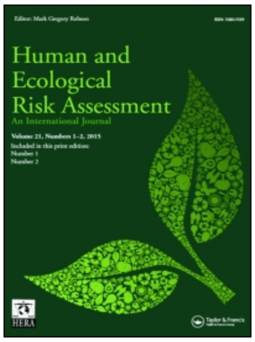

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Exposure Assessment of Tractor-Related Tasks Presenting Potential Overturn Hazards on Catfish Farms in Mississippi, USA

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ABSTRACT

Tractors are used in pond culture of catfish for a variety of mobile tasks, including placing aerators into ponds, mowing, spreading feed into ponds, and transporting equipment (*e.g.*, seining reels), as well as for the stationary task of using the tractor's power-take-offs to operate aerators in the ponds. The mobile tasks place the tractor operator at risk of injury in the event of an overturn, and rollover protective structures (ROPS) are a proven intervention to mitigate injury in a tractor overturn. A 2008 survey was conducted among 96 participants in Mississippi (USA) to determine the hours of tractor use for these tasks. This article reports on exposures to tractor-related tasks conducted on catfish farms as identified in this survey. Annual exposure to potential tractor overturns was calculated based on the hours of mobile operation. The overall annual exposure to potential tractor overturns on the catfish farms participating in the survey was 7322 h per farm and 837 h per tractor on these farms. Findings show a prevalence of 88.2% of ROPS-equipped tractors on farms surveyed and a seasonal variation in exposure to each of the tasks, culminating in an annual estimate of exposure by task.

Key Words: aquaculture, catfish farms, tractor overturns, ROPS, Mississippi farming, occupational injuries.

INTRODUCTION

Agriculture has the highest rate of occupational fatalities in the United States, and the leading cause of these fatalities is tractor incidents. Aquaculture is an emerging sector of agriculture worldwide (Watterson *et al.* 2008), and catfish farming dominates aquaculture in the United States with most of the production located in

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Mississippi. Since the farm tractor is the leading source of fatalities on U.S. farms and tractors are an integral part of catfish production (Murphy *et al.* 2010; Durborow 1999), we chose to explore the exposure of Mississippi farmers to potential tractor hazards of catfish farming.

Agriculture employed more than 9.2% of Mississippi's employed workforce in September 2011 (BLS 2011). Mississippi leads all other states in the United States in catfish production (26.1% of the total U.S. production) according to the year 2007 Census of Agriculture (USDA 2009). Records over a 20-year period indicate that about 20 farm tractor–related deaths occur in Mississippi annually. Another leading cause of farm-related deaths in Mississippi is drowning in ponds (MSU 2010). The U.S. Department of Agriculture (USDA) 2005 Census of Aquaculture reported 102,898 acres of freshwater on 403 farms in Mississippi, 361 of which were catfish farms (USDA 2006).

Two sources of serious or fatal injury related to tractor operation are overturns and power-take-off (PTO) entanglements (Myers 2002). Tractors have been shown to overturn under certain circumstances, such as while maneuvering on slopes or when making high-speed turns. Tractors have also been known to tip to the rear when pulling objects with improper hitching, driving up steep inclines, or encountering situations where the drive wheels become immobilized by mud or other obstructions leading to "gear-over" rotation of the tractor around the rear axle as the engine continues to run. A rear overturn is fast, occurring in 1.5 s (Murphy 1992). A proven technology to mitigate injury in the event of an overturn is to equip the tractor with a rollover protective structure (ROPS) and seatbelt (Cole *et al.* 2006).

Tractor PTOs are used as a source of mechanical power for other equipment and implements. A PTO transfers power from the tractor's engine by a drivetrain shaft attachment at the rear of the tractor. The PTO is used to power both stationary equipment such as pumps and equipment attached to the tractor such as mowing machines.

A perennial challenge in estimating the risk of injury has been measuring exposure to the injury-producing agent (Bailer *et al.* 1998) (*e.g.*, the agricultural tractor). Two prominent uses of tractors are for traction (mobile operations) and transferring power to implements through a PTO. On catfish farms, tractors are used for placing aerators into ponds, mowing, spreading feed into the ponds, and transporting equipment, such as seining reels. In these mobile operations, depending upon circumstances such as steep terrain around pond levees, the tractor could overturn and crush the driver. Practically all of the tasks are performed on levees that have slippery surfaces, inclined banks, and corner turns that present overturn hazards. Erosion around a pond can undercut a levee, and as a result the bank could collapse when a tractor is driven on the levee. Narrow roadways heighten this risk. Particularly hazardous is nighttime placement of aerators by backing them down inclines into the water, typically done in the pre-sunrise hours at locations of low water oxygen levels. Overturn hazards associated with tractor driving on catfish farms include the following:

- Transporting and hauling: slide off levee, collapse of levee, positioning loads close to pond (*e.g.*, seining reels)

- Feeding and spreading: slide off levee, collapse of levee under load or tractor weight, sharp turns, operating close to edge of pond, asymmetrical loads, fluid shifts, or sloshing in loads
- Mowing and bush-hogging (*i.e.*, bush-cutting): slide off levee, mowing too close to edge of pond, or collapse of levee
- Placing aerators: slide off levee or down bank, collapse of levee, driving over bank in the dark, driving up inclines

Tractors are used on catfish farms to drive PTO drivelines for powering mowers, or in stationary operations for powering the seining reel, or more often, powering aerators. Aerators on catfish farms are powered either by electricity or by PTOs. The tractor-powered aerator is used because of its mobility to add oxygen at specific locations where oxygen levels have been depleted. Aerators are mounted on wheels for transporting and for backing into ponds by tractors from levees. Aerators are attached to tractor PTOs with a long driveline. An unguarded PTO exposes workers near the rotating shaft to an entanglement hazard.

National statistics show that tractors overturn and injure or kill their operators (Myers *et al*. 2008). In 2008, the Mississippi Agricultural Statistics Service (MASS) incorporated into its annual survey of catfish farms questions regarding farm injuries related to tractor overturns, and machinery entanglements (Stephens *et al.* 2010; Stephens and Ibendahl 2009; Ibendahl and Stephens 2011). Of 120 farms contacted (33.2% of catfish farms in Mississippi), 96 participated in the survey (80% response rate). In the MASS survey, 89 of the 96 participating farms reported 35,605 acres (34.6% of freshwater acreage in Mississippi) of freshwater in the survey.

Many analyses have calculated the rates of tractor overturns and associated fatal and non-fatal injures, but good exposure information regarding the hours per year that a driver operates a tractor has been missing from these analyses. Attempts to document the hours of tractor use per year through surveys have been few and have met with questionable estimates. Another approach has been documenting the hour meter reading and model year of tractors to measure their annual use. This approach has failed because many older tractors have non-functional hour meters, and furthermore, the meters record both mobile and stationary hours, presenting confounders for determining exposure to potential overturns.

A continuing challenge in estimating the risk of injury has thus been measuring specific exposures to the tractor as an injury-producing agent. An injury results from a transfer of energy (Bailer *et al.* 1998). The purpose of this article is to report on exposures to tractor-related hazards during both the mobile and stationary tasks in which tractors were used on catfish farms in Mississippi.

METHODS

Exposure has been defined as a contact with a hazard in such a manner that effective transmission of the agent or harmful effects of the agent may occur (NAS 2003), and exposure assessment has been defined, for our purpose, as the determination of the extent of human exposure (Myers 2007). Exposure assessment of occupational injury can be done by analyzing each discrete task to ascertain duration and frequency of exposure (Bailer *et al.* 1998). Exposure assessment of tractor-related tasks presenting potential overturn hazards on catfish farms in Mississippi was the method used in this analysis. The analysis summarized the data collected in the MASS survey with a focus on the hours that a worker drove a tractor and the likelihood of an exposure to an overturn.

Five exposure measures were used in our study: number of tractors per farm (1) with a ROPS and (2) without a ROPS, (3) type of task (n = 5), (4) hours of tractor operation by quarter per year, and (5) size of farm by pond acreage. The year-2008 MASS telephone survey was conducted among 96 participants in Mississippi to determine the hours of tractor use for a number of tasks by quarter: mobile operation: placing aerators into and out of ponds, mowing or bush-hogging, spreading feed or fertilizer into the ponds, and transporting equipment or hauling materials (including towing), and stationary operation: PTO driven aeration.

We adjusted the quarters by months to different intensities of operations during the year: March–May, June–August, September–November, and December–February. The participants were asked by telephone for average daily hours of tractor operation by task and by quarter based on recall. The reply was the participant's oral response like previous USDA surveys conducted for the National Institute for Occupational Safety and Health (NIOSH) in which two questions regarding tractor use were asked (Cole *et al.* 2007):

1. What was the total number of hours that the tractor was used on the farm in 2001?
2. How many hours was the tractor used for fieldwork (non-stationary work) on the farm in 2001?

The MASS survey sought more specificity by asking for hours that all tractors on the farm were used for each task and for each quarter. Moreover, by asking for hours for all tractors on the farm, the task of recall was simplified. The annual use was derived by adding the quarterly use responses.

Four questions in the MASS survey related to the demographics of operators of the catfish farms in Mississippi. These questions were:

1. For how many years have you operated a catfish farm operation?
2. How many acres of pond area are on your farm?
3. How many tractors were used on your catfish farm operation during 2008?
4. How many of those tractors were ROPS equipped?

The first step in the analysis was to summarize the answers to these questions, including a calculation of the percentage of ROPS-equipped tractors on these farms. The second step was to determine the proportion of seasonal and annual exposures during each task for tractor operations by assessing answers to the question consistent with the five previously identified tasks, "How many hours a day were your tractors used for each of the following tasks during the four seasons listed?" Catfish farming is a 24-h operation, 7 days per week, thus calendar days were assumed for each quarter regarding the farmers' estimated hours of operation per day.

Four tasks represented exposure to overturns: (1) transporting or hauling, (2) mowing or bush-hogging, (3) spreading (feed, fertilizer, or pesticides), and (4) placing aerators. An additional question related to the number of overturns and PTO entanglements experienced in the last 10 years. The results from this question were reported, but the period was adjusted to account for farms that have been in operation for fewer than 10 years. Calculations were made by adjusting the total according to the response number for each season. As for the totals across all tasks and seasons, the denominator used was the total number of hours that tractors were used per farm adjusted to the average number of tractors on each farm.

We only analyzed exposure to tractor overturns based on mobile operations. We also reported the hours of stationary operation since it was a factor in total tractor operation, but we did not relate this operation to PTO injury exposure. The only time workers were exposed to potential PTO entanglements was when working near an unguarded rotating PTO shaft. Aerators were engaged for hours without anyone present, thus, hours of stationary operation were an inadequate measure of exposure to PTO entanglement.

RESULTS

Demographics

Ninety-six farm operators responded to the demographic questions with the results summarized in Table 1. The respondents had engaged in catfish farming for an average of 16.4 years, ranging from 2 to 40 years. The average number of tractors on each farm was 10.6 tractors, 88.2% of which were ROPS-equipped. However, one respondent reported that his farm used 200 tractors; whereas the next highest number reported was 40 tractors. Also summarized in Table 1 are the data without the farm reporting 200 tractors, which reduced the average number to 8.6 tractors per farm with 85.4% of the tractors equipped with ROPS. If no number was reported by the subjects, those omissions were ignored in the calculations.

Table 1. Demographics of catfish farms and tractors in Mississippi, 2008.*

			ROPS-equipped tractors (n = 89 farms)	
Parameter	Years of catfish farming	Number of tractors used per farm	Number per farm	Percentage
Mean (n = 96 farms)	16.4	10.6	10.1	88.2%
Range	2–40	1–200	1–200	—
Mean (n = 95 farms)**	16.2	8.6	8.0	85.4%
Range	2–40	1–40	1–40	—

*Excludes blank responses; **excludes one farm with 200 tractors.

ROPS Prevalence

The high prevalence of ROPS-equipped tractors (88.2%) may be attributed to aquaculture being an emerging industry; owners and managers likely purchased new tractors that were equipped with ROPS as standard equipment. The data also provide for differentiating the prevalence of ROPS by farm size. Twenty-five farm operators reported the total acreage of water surface area of ponds on their farms. The reports show much variability between farm operations as shown in Figure 1. These reports indicate that the larger the farm operation, the greater the prevalence of ROPS-equipped tractors.

An average of 6890 of hours/farm was involved in tractor driving annually on catfish farms in Mississippi (n = 96). Placing aerators involved the most hours for mobile operations at 2583 hours/farm (37.5%), followed by transport or hauling at 1692 hours/farm (24.6%). Mowing or bush-hogging was third at 1492 hours/farm (21.7%), and feeding or spreading averaged 1124 hours/farm (16.3%).

Regarding farms that present risk because of the presence of non-ROPS tractors (n = 25), shown in Figure 1 is the percentage of ROPS-equipped tractors on participating farms by acreage of water surface, indicating the rise in the percentage of ROPS-equipped tractors by water surface area (correlation coefficient = 0.563). The proportion of variance of percentage of ROPS-equipped tractors accounted for in-pond acres was $r^2 = 0.317$.

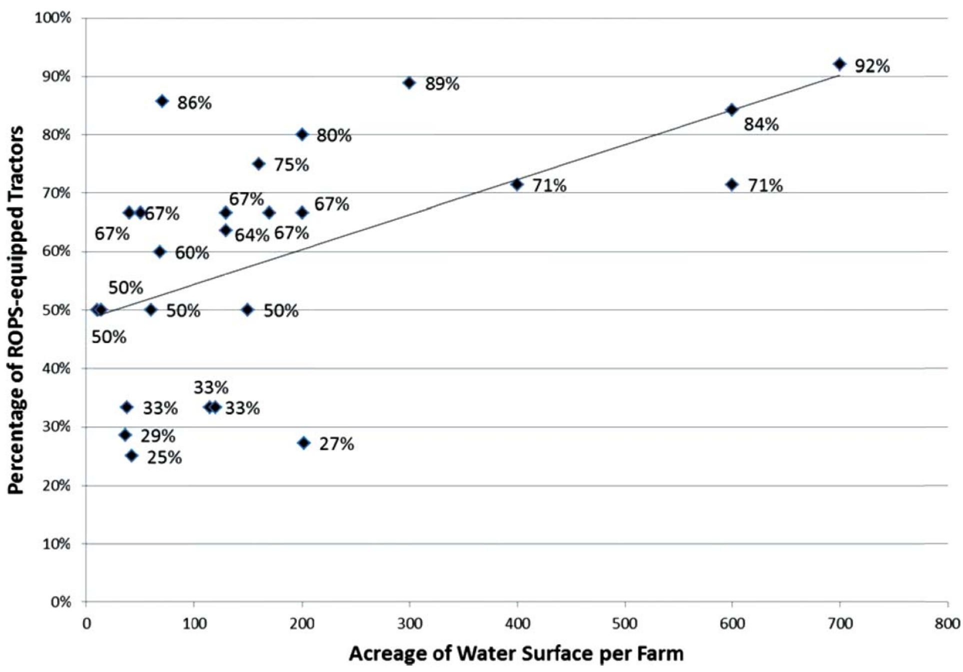

Figure 1. Reported proportion of ROPS-equipped tractors for those farms with less than 100% of ROPS-equipped tractors by area of farmed surface waters on catfish farms as reported in 2008, n = 25. (Color figure available online.)

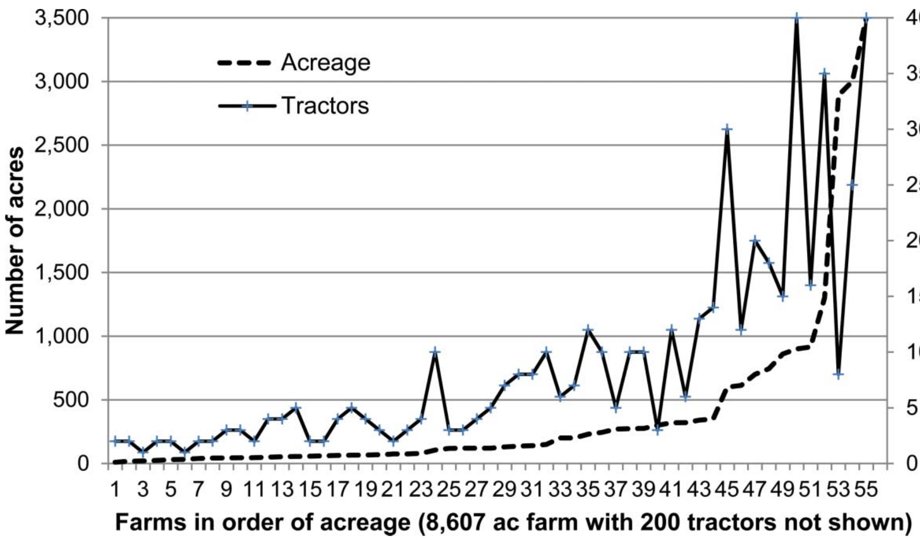

Figure 2. A comparison of pond acreage and number of tractors on farms that have 100% ROPS-equipped tractors, n = 56. (Color figure available online.)

Another result of the analysis was the increased number of tractors on farms relative to the increased acreage of ponds on farms. As shown in Figure 2, the number of tractors on farms correlates with water surface acres on those farms with 100% ROPS-equipped tractors (correlation coefficient = 0.914, $r^2 = 0.956$). The correlation coefficient remains nearly the same when the 56 farms with 100% ROPS-equipped are combined with the 25 farms with less than 100% of ROPS-equipped tractors (correlation coefficient = 0.906, $r^2 = 0.820$).

A fixed-effects repeated measures analysis of variance for tractor hours of operation found statistically significant differences in hours of tractor operation across four seasons ($p \leq .0001$) and across four tasks ($p \leq .0001$). See Table 2.

Annual Exposure

The average annual exposure to potential tractor overturns per farm on the catfish farms participating in the survey was 7322.5 h, or 3.7 full-time equivalents (FTEs at 2000 h per year) of exposure per farm. The annual exposure on these farms per tractor was 690.8 h. The exposure of 2.3 h per day per tractor to operators was indexed against the total hours of tractor operation per farm. When calculated for each tractor, the exposure was 837.2 h annually per tractor based on 364 days

Table 2. Fixed effects repeated measures analysis of variance for hours of mobile tractor operation by season and task.

Effect	Degrees freedom	*F* value	$p \leq$
Season (4)	3	30.06	.0001
Task (4)	3	45.06	.0001

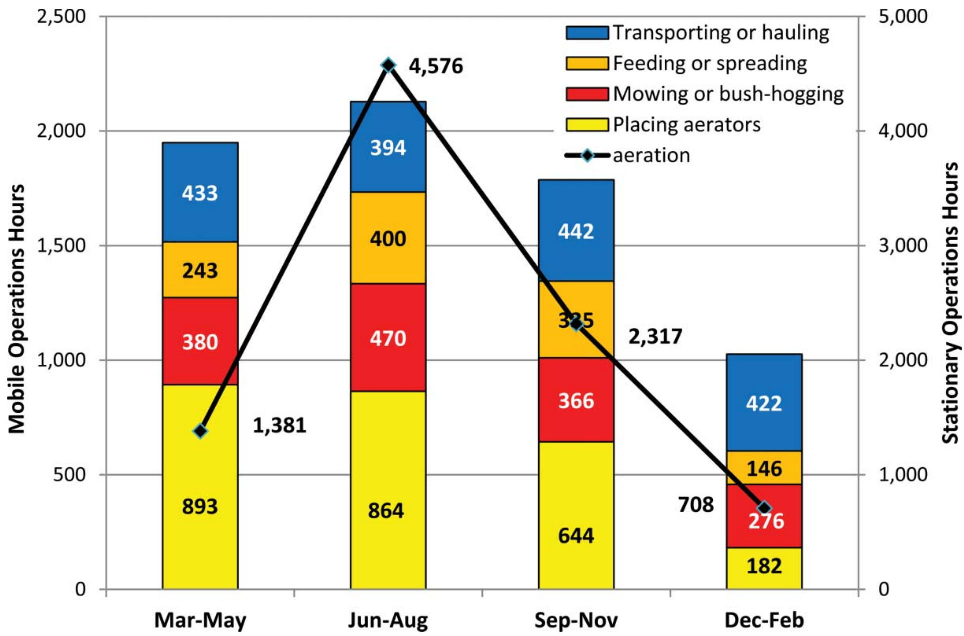

Figure 3. Quarterly and annual tractor operation in hours on catfish farms in Mississippi by task as reported in 2008, n = 96 farms. (Color figure available online.)

per year. The total annual hours of potential workers' exposure on farms to tractor operations was 7322.5 h per farm (n = 96). The relationship of hours of tractor use on catfish farms in Mississippi by task is shown in Figure 3.

Of 77 participants (82.2% of respondents) who reported both hours of mobile operation and ROPS status, the average FTEs for all 77 farms was 2.7 FTEs/year; 52 (67.5%) of the 77 farms had 100% ROPS-equipped tractors and operated tractors on an average of 3.0 FTEs/year. The 25 farms that had non-ROPS tractors operated tractors with 1.9 FTEs per year, and when adjusted for the percentage of ROPS-equipped tractors, the time operating tractors per farm was 1.1 FTEs/year, indicating one-half to one-third less exposure to the overturn hazard when non-ROPS tractors are used on the farm.

The seasonal findings culminated in an annual estimate of exposure by task. Of the four mobile tasks reported, the most hours per tractor were reported for mowing or bush-hogging, but this task also represented the fewest tractors used, as shown in Table 3. The highest number of tractors used for a task was for placing an aerator into or removing it from a pond, with the task of mowing or bush-hogging involving the second highest hours of use per tractor. The remaining two tasks, feeding or spreading and transporting or hauling, entailed the same number of hours of tractor operation, albeit less than the previous two. However, both of these latter tasks exceeded the number of tractors used for mowing or bush-hogging while, conversely, both involved fewer tractors than did placing aerators.

Table 3. Exposure to mobile tractor operation by season per farm, n = 96 farms.

		Season (as reported in 2008)				
Task	Exposure Parameter Averages*	March–May	June–August	September–November	December–February	Annual average adjusted for n
Placing (or removing) aerator into pond	Tractors/farm	3.3 (n = 36)	4.0 (n = 46)	3.4 (n = 40)	1.8 (n = 8)	3.5
	Hours/tractor/day	2.9 (n = 32)	2.3 (n = 43)	2.1 (n = 36)	1.1 (n = 5)	2.3
	Hours/tractor	270.7	215.9	189.4	101.2	827.5
Mowing or bush-hogging	Tractors/farm	1.3 (n = 70)	1.5 (n = 84)	1.5 (n = 71)	1.0 (n = 5)	1.4
	Hours/tractor/day	3.2 (n = 68)	3.4 (n = 82)	2.6 (n = 71)	3.0 (n = 3)	3.1
	Hours/tractor	292.6	313.3	243.7	276.0	1121.3
Feeding or spreading	Tractors/farm	1.4 (n = 24)	1.7 (n = 26)	1.7 (n = 25)	1.1 (n = 8)	1.6
	Hours/tractor/day	1.9 (n = 24)	2.6 (n = 26)	2.1 (n = 26)	1.4 (n = 8)	2.1
	Hours/tractor	173.5	235.3	197.1	132.3	775.7
Transporting or hauling (not placing aerator)	Tractors/farm	2.2 (n = 38)	2.1 (n = 34)	2.2 (n = 30)	1.8 (n = 22)	2.1
	Hours/tractor/day	2.1 (n = 36)	2.0 (n = 30)	2.2 (n = 28)	2.6 (n = 19)	2.1
	Hours/tractor	197.0	187.8	200.9	234.6	775.7
Total for all tractors	Mean number tractors/farm as reported by the participants					10.6
	Daily exposure h/tractor					2.3
	Annual exposure h/tractor					837.2
	Annual exposure h/farm					7,322.5

*Blank responses omitted.

Seasonal Exposure

Findings showed a seasonal variation in exposure for each task with the least exposure during the period December through February but with the most exposure during the summer months of June through August, as shown in Figure 3. The transporting or hauling task is consistent across all four seasons with a range of 394 to 443 h/quarter of driving time per farm. Tractors used for this task ranged from a low of 1.8 in December through February to nearly identical values of 2.1 to 2.2 tractors used per farm for the other three quarters as shown in Table 3.

Feeding or spreading was more frequent from June through August when the catfish are more active in warm water. The highest quarter, June through August, was nearly three times more active than the winter months of December through February. Likewise, most mowing or bush-hogging hours occurred during the summer months of June through August and least during the winter months of December through February. This task involved more hours during the spring quarter of March through May than during the fall quarter of September through November.

The most variability in tractor use is the task of placing aerators, which is much higher during each of the two quarters that cover March through August. The activity drops by 27.9% during September through November from the high in March through May. Activity falls sharply in the winter quarter of December through February by 79.6% from the March through May quarter.

Overturns

Subjects in this survey reported two tractors' overturns during the previous 10 years, but when adjusted for 21 of 96 farms that were in operation less than ten years, the equivalent period that was represented by the replies was 9.3 years. The tractors involved in both overturns had a ROPS with no reported injury. One reported that the overturn occurred while placing an aerator, but no report of the task for the other tractor was made. One overturn occurred in June 2005, and the other occurred in May 2004.

Stationary Operations

The proportion of stationary tractor operation for aeration relative to the hours of mobile operation on catfish farms represents 59.2% of tractor engine running time. As shown in Figure 3, the majority of tractor running time was for stationary operations (aeration), and the hours of tractor operation for the stationary task of powering aerators are detailed in Table 4. Tractors were used more intensively for this task at an average of 3.5 h per tractor per day, in contrast with the average for mobile operations of 2.3 h operation per day.

Aerators are used to add oxygen to the water, and since oxygen is depleted during hot weather, its less intense use in the winter months is understandable. As shown in Figure 3, considering stationary uses of tractors as a confounder was critical when determining the risk of exposure to overturns, which occurs during mobile operations. The respondents in the survey reported no machine entanglements related to tractor operations.

Table 4. Stationary tractor operation by season per farm, n = 96 farms.

Task	Parameter averages*	Season (as reported in 2008)				Annual average adjusted for n
		March–May	June–August	September–November	December–February	
Aeration	Tractors/farm	4.5 (n = 53)	9.2 (n = 74)	7.1 (n = 69)	4.4 (n = 7)	7.1
	Hours/tractor/day	3.3 (n = 52)	5.4 (n = 73)	3.5 (n = 67)	1.8 (n = 4)	3.5
	Hours/tractor	303.8	499.4	499.4	161	1500
	Hours/farm	1367	4594	2317	708	8130

*Blank responses omitted.

DISCUSSION

Few studies have analyzed task-specific exposure to tractors, especially during mobile operations when the risk of overturns is present. This study demonstrated an approach to collect and analyze exposure data on one type of farm, catfish aquaculture. The method provides a step forward toward improved collection of detailed exposure data regarding not only tractor hazards but other injury agents as well.

The hours of tractor operation while driving was a fair measurement of exposure to the potential for a tractor overturn. However, data were needed regarding overturn experiences during tractor operation, and in this analysis the data were few for the overturn event—an event that was potentially catastrophic if a ROPS had not been in place. Furthermore, no participant reported PTO entanglements.

More research is needed to acquire information about overturns on catfish farms, for there may have been more overturns than were reported. The same is true for entanglements. Two possibilities contribute to underreporting of these events. First is the healthy worker effect, which argues that the victims are not part of the population sampled. An overturn, especially on a small farm, can result in the farmer's not surviving to continue farming or can render the farmer so disabled or traumatized that he or she would leave the farming enterprise (Cole *et al.* 2006). Second is the fear of potential targeting for inspections by the U.S. Occupational Safety and Health Administration (OSHA). This possibility is supported by a study conducted by Ibendahl and Stephens (2011) in which catfish farmers may be motivated by risk aversion. However, this fear is unfounded since most of the farmers participating in the MASS study worked on small farms (an average of 3.7 FTEs driving tractors), and OSHA does not regulate the self-employed and cannot inspect farms that have 10 or fewer employees.

In a national study of tractors in aquaculture, farms in the U.S. South had an average of 4.1 tractors per farm on which tractors were present in contrast with the 10.6 tractors per farm reported in this study (Myers *et al.* 2009). However, in that study, the South reported that 90.7% of its tractors were ROPS-equipped as compared to the agriculture sector generally at 48.8% of tractors equipped with ROPS. This measure in the South for aquaculture was in accord with the findings in this study in which 88.4% of the tractors were ROPS equipped. Thus, it appears that tractor operators in aquaculture in the South, and more specifically, in Mississippi, were well protected against injury in the event of an overturn.

However, some farms have few ROPS-equipped tractors, and the study provides for setting priorities for interventions on those farms to encourage retrofitting unguarded tractors with ROPS. In addition, by providing the results of the study, we can show the farmers on those farms that the standard in their industry is to use ROPS-equipped tractors.

Stationary uses of tractors on catfish farms include powering paddle aerators in ponds via the PTO, which can pose an entanglement hazard. For years, farmers have relied on paddlewheel aerators powered by a tractor PTO for use in large ponds (Boyd and Ahmad 1987). The aerators are necessary for oxygenating the water where high concentrations of fish are raised, especially at night when oxygen levels are lower because of the absence of sunlight and reduced photosynthesis by some algae. Paddlewheels consist of paddles attached to a rotating hub. Although less efficient and thus more expensive to operate than electrically powered aerators, PTO-operated aerators are useful, indeed critical, in emergencies during oxygen-deficient episodes in the ponds. These episodes are indicated by catfish gulping at the water surface, but more scientifically and particularly at night by oxygen monitors. These monitors have increasingly become automated with telephonic alarms to the farmer to act quickly to move a PTO-powered aerator to the oxygen-deficient location. Since PTO-powered aerators are portable, they can be moved and backed into a pond from any bank anytime oxygen levels are low in any pond.

The proportion of hours of stationary tractor operation for aeration relative to the hours of mobile operation is enormous on catfish farms, representing 56.6% of engine running time. However, most of these hours of stationary operation did not pose an exposure to entanglement hazards, because workers were not present during much of the aeration operation. Nevertheless, entanglement remains a serious injury hazard. Fatal entanglements have occurred on Mississippi farms, and on January 21, 2011, a trout farm manager in Kentucky lost his life when he became entangled in a PTO connected to a posthole digger (Anonymous 2011). Our analysis was a start from which more can be learned about potential exposures to entanglement. This problem warrants further research.

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