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## MAJOR REVIEW

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# Review of Occupational Hazards Associated With Aquaculture

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**ABSTRACT.** Aquaculture is an emerging sector that is associated with most of the same hazards that are present in agriculture generally, but many fish farming tasks entail added danger, including working around water and working at night. Comprehensive studies of these hazards have not been conducted, and substantial uncertainty exists as to the extent of these hazards. The question addressed in this investigation was, “What is known about potential hazardous occupational exposures to aquatic plant and animal farmers?” In this review, causes of death included drowning, electrocution, crushing-related injury, hydrogen sulfide poisoning, and fatal head injury. Nonfatal injuries were associated with slips, trips, and falls; machines; strains and sprains; chemicals; and fires. Risk factors included cranes (tip over and power line contact), tractors and sprayer-equipped all-terrain vehicles (overturn), heavy loads (lifting), high-pressure sprayers, slippery surfaces, rotting waste (hydrogen sulfide production), eroding levees (overturn hazard), storm-related rushing water, diving conditions (bends and drowning), nighttime conditions, working alone, lack of training, lack of or failure to use personal flotation devices, and all-terrain vehicle speeding. Other hazards included punctures or cuts from fish teeth or spines, needlesticks, exposure to low temperatures, and bacterial and parasitic infections.

**KEYWORDS.** Aquaculture, exposures, fish farming, hazards, risk factors

### INTRODUCTION

Worldwide, 11,289,000 people worked in aquaculture in 2004—up nearly 3-fold from 3,832,000 workers in 1990.<sup>1</sup> Aquaculture is an emerging sector that is associated with most of the same hazards that are present in agriculture generally, but it has additional exposures

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related to water impoundments, nighttime work, and offshore operations. According to the US Bureau of Labor Statistics, the nonfatal occupational injury rate per year for aquaculture is 6.8 injuries per 100 full-time employees. In comparison, this rate lies between 5.3 and 7.8 injuries per 100 full-time employees in 2006 for terrestrial crop and animal production, respectively.<sup>2</sup> The rate of 6.8 injuries per 100 full-time employees in aquaculture compares to 4.6 injuries per 100 full-time employees across all sectors.

Aquaculture has been a fast growing sector of US agriculture but has unaddressed safety and health issues for its workers. Working around water poses an additional danger, and working at night adds to the danger. Substantial uncertainty exists as to the variety and extent of these hazards.

The US Department of Agriculture National Agricultural Statistics Service (NASS) Census of Aquaculture in 1998 was the first dedicated national census taken expressly for this industry.<sup>3</sup> This census responded to the need for knowledge of the aquaculture sector, which grew from \$45 million for value of products sold in 1974 to more than \$978 million in 1998.

The 2005 Census of Aquaculture<sup>4</sup> defined aquaculture as the farming of fish, crustaceans, mollusks, and other aquaculture products. Farming implied some form of intervention in the rearing process, such as seeding, stocking, feeding, and protection from predators. Farming also implied individual or corporate ownership of the stock being cultivated, with harvesting conducted in controlled environments, as is the case with ocean-raised fish (in pens, cages, etc.) or shellfish harvested from leased, owned, controlled, or managed beds. Products caught or harvested from noncontrolled waters or beds by the public were deemed "wild caught" and excluded from the census.

On January 1, 2003, the Occupational Safety and Health Administration began using the North American Industry Classification System (NAICS) for industry identification in its various data sets. The 2007 code merged "other animal aquaculture" and "all other miscellaneous crop farming (algae, seaweed, and other plant aquaculture)" into "Other Aquaculture." Table 1 shows the NAICS classifications of aquaculture subsectors, as well as the corresponding Standard Industrial Classification (SIC).

TABLE 1. Codes for Aquaculture: North American Industrial Classification System (NAICS) in 2007 and Corresponding Standard Industrial Classification (SIC) System in 1989

NAICS	SIC	Description
111419	Other Food	Crops Grown Under Cover
	0182	Hydroponic crop farming
	0182	Seaweed grown under cover
112511	Finfish Farming and Fish Hatcheries	
	0273	Baitfish, catfish, finfish, goldfish, hybrid striped bass, minnow, ornamental fish, tilapia, tropical fish, and trout production, farm raising
	0921	Finfish hatcheries
112512	Shellfish Farming	
	0273	Clam, crawfish, crustacean, shellfish, mollusk, mussel, oyster, shrimp production, farm raising
	0919	Cultured pearl production, farm raising
	0921	Shellfish hatcheries
112519	Other Aquaculture	
	0279*	Alligator, frog, and turtle production, farm raising; animal aquaculture (except finfish, shellfish)
	0191	Algae and seaweed farming
	0919	Plant and sea plant agriculture
924120	Administration of Conservation Programs	
	9512	Wildlife conservation agencies

\*0279 specialty farming including apiculture, small animal raising.

A review of the occupational safety and health literature related to aquaculture was completed to provide objective data for initiating additional research, including potential field and telephone surveys to be conducted with the purpose of developing more in-depth prevention methods regarding hazards in an emerging agricultural sector. This review focuses on a single question and is a summary of research that uses explicit methods to perform a thorough literature search and critical appraisal of individual studies to identify valid and applicable evidence in answer to the question.<sup>5</sup>

## METHODS

The review included both "grey" (non-peer-reviewed) and peer-reviewed literature. For the

grey literature, the reports were identified by an online search of investigation reports by Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH). Additional reports, e.g., court cases, were acquired through a "Google" search using the keywords "aquaculture" or "fish farming" in combination with the words "accident" or "fatality." This review incorporated the results of governmental investigations and court documents in order to identify a range of hazards in aquaculture. Additional articles were identified from the aquaculture literature and from the author's personal files.

When OSHA investigations were identified, Freedom of Information Act requests were sent to the investigating office, whether a Federal Area Office or a State Plan OSHA. NIOSH investigations were of two types: one dealt with occupational fatalities (Fatality Assessment and Control Evaluations) and the other reported on health hazards (Health Hazard Evaluations). These identified reports were downloaded. The exclusion criteria for the grey literature were nonaquaculture enterprises (e.g., commercial fishing, fish processing), no report issued (e.g., self-employed), and records destroyed.

For the peer-reviewed literature, a literature search was conducted on October 15, 2009 on PubMed with the words "aquaculture occupational." Additional articles were identified through a review of reference lists of review articles and from the author's files.<sup>2,6-8</sup> The selected peer-reviewed literature originated worldwide, whereas the grey literature was limited to documents in the United States since a worldwide search would vary greatly in accessibility, quality, and language. Articles regarding fishing, fish processing, and food safety were excluded.

The question addressed in this review was, "What is known about potential hazardous occupational exposures to fish farmers?" Studies meeting criteria for inclusion in the review were screened to determine whether they discussed the review topic (aquaculture) and included outcome data such as exposure, illness, injury, or fatality. The review process is shown in Figure 1.

## RESULTS

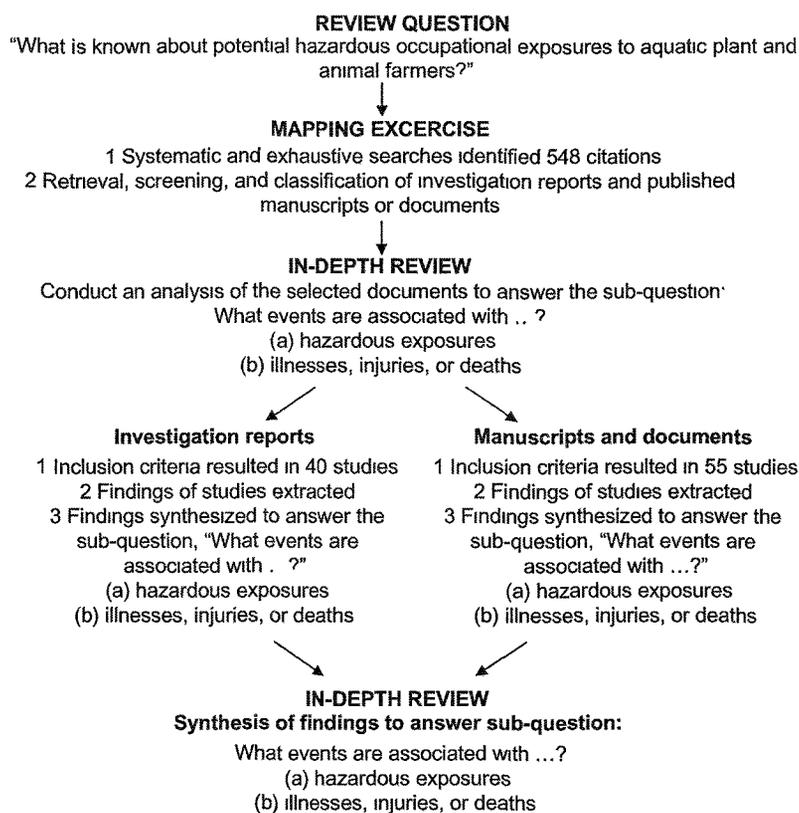
A high level of evidence was found regarding six hazard types: electrical contact, drowning, crushing injury, falls from elevations, sprains and strains, and chemical exposure, including decomposition products and confined spaces. Low-level hazards included fires, chemicals, and slips, trips, and falls. Most high-quality studies were fatality investigations, which detailed circumstances—and because they were fatalities, they were severe.

Of 181 non-peer-reviewed citations (including 49 OSHA investigations), 40 grey literature documents met screening criteria for this review. These grey documents covered 27 OSHA investigation summaries and reports (as shown in Table 2) and 13 other documents (as shown in Table 3). Table 2 shows the 27 OSHA investigation numbers, year, state, and a description of the hazards identified in those reports and summaries. Hazards, many leading to work-related fatalities, included falls overboard, tractor overturns, flooded waders, overhead power line contact, high-pressure water jets, building fires and fuels, chemicals, forklift operations, diving, unsanitary operations, ozone exposure, solvents, confined spaces, chemicals, unguarded equipment, all-terrain vehicle operation, slippery surfaces, and carbon monoxide poisoning.

In addition to the OSHA investigations, 13 other investigations identified hazards associated with aquaculture. These investigations are listed in Table 3 along with the potential hazardous exposures that were identified. They include fatal tractor and crane overturns, exposures to styrene and acetone during sealing of fiberglass tanks, fatal exposure to hydrogen sulfide, fatal head injuries from falls, heavy lifting, and roadway collisions.

The PubMed search identified 367 peer-reviewed articles, of which 24 met the original screening criteria, although 3 were dropped because the aquacultural hazard was integrated into the exposures to hazards of larger populations and not descriptive of hazards specific to aquaculture, e.g., agriculture. Additional peer-reviewed literature identified from the reference list of review articles, from personal files,

FIGURE 1. The review process.



and while searching for grey literature added another 34 articles, totaling 55 selected articles. Hazards identified in the peer-reviewed literature are listed in Table 4, which add a variety of risks to those already identified, including exposures to needlestick injuries, dermal effects, and spine stings. Moreover, the peer-reviewed literature taps into worldwide literature in identifying potential exposures to hazards, much of which will be discussed below.

## DISCUSSION

The review articles summarized many of the hazards identified in this research. Although peer-reviewed literature was evaluated worldwide, a limitation in this study was constraining the review of grey literature to the United States. Much more could be learned if grey literature was reviewed from other countries. The study integrates actual with potential hazardous

exposures because the intent of the study is to identify potential exposures. Hazards vary from species to species where the type of culture and operation varies, as well as the size of the operation.<sup>2</sup> Thus, the following discussion summarizes the findings by species and the dominant culture technology used to rear the species.

**Catfish** (warm water fresh water fish, pond culture)

The OSHA investigations identified three hazards on catfish farms: crushing or drowning from tractor or all-terrain vehicle (ATV) overturns, electrocution from contact with overhead power lines, and drowning when waders filled with water and drew the worker under water. Other investigations in the United States found operating live tank trucks on highways associated with fatigue and crashes, strains and overexertion disorders related to lifting and awkward work postures, and the potential for

TABLE 2. OSHA Investigations That Identified a Potential Hazard,  $n = 27$ 

OSHA no	Year	State	Species	Description
001966977	1985	MS	Catfish	Drove tractor with feed hopper attachment into pond, drowned (asphyxia and broken leg)
105985733	1990	AL	Catfish	Tractor overturn on a levee, fatal
107005308	1991	AL	Catfish	Crane, electrocution, contact with overhead power line
125943753	2004	CA	Catfish, carp	Ponds, wading access, working alone, holey waders, formalin, potassium permanganate, sodium periodate, sulfonic acid
306162819	2003	AR	Catfish, baitfish	All-terrain vehicle (ATV) overturn, drowned
300916723	1997	PR	Caiman	Capturing, no potable water or restrooms available
300993029	1998	PA		O <sub>3</sub> generation, eye and throat burning
302028360	2005	NY	Hatchery (trout)	Fuels, solvents, hypochlorite, confined space, water jet
302284310	2001	NY	Hatchery (trout)	Formaldehyde, formalin, unguarded table saw
303927511	2001	OR	Hatchery (trout)	Oxygen-acetylene system, table saw, lack of guards
306821984	2004	VA	Hatchery (trout)	Asbestos in ceiling of break room
119978203	1999	CA	Trout	High-pressure H <sub>2</sub> O spray, foot penetration
302587597	2000	ID	Trout	No guardrails above fish runs
125837252	1999	CA	Sturgeon	Hydrogen peroxide, keylime, salt, liquid oxygen (cryogen-fenced), muriatic acid, forklift (propane), scuba diving
306277047	2004	MA	Tilapia	Raised in tanks, extension cords lying in water, insufficient sheet metal flooring, absence of hand rail, chlorine, hydrogen peroxide, open drums of other hazardous chemicals, warafin, forklift, algae growth, trip hazards
307912170	2004	PA	Tilapia	No fall protection, hydrochloric acid, work alone on raceways at night, past falls into 5 feet deep raceways
308346741	2005	MA	Tilapia	Wood-burning heating system, CO exposure
306930231	2003	CA	Shellfish	Harvesting mussels, divers at 80 feet deep with air supplied from the surface, reserve tank not used, drowned (possible cause was a stroke)
307969444	2004	WA	Shellfish	Broken electrical conduits, hand rails broken loose, safety latches missing on electric hoists
307194696	2004	WA	Shellfish, oyster	Dredge, inflatable life jackets not approved
305397978	2002	UT	Shrimp (brine)	Harvesting, unsanitary conditions, arm injury after falling off an ATV
306261199	2003	HI	Shrimp, algae	Shrimp breeding/algae production, hydrochloric acid (muriatic acid), formaldehyde, PVC cement, ferric chloride hydrate, tolidine, chloride, exposed floor openings
301827788	1998	FL	Lily pads	Harvesting, canoe capsized, one employee drowned, no personal flotation device (PFD)
001870625	1989	CO	Unreported	Feeding fish in three holding pens on reservoir, fell from boat, drowned, no PFD
103681730	1988	AK	Unreported	Fish pen on lake, fell from boat, wore waders, no PFD, drowned
120087820	1999	CA	Unreported	Ponds, building fire, burns
305143307	2002	WA	Unreported	No safety meetings

Source. OSHA Web site: <http://www.osha.gov/pls/imis/industry.html>.

TABLE 3. Other US Investigations or Cases That Identified a Potential Hazard,  $n = 13$ 

Source	State	Species	Description
Strickland v Carolina Classics Catfish 1995 <sup>28</sup>	NC	Catfish	Return at 1:20 AM from delivery of catfish fingerlings in a three-tank truck, driver lost control in a sharp curve and was killed with a head injury when the truck overturned. Fatigue, shifting of load, excessive speed, difficulty of handling the truck on the curve, and an unused seat belt were contributing factors to the death
Blue Water Catfish v. Hall 1996 <sup>29</sup>	AL	Catfish	Truck ran off the road and flipped over, resulted in back injury, driver was intoxicated
Smith v Rizzo Farms 2004 <sup>30</sup>	MS	Catfish	Fifteen hour work days common, lifted 50-pound chemical bags, 120-pound potassium cans, and handled aerator equipment that ranged from 250 to 500 pounds, routinely climbed a 30-foot ladder to dump 50 pound bags of chemicals into a feed distributor bin, knee injury
Coblentz 2005 <sup>31</sup>	MS	Catfish hatchery	Hair entanglement, cuts and scratches from paddles in hatching trays
NIOSH 2003 <sup>32</sup>	OR	Trout	Pond, crane overturn, crushed to death
Page 2000 <sup>33</sup>	*	Trout	Hatchery, acoustic neuroma, 15.41 per 100,000 person-years, 15 times greater than to general population
Hales et al 1997 <sup>34</sup>	GA	Sturgeon	Hatchery, potential exposure to the dinoflagellate <i>Pfiesteria piscicida</i>
Sylvain 1999 <sup>35</sup>	MA	Salmon	Hatchery, formaldehyde, formalin, methanol
Sylvain 1999 <sup>36</sup>	NH	Salmon	Hatchery, formaldehyde; formalin, methanol
Delaney 2001 <sup>37</sup>	WI	Salmon, perch	Fiberglass tank seams, styrene, acetone
Nacelewicz 2002 <sup>38**</sup>	ME	Halibut	Rescuer fatally overcome by H <sub>2</sub> S gas when retrieving teenage worker who was cleaning the bottom of a 6-foot cement waste recycling tank
Alaska 1991 <sup>39</sup>	AK	Unreported	Worker slipped while cleaning a fiberglass tank, struck head, died three days later
MacCollum 1993 <sup>40</sup>	WY	Unreported	Crane overturn into pond, trapped in cab, drowned

\*Not reported.

\*\*Same as Nikkanen and Burns, 2004.<sup>60</sup>

TABLE 4. Potential Hazards Identified in Peer-Reviewed Literature,  $n = 55$ 

Reference	Location	Species <sup>†</sup>	Description
Ajmal et al. 2003 <sup>41</sup>	TN	Catfish	Spine envenomation, venomous injuries, hand infections
Ashford et al 1998 <sup>42</sup>	Australia	Catfish	Spine injury and septic arthritis caused by <i>Edwardsiella tarda</i>
Johnson et al 1992 <sup>43</sup>	MS	Catfish	Spine puncture and infection
Das et al 1995 <sup>44</sup>	MS	Catfish	Stings, medical extraction, clinical infection
Reed, 1985 <sup>45</sup>	MS	Catfish	Tractor overturns, electricity, entanglements
Yajima and Kurokura 2008 <sup>46</sup>	Vietnam	Pond culture	Fish contaminated with animal feces posing infection hazard to workers
Krasnyuk et al 1982 <sup>47</sup>	Russia	Pond culture	Dermatitis from microtrauma caused by plant leaves and thorns, fish fins, shellfish scrapes, as well as mechanical impact with nets and boat oars; low temperature and elevated humidity, cold winds, icy water, hypothermia, stiffness and pain of finger joints, peripheral angioneurosis, and arterial hypertension associated with harvesting
Boyd and Massaut, 1999 <sup>48</sup>	AL	Pond culture	Chemicals, fertilizers and lime as well as oxidants, disinfectants, osmoregulators, algicides, coagulants, herbicides, and probiotics
Myers and Cole 2009 <sup>49</sup>	US	Trout and catfish	Slips and falls, electrical contact, drowning, sprains and strains, machine-related hazards, chemical exposures, and fires and explosions
Robertson et al. 1981 <sup>50</sup>	Great Britain	Trout	Leptospirosis
Wooster et al 2005 <sup>51</sup>	NY	Trout	Formaldehyde
Gill, Coghlan et al. 1985 <sup>52</sup>	Great Britain	"fish" (trout)	Leptospirosis among fish farmers
Gill, Waitkins et al 1985 <sup>53</sup>	Great Britain	"fish" (trout)	Leptospirosis among fish farmers
Stewart 2006 <sup>54</sup>	DE	Tilapia	Musculoskeletal disorders
Charmish 1996 <sup>55</sup>	Israel	Tilapia	Spine prick infection by <i>Vibrio vulnificus</i> led to amputation of fingers
Said et al 1998 <sup>56</sup>	Israel	Tilapia	Fish-related injury, infections, amputations
Carino et al 1985 <sup>57</sup>	Italy	Fish and shellfish	Shrimpmeal allergy
Granslo et al. 2009 <sup>58</sup>	Norway	Shrimp, fish fry	Asthma associated with respiratory and skin exposure to brine shrimp used as feed
Graslund et al 2003 <sup>59</sup>	Thailand	Shrimp	Soil and water treatment compounds, pesticides and disinfectants, antibiotics, microorganism products, immunostimulants, vitamins, feed additives
Nikkanen and Burns 2004 <sup>60</sup>	ME	Halibut	Hydrogen sulfide poisoning and death
Doolette and Gorman 2003 <sup>61</sup>	Australia	Tuna	Diving, decompression illness
Douglas and Brough 1991 <sup>62</sup>	United Kingdom	Salmon	Decompression sickness
Douglas 1995 <sup>63</sup>	United Kingdom	Salmon	Falls from boats and cages, respirable dust from feed, leptospirosis, musculoskeletal injuries from lifting nets, diving risks, pesticides, needlestick injuries
Leira and Baalsrud 1992 <sup>64</sup>	Norway	Salmon	Self-injection of fish vaccine into finger, inflammation, anaphylaxis
Leira et al. 1993 <sup>65</sup>	Norway	Salmon	Self-injection of fish vaccine
Leira and Baalsrud 1997 <sup>66</sup>	Norway	Salmon	Self-injection of fish vaccine
O'Neill et al. 2005 <sup>67</sup>	Ireland	Salmon	Vaccine injection into finger, 3 infection cases, swelling, inflammation
Jacobs et al. 2002 <sup>68</sup>	Scotland	Salmon	Organohalogenated compound contamination (polychlorinated biphenyls, organochlorine pesticides) in fish feed
Buchanan 1992 <sup>69</sup>	Scotland	Salmon	Cages, diving, cranes and hoists, sea-going workboats

Dyrkorn et al. 1993 <sup>70</sup>	Norway	Salmon including smolt	Vaccine injection, 12 incidents in one season, no infection, 24-h inflammatory response, referred to anaphylactic shock in other cases
Tong 1996 <sup>71</sup>	Australia	Ornamental fish	Marine life, skin hazards: stings and envenomations (sea anemones, corals, sponges, sea urchins, venomous fish), infections (zoonoses including <i>Mycobacterium marinum</i> and erysipeloid and infections of wounds), irritant contact dermatitis (washing gravel, sea salt crusts, extended immersion), ultraviolet lighting, contact sensitization (antiseptics, hydrazine in nitrate kits), contact hypersensitivity (prophylactic antibiotics), and chemical burns and irritation (sodium hydroxide and sodium hypochlorite in ammonia test kits)
Tong 1996 <sup>72</sup>	Australia	Ornamental fish	Salt dermatitis
Tong 1995 <sup>73</sup>	Australia	Ornamental fish	Coral dermatitis
Schmoor et al. 2003 <sup>74</sup>	France	Ornamental fish	Chronic disease, fish tank granuloma, a potentially disabling skin infection
Fölster-Holst et al. <sup>75</sup>	Germany	Ornamental fish	Skin inflammation from cercarial dermatitis (swimmer's itch) caused by penetration of <i>Schistosoma</i> parasites
Gray et al. 1990 <sup>76</sup>	Great Britain	Ornamental fish	Granulomas of the skin due to <i>Mycobacterium balnei</i> (source of fish TB) after abrasions from a fish tank
Arai et al. 1984 <sup>77</sup>	Japan	Ornamental fish	<i>Mycobacterium marinum</i> infection of the skin
Whyte et al. 2001 <sup>78</sup>	Australia	Tuna	Diving, decompression illness
Darek and Moreau 2009 <sup>79</sup>	Canada	Mariculture	Falls, transport, machinery, electricity, fire, extreme temperatures, diving, noise, confined spaces, chemicals, biological hazards, psychosocial hazards
Anh et al. 2009 <sup>80</sup>	Cambodia	Plants	Dermatitis, wastewater-fed aquatic vegetation production
Anh et al. 2007 <sup>81</sup>	Vietnam	Water spinach, mimosa, dropwort, cress	River water used for aquaculture contaminated with untreated wastewater resulting in dermatitis
Vuong et al. 2007 <sup>82</sup>	Vietnam	Aquatic vegetables, carp	Dermatitis, wastewater-fed aquatic food production
Srivastava et al. 2004 <sup>83</sup>	India	Aquaculture	Malachite green (parasiticide) reported to cause carcinogenesis, mutagenesis, chromosomal fractures, teratogenicity, and respiratory toxicity
Ogbondeminu and Okaeme 1986 <sup>84</sup>	Nigeria	Aquaculture	Wastewater contamination by <i>Pseudomonas</i> sp., <i>Escherichia</i> sp., <i>Aeromonas</i> sp., and <i>Staphylococcus</i> sp
Katz et al. 2002 <sup>85</sup>	Hawaii	Aquaculture, taro, watercress	Leptospirosis
Anderson et al. 1982 <sup>86</sup>	Hawaii	Aquaculture	Leptospirosis
Taylor et al. 2002 <sup>87</sup>	US	Aquaculture	Electrocution
Erondu and Anyanwu 2005 <sup>88</sup>	Africa	Aquaculture	Noise, cuts, sprains, fractures, catfish stings, asthma, rhinitis, snake and fish bites, crab scrapes, bronchitis, chemical burns and skin irritation, pesticide and disinfectant poisoning, parasites, and pathogens
Myers et al. 2009 <sup>89</sup>	US	Aquaculture	Tractor overturns
Trang et al. 2007 <sup>90</sup>	Vietnam	Aquaculture	Skin ailments related to wastewater use
Conway and RaLonde 1998 <sup>6</sup>	Review		Entanglement, hearing loss, slips and falls, drowning, lacerations with associated infections, electric shock, hypothermia, repetitive strains, sleep deprivation, decompression illness, organophosphate poisoning, respiratory illness, sunburn, keratotic injury, leptospirosis, eczema, dermatitis

(Continued)

TABLE 4. (Continued)

Reference	Location	Species <sup>†</sup>	Description
Cole et al. 2009 <sup>2</sup>	Review		Physical hazards (tractors, electricity, drowning, repetitive lifting, extreme environments, decompression illness), chemical and toxic exposures (ammonia, H <sub>2</sub> S, chemical cocktails), and infectious disease risk (antimicrobial self-injection, microbes, parasites, protozoans, dinoflagellates)
Watterson et al 2008 <sup>1</sup>	Review		Machinery and equipment: drowning, boats, work systems, shift and night work, ergonomics, noise and vibration, lighting; personal protective equipment. heat and cold, chemical exposures, zoonoses, confined spaces, electricity, fire, and psychosocial factors
Durborow 1997 <sup>8</sup>	Review		Bacterial infection from fish spines, H <sub>2</sub> S, sodium metasulfide, sodium bisulfite, anesthetics, antibiotics, vaccines, tractor overturns, electricity, overhead power lines, power take-off or paddlewheel entanglements, falls, muscle strains (tenosynovitis), drowning, hypothermia, decompression illness
Durborow, 1999 <sup>7</sup>	Review		Bacterial infection, parasites, leptospirosis, electricity, chemicals, vaccines, H <sub>2</sub> S, injuries

<sup>†</sup>The "Aquaculture" term was used generically when species were unidentified. Review articles were designated "Review."

hair entanglement in hatchery paddles. In both catfish and trout farms, the following hazards were identified: slips and falls, electrical contact, drowning, sprains and strains, machine-related hazards, chemical exposures, and fires and explosions. Spine pricks or stings were reported, although it was undetermined if they occurred on fish farms or during recreational fishing. Spine envenomation or infection was reported, including a related case of septic arthritis.<sup>9-17</sup> Dermatitis was reported in pond cultures when the growing medium was wastewater. In a crane overturn into a pond, the operator was trapped inside the cab and drowned.

**Trout or Sturgeon** (cold water fresh water fish, raceway culture)

OSHA investigations reported hazards—all indoors—at hatcheries that included confined spaces, fuels and solvents, chemicals (formaldehyde, hypochlorate), no guards on saws, water jet spray, asbestos in ceilings, and oxyacetylene, whereas the rearing farms included high-pressure water jets and lack of railings at raceway wall edges (later reversed by the Occupational Safety and Health Review Commission). Nonetheless, slips and falls are a hazard. An investigation on a sturgeon farm identified exposures to hydrogen peroxide, keylime, liquid oxygen, muriatic acid, forklift (propane) operation, and scuba diving. Another US investigation reported a crane overturn into a trout pond being refurbished, crushing the operator as he attempted to jump clear.

Leptospirosis exposure was also associated with trout farms, and potential dinoflagellate *Pfiesteria piscicida* were observed at a sturgeon hatchery. Dermatitis can occur when the skin is abraded by a number of contacts and infection occurs. Three OSHA investigations did not identify the species but likely involved trout farms: two separate incidents involved drownings from two different boats on which neither decedent wore a personal flotation device (PFD); the third was a building fire at a farm. Elevated levels of acoustic neuroma were found among hatchery workers.

**Tilapia** (tropical fish, tank culture)

OSHA investigated three farms. On one there was no fall protection where there had been a fall into a 5 feet deep raceway. The investigation also noted potential hydrochloric acid exposure and the problem of working alone on raceways at night. At the second farm observations included extension cords lying in water, poor flooring, absence of hand rails, chlorine and hydrogen peroxide exposure, open drums of other hazardous chemicals, warafin exposure, forklift hazards, and algae growth as well as trip hazards. At the third farm, a wood-burning heating system caused carbon monoxide (CO) exposure to workers. An engineering investigation aimed to reduce musculoskeletal strains, while another investigation identified a spine prick infection.

**Salmon** (freshwater hatchery and smolt, salt water grow-out, pen culture)

No OSHA investigation of salmon farms was identified, but other investigations observed potential formalin exposure at a hatchery and styrene and acetone exposures during the construction of fiberglass tanks. However, several studies identified multiple hazards, including falls from boats and cages, respirable dust from feed, leptospirosis, musculoskeletal injuries from lifting nets, diving risks including decompression illness, pesticides, several needlestick injuries and associated complications, and polychlorinated biphenyl- and organochlorine pesticide-contaminated fish feed. Self-injection of fish vaccine was another potential hazard exposure that can cause inflammation and at times anaphylactic shock. Moreover, cages, diving, cranes and hoists, and sea-going workboats presented injury hazards. In addition, Norway has investigated the hazards of salmon farming that identified drowning, decompression illness, crane hazards, and boat operation.<sup>18,19</sup>

**Shellfish** (spawning onshore, grow-out in estuaries)

OSHA investigated a drowning of a diver harvesting mussels. At another farm, OSHA found electrical hazards associated with broken

conduits and broken railing as well as missing latches on electrical hoists. Dredging and unapproved PFDs posed hazards on an oyster farm. An investigation not identifying the species but likely on a clam farm found that no safety meetings were held. A study found the hazard of fishmeal allergy. The estuarine environment can pose exposures to dinoflagellate *Pfiesteria piscicida* that produces exotoxin, which can be absorbed either through the water or inhaled in aerosols.<sup>20</sup>

### ***Shrimp or Prawns*** (tanks and ponds)

OSHA investigated brine shrimp harvesting where unsanitary conditions and an arm injury after falling off an ATV were identified. Another farm engaged in shrimp breeding and algae production presented exposures to hydrochloric acid (muriatic acid), formaldehyde, polyvinyl chloride (PVC) cement, ferric chloride hydrate, tolidine, chloride, and floor openings. A study found asthma associated with respiratory and skin exposures to brine shrimp used as feed, and in another study occupational exposures were found to soil and water treatment compounds, pesticides and disinfectants, antibiotics, microorganism products, immunostimulants, vitamins, and feed additives.

### ***Ornamental Fish***

A review of marine life used in aquariums identified skin hazards, stings and envenomations (sea anemones, corals, sponges, sea urchins, venomous fish), infections (zoonoses including *Mycobacterium marinum* and erysipeloid and infections of wounds), irritant contact dermatitis (washing gravel, sea salt crusts, extended immersion), ultraviolet lighting, contact sensitization (antiseptics, hydrazine in nitrate kits), contact hypersensitivity (prophylactic antibiotics), and chemical burns and irritation (sodium hydroxide and sodium hypochlorite in ammonia test kits). Salt or coral dermatitis is possible as well as "swimmer's itch"—caused by skin penetration by a parasite. Infections of abraded skin can lead to bacterial infection when working with aquariums.

### ***Tuna and Halibut*** (mariculture)

At a halibut research facility, a rescuer was fatally overcome by hydrogen sulfide gas when retrieving a teenage worker who was cleaning the bottom of a 6-foot cement waste-recycling tank. A study of a tuna farm identified a death from decompression illness of a diver. A review article of mariculture identified several hazards with regard to falls, transport, machinery, electricity, fire, extreme temperatures, diving, noise, confined spaces, and chemicals as well as biological and psychosocial hazards.

### ***Aquatic Plants***

On a pond lily farm, a harvesting worker's canoe capsized, and he drowned in the absence of wearing a PFD. In Southeast Asia, several studies were conducted regarding occupational hazards associated with growing plants in wastewater. Findings included the identification of the associated outcome of dermatitis. However, a study of wastewater use in Thailand concluded that World Health Organization standards for its use in aquaculture were adequate.<sup>21</sup> In Hawaii leptospirosis was associated with taro and watercress farming.

## **CONCLUSION**

This review addressed the question, "What is known about potential hazardous occupational exposures to aquatic plant and animal farmers?" Many hazards associated with aquaculture were identified, but detailed data regarding the extent of the safety and health consequences of these hazards are lacking. The results from this study will help to design more detailed research into the occupational safety and health problems associated with aquaculture as well as solutions to these problems.

Causes of deaths included drowning, electrocution, crushing-related injury, hydrogen sulfide poisoning, and fatal head injury. Nonfatal injuries were identified with slips, trips, and falls; machines; strains and sprains; chemicals; and fires. Other hazards included punctures or cuts from fish teeth or spines, needlesticks,

exposure to low temperatures, and bacterial and parasitic infections. However, the paucity of scientific studies of occupational hazards in aquaculture suggests that there exists a need for rigorous epidemiological research in this sector to better plan intervention strategies, as well as allergy associated with fish feed exposures.<sup>22</sup> Although not reported in the aquaculture literature, other health effects may occur such as latex allergy related to wearing boots and waders<sup>23</sup> and injuries from boat propellers.<sup>24</sup>

The application of research needs to be targeted by the type of species being raised, since the technologies differ greatly between rearing methods.<sup>2</sup> For example, catfish or bass are warm water fish and are raised in ponds, trout are cold water fish raised typically in raceways, and tilapia are a tropical fish raised in indoor tanks (in the United States). Salmon are hatched on land-based facilities including brood stock ponds but are finished in offshore net pens or cages. Clams are hatched on land inside buildings and can be reared inside nets in estuaries, whereas oysters, hatched similarly, are raised on vertically strung ropes in estuaries.<sup>25</sup> Pioneering experiments are being conducted regarding animal mariculture as well, namely deep ocean farms with "aqua-pods" suspended in the ocean between buoys and anchors and farms built on decommissioned offshore oil platforms in the Caribbean.<sup>26</sup> The challenge to the survival of depleted wild fish stocks continues to drive evolving aquacultural technologies to meet the demand for fish worldwide.

The demand for food from fish is not the only driver of this emerging subsector. Plant aquaculture is an emerging endeavor focused around algae growth driven by the potential demand for biofuels. Two principal algae technologies are evolving, one for larger plants and the other for microalgae, which utilize, respectively, recirculated water through a serpentine ditch and shallow ponds (4 to 6 inches deep). In addition, duckweed production is seen as a source of biofuels while cleansing animal waste water.<sup>27</sup> These emerging subsectors likewise may warrant more detailed study of potential occupational hazardous exposures as they employ a growing number of men and women.

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