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AQUACULTURE

Occupational Safety and Health in U.S. Aquaculture: A Review

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ABSTRACT

Objectives: Aquaculture encompasses a variety of species in both freshwater and marine settings and can combine elements of agriculture and fishing, two recognized hazardous occupations. Efforts are underway to expand the aquaculture sector in the United States (U.S.), and should be informed by occupational safety and health (OSH) research. The objectives of this review paper are to: i) describe the U.S. aquaculture sector, ii) summarize statistics, peer-reviewed studies, and reports focused on U.S. aquaculture OSH, and iii) describe the policy landscape specific to U.S. aquaculture OSH.

Methods: Literature searches employed databases and Internet search engines to identify relevant peer-reviewed articles, reports, and other resources. Due to the expected U.S. expansion of marine aquaculture and paucity of peer-reviewed U.S.-based OSH literature in this sector, additional searches for international research on marine aquaculture were conducted.

Results: The U.S. Bureau of Labor Statistics estimated high rates of illness and injury among U.S. aquaculture workers in 2014 and 2015. Peer-reviewed literature on aquaculture OSH identified numerous physical, chemical, and biological OSH risks depending on production methods and settings. Significant policy gaps exist regarding U.S. aquaculture OSH surveillance, reporting, and regulation.

Conclusion: This review identifies a critical need for research, surveillance, and best practices information, specific to the major types of aquaculture in the U.S., to augment and inform worker safety and health efforts in this expanding sector.

KEYWORDS
Aquaculture; worker safety; hatchery; agriculture; fish farm

Introduction

Around the world, individuals work daily to provide food for billions of people. Jobs in the food production sector tend to be physically demanding, frequently resulting in higher injury and illness rates compared to other occupations.[1] Additional research on occupational safety and health (OSH) is needed to increase understanding of job hazards, rates of injury and illness, differences between subpopulations, and develop and evaluate various types of interventions that can prevent or reduce the severity of workplace injuries and illnesses. In this article, we focus on aquaculture workers in the United States (U.S.). Aquaculture refers to the breeding, rearing, and harvesting of animals or plants in an aquatic setting.

Food from aquatic sources is increasingly farmed instead of wild-caught. Globally, 53% of the seafood consumed by people is produced by aquaculture (excluding aquatic plants).[2] Global aquaculture production totalled 80 million metric tons of aquatic animals and 30.1 million metric tons of aquatic plants in 2016.[2]

In addition to farming finfish, crustaceans, mollusks, seaweeds and other aquatic organisms for human consumption, aquaculture also includes hatchery production of fish and shellfish for conservation, stock enhancement, recreational angling and bait, ornamental fish, and algae (e.g., kelp) for a variety of uses including cosmetics, fertilizer, fuel, and animal feed.[3,4] For this review, we focus on the farming of aquatic animals and plants for food, as well as hatcheries producing fish for recreation, conservation, and stock enhancement.

Aquaculture occurs both indoors in tanks of various sizes and outdoors in ponds, cages, raceways, or longlines using flowing or static freshwater, brackish water, or saltwater (Figure 1). The majority of farmed seafood is produced in Asian countries; the U.S. currently contributes less than 1% of global aquaculture.[5] The

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current U.S. National Strategic Plan for Federal Aquaculture Research describes nine goals to support the growth of aquaculture through research and adoption of new technology, including the creation of a skilled workforce.[6] The U.S. National Oceanic and Atmospheric Administration (NOAA) has a specific goal to grow marine aquaculture (coastal and offshore) 50% by 2020,[7] and NOAA as well as other government agencies, including the U.S. Department of Agriculture (USDA), are investing in growing the U.S. aquaculture sector.[8] Supporting and growing freshwater aquaculture is a priority for the USDA.

Considering the size of the industry globally, limited research has been conducted on aquaculture workers' safety and health.[5] Thus, the objectives of this review paper are to: i) describe the size, employment estimates, major species produced, and geographic spread of the U.S. aquaculture sector, ii) review statistics, peer-reviewed studies, and reports focused on OSH in U.S. aquaculture, and iii) summarize the policy landscape specific to OSH in U.S. aquaculture.

Methods

Information was extracted from websites of government agencies and non-governmental organizations relevant to OSH in agriculture and aquaculture. Literature searches were conducted between January 15 and February 4, 2019. Searches employed Google Scholar and PubMed. Google Scholar search terms included: "fish hatchery" "occupational safety" "occupational health" "risk factors" "hazards" and "fish farms." PubMed search terms included: "Aquaculture [MeSH]" "Occupational Health [MeSH]" "Exposure[tiab]" "Worker[tiab]" Pond[tiab]" "exposure[tiab]" "shellfish[tiab]" "raceway[tiab]" "risk*[tiab]" "injur*[tiab] and "safety management-[MeSH]." Due to limited search results on this topic, all peer-reviewed scholarly references for U.S.-based aquaculture were included, regardless of publication date. For the first search, articles about international aquaculture practices, food safety, and non-occupational safety and health-related aquaculture practices were excluded.

Figure 1. Examples of U.S. aquaculture operations. Clockwise from top left: coastal oyster farm (Credit: NOAA), freshwater catfish pond (Credit: David Love, Johns Hopkins University), coastal salmon net-pen (Credit: NOAA), and indoor fish hatchery (Credit: U.S. Fish and wildlife service).

Due to a lack of U.S.-based research on occupational safety and health in marine production settings, two additional searches were conducted on February 12, 2019 for the terms "Marine Aquaculture Occupational Health Safety" on Google Scholar, and on February 13, 2019 for the terms "aquaculture[MeSH] AND marine-[tiab] AND occupational safety[text]" on PubMed. Searches yielded results from international aquaculture OSH studies. For this search, results were included if they were published in 2015 or later. Resources were also included from the authors' personal files.

Results

U.S. aquaculture sector

The U.S. had slightly more than 3,000 aquaculture operations reporting $1.37 billion in sales in 2013.[9] Figure 2 shows the number of farms and value of aquaculture production by state.[9] The U.S. Bureau of Labor Statistics (BLS) estimated that in 2017, 6,600 people were employed at 852 private U.S. aquaculture operations.[10] The Census of Aquaculture, conducted by the USDA collected employment information in 2005 (but not in 2013) and estimated that aquaculture directly employed 10,519 people in 2005, with an additional 3,263 volunteer workers who were likely family members of the farm owner.[11] The discrepancy between the BLS and USDA estimates is likely due to data collection methods, inclusion criteria, and other factors.

Major-farmed species in the U.S. include food fish (e.g., catfish, trout, salmon), molluscan shellfish (e.g., oysters, clams, mussels), crustaceans (e.g., crawfish), sportfish for recreational fishing, baitfish (e.g., minnows), and ornamental fish.[12] In 2013, top species produced were catfish (predominantly channel catfish

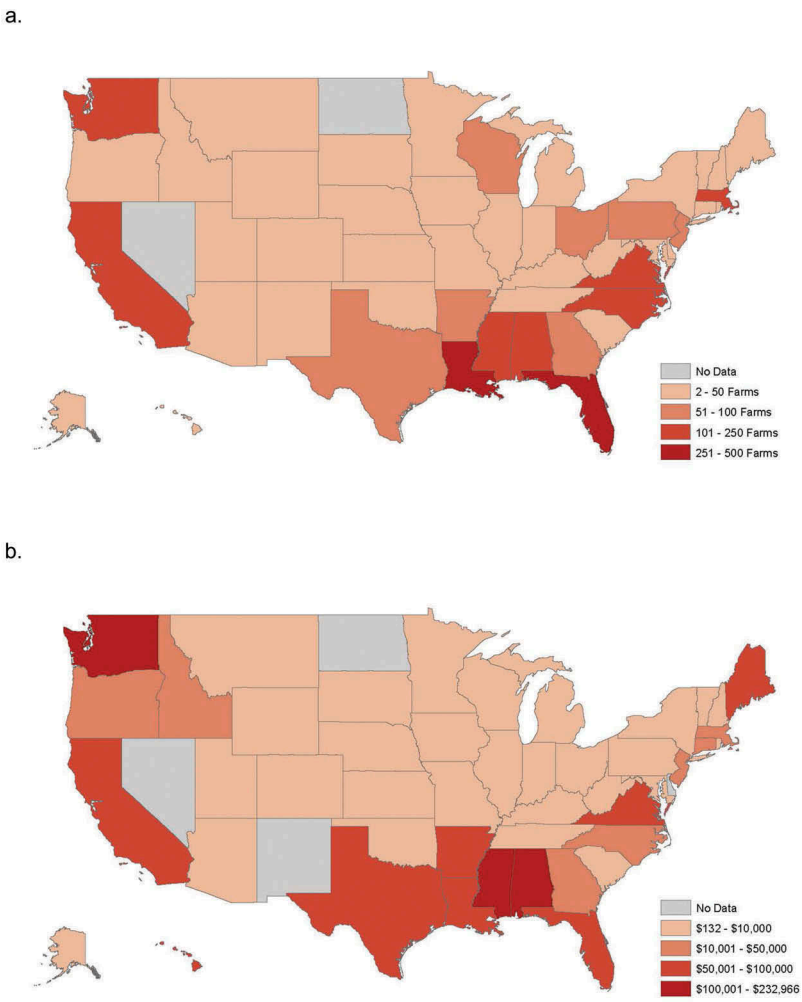

Figure 2. The (a) number of aquaculture farms and (b) value of aquaculture production by state.
Source: USDA census of aquaculture, 2013.

(*Ictalurus punctatus*)), rainbow trout (*Oncorhynchus mykiss*), and freshwater crawfish (*Procambarus clarkii* and other spp.). Marine aquaculture is primarily focused on Atlantic salmon (*Salmo salar*) and mollusc culture.

Over 1.5 billion salmon smolts are produced annually in hatcheries for ocean ranching, making it a major component of the commercial Pacific salmon fishery.[13] Approximately 40% of the Pacific salmon caught in Alaska and up to 90% in Washington, Oregon, and California originate from hatchery releases.[14] Additionally, aquaculture production supporting recreational fishing is mostly carried out by state and federal government agencies. In total, government-run hatcheries produced nearly 29,000 tons of fish for recreational purposes in 2013, over half of which was rainbow trout.[12]

Demographic and socioeconomic factors relevant to the U.S. agricultural workforce, and potentially pertinent to aquaculture, have implications for OSH. In 2016, the mean hourly wage in U.S. animal agriculture (including aquaculture) was $12.90 per hour versus $25.78 for all occupations.[15] The 2015–2016 National Agricultural Workers Survey (NAWS) found that 75% of farmworkers employed by crop-producing operations in the U.S. were foreign-born.[16] In addition, NAWS reports that approximately a third of crop farmworkers were living below the poverty line and 53% did not have health insurance.[16] Finally, an estimated 42,000 workers 16 to 19 years-old were employed in U.S. animal production in 2016.[17] It is unknown if, or how the U.S. aquaculture workforce differs from the overall agricultural workforce.

Current knowledge of U.S. aquaculture OSH

U.S. aquaculture workers experienced 8.1 and 13.6 nonfatal injuries and illnesses (combined) per 100 fulltime workers in 2014 and 2015, respectively.[18] The 2015 combined injury and illness rate was the highest of any industry that year.[19] Comparable rates in 2015 were 3.0 for all private industry workers, 5.7 for the agriculture, forestry, fishing, and hunting sector (including aquaculture), 3.8 for manufacturing, and 11.3 for local police officers.[19,20] The 2017 rate of injury and illness in aquaculture was 3.9 per 100 fulltime workers,[21] possibly signaling underreporting or estimate instability due to worker population size. BLS data includes 10 total fatalities among aquaculture workers in 2011, 2012, 2014, 2015, and 2017.[22]

Hatcheries and indoor aquaculture

Finfish and shellfish hatcheries contain chemical, biological, and physical hazards.[23] Chemical hazards in hatcheries can originate from veterinary pharmaceuticals, disinfectants, sterilizers, and other sources. According to Myers (2010), hatchery investigations by the U.S. Occupational Safety and Health Administration (OSHA) identified exposure to formalin, methanol, hypochlorite, oxygen-acetylene systems, fuels, and solvents.[23]

Some occupational exposures in aquaculture are not yet characterized in detail beyond case studies. Lee and Radtke (1998) and Wooster et al. (2005) suggested that formalin exposure poses minimal risks to aquaculture workers, but more recently Voorhees and Barnes (2016) reported hazardous levels of formalin exposure during simulated egg treatments.[24–26] Acute exposure to the fish anesthetic MS-222 was implicated in a 1997 report of temporary blindness in a Utah salmon hatchery worker.[27] Furthermore, Page (2000) described an apparent cluster of acoustic neuroma cases (i.e., noncancerous growth on the nerve connecting the inner ear to the brain) found among four former hatchery workers the 1990s. No cause was formally identified, and Page suggested that some commonly used hatchery chemical could be associated with this illness cluster.[28]

Many aquaculture farms use ozone or ultraviolet lights to decrease microbial loads in the water supply.[23,29,30] Ultraviolet (UV) radiation exposure can damage the skin and eyes,[31] and ozone gas can cause lung tissue damage, and fatalities at high exposures. UV exposure limits are regulated by OSHA.[32] Modern UV water treatment used in aquaculture utilizes enclosed UV light systems, reducing occupational risks. In addition to ozone for water sterilization, oxygen is also routinely used during aquaculture production and transportation of aquaculture products. Oxygen increases the risks of fire and explosions,[33] and liquid oxygen, in particular, can cause cryogenic burns and tissue damage.[34] Prolonged exposure to oxygen exceeding atmospheric levels can produce

respiratory issues, sinus and eye irritation, and a variety of neurological effects.[35] Lastly, workers can also be exposed to hazardous concentrations of radon, a carcinogenic gas occurring naturally in groundwater used for aquaculture production.[36]

Barnes et al. (2015) and Voorhees and Barnes (2017) recorded occupational noise levels attributable to flowing water in two trout and salmon hatcheries in South Dakota.[37,38] While no values exceeded regulatory limits, the noise levels they found have been linked to a number of negative physiological effects.[39–43]

Electrical hazards are prevalent in fish hatcheries and aquaculture facilities in the U.S. due to a combination of electrical equipment and wet working environments.[23,30,44] Myers (2010) also describes confined work spaces on trout farms, hazardous equipment like unguarded table saws (trout), and hatchery paddle wheels which can scrape, cut, and entrap workers by the hair (catfish). Confined work hazards have been documented in some finfish hatchery operations. Ogunsanya et al. (2011) documented sediment tanks at trout hatcheries, and Myers (2010) described the risks from the release of toxic gases from the products of decomposition. Some hatcheries have lift stations and wet wells to handle domestic sewage, which have led to worker injury or death in other non-aquaculture situations.[45] A 2004 case study in *Pediatrics* detailed a perilous event in which a 16-year-old summer worker and his supervisor were overcome by hydrogen sulphide (H_2S) gas while cleaning out a halibut tank;[46] the supervisor died and the juvenile required extensive medical care and survived.

Fish health monitoring and inspection requires the use of laboratory tools, such as scalpels and forceps, creating additional worker safety issues.[47] At government hatcheries producing fish for conservation or recreational stocking, fish tagging and marking often involves surgical implantations of tags or injection of various-sized tags, each of which carry worker hazards. In addition, workers at a Kentucky indoor tilapia facility contracted a species of *vibrio* from infected fish in 1991.[44]

An analysis of workers' compensation claims in Washington found that shellfish hatchery workers experienced 11.4 injuries per 100 full-time employees from 2006 to 2014.[36] The most commonly reported injuries were work-related musculoskeletal disorders, specifically sprains, strains, and tears of the lumbar region or shoulder. Hand tools were also cited as causing injury, with lacerations of the hands or fingers most frequently reported.[36]

Freshwater aquaculture

Most occupational health research in U.S. aquaculture has focused on freshwater aquaculture sites. Durborow and Myers described the occupational hazards posed by large equipment on freshwater farms, particularly on catfish farming.[48–51] Tractors are used to renovate ponds, move and operate implements (particularly pond aerators), and perform mowing and general farm activities.[44,48,52] Because of the steep, wet, and slippery slopes associated with catfish farms, crushing and drowning has resulted from rollovers of tractors not equipped with a roll-over protection structure (ROPS).[52,53] Myers (2009) found that the percentage of ROPS-equipped tractors varied dramatically by geographic region, at over 90% in the southern U.S. compared to only 37.4% in the north-eastern U.S. states.[54] A roll-over fatality has also been reported at a trout farm.[33,55] Widespread education programs on tractor rollovers and ROPS protection in the catfish industry[56] and the voluntary addition of ROPS on nearly all farm tractors manufactured in the U.S. since 1986,[52] has led to dramatic improvements in tractor roll-over protection in the southern U.S..

Other potentially hazardous equipments used on freshwater farms include hydraulic fish pumps,[23,49] fish transport vehicles, cranes,[23,30,55] all-terrain vehicles,[23,49] fork lifts, backhoes, skid steers, mowers, and other motorized equipment which are used to haul fish or other loads around the farm.[23] Tractor power take-offs (PTO), rotating shafts transferring power from the tractor to an external implement such as a pond aerator, create a serious hazard in aquaculture, resulting in at least one fatality.[30,33,49,50] Pressure (or power) washers, used to clean aquaculture rearing units and other equipment, can also cause injury.[23]

Trips, slips, and falls are a common hazard at fish hatcheries and farms in the U.S. Wet walking surfaces, including raceway walls, catwalks, docks,

pond dikes, and pond liners, coupled with frequently narrow access points,[53] create a high degree of risk.[23,33,36,49] Ogunsanya et al. (2011) described a number of injuries due to slips at aquaculture facilities, such as abrasions, lacerations, bruises, and broken bones. Falls from height can occur into the deep sumps used for plumbing and drains.[57] Falls from height can also occur when ladders are used to access feed bins, aeration towers, or sumps.[33,49] More generic physical hazards include the use of knives, saws, power tools, welding equipment, acetylene torches, and general shop tools.[23,36]

Lifting-related musculoskeletal injuries at aquaculture facilities represent a significant aquaculture worker safety concern.[23,49] The repetitive lifting of feed buckets, feed bags, and nets containing fish[33,36,53] can precipitate overuse injuries, such as tenosynovitis. Beyond fish and fish gear, workers must also lift chemical containers, generators, oxygen bottles, screens, mechanical equipment, and building materials.[49] Primarily because of the repetitive lifting of traps, crayfish farmers in Louisiana self-reported a 90% incident rate of musculoskeletal injury, primarily in their shoulders and upper back.[58] Torn knee cartilage, back injuries, and a torn bicep resulting from lifting by trout farmers were described by Ogunsanya et al. (2011). Similar to lifting injuries, pinching or crushing injuries are also a frequent possibility for aquaculture workers.[23] Actions such as installing or removing screens or dam boards and the use of hand tools can cause pinching injuries. Tanks used to move fish have had premature lid closures, resulting in smashed and severed fingers.[33,49]

Overhead power lines can be contacted by cranes, augers, and other aquaculture equipment.[33,44,49] The use of electrically powered automatic feeders, aerators, and other equipment in close proximity to water presents hazards, as well as extension cords.[23,33,49]

Aquaculture work at ponds and raceways in the U.S. involves the use of various hazardous chemicals.[30,33,59] Workers at freshwater operations can be exposed to chemical disinfectants, chemical sterilizers, anesthetics, water-testing chemicals, pesticides, herbicides, and chemicals which alter water chemistry.

Fish vaccines are typically delivered by injection,[60] and accidental needle sticks to the worker injecting the fish can occur,[44,49,53] resulting in tissue damage, rash, and potential anaphylactic shock.[33] In addition to vaccinations, a variety of veterinary drugs and other chemicals are used to prevent and treat diseases; Table 1 lists substances approved for disease control in U.S. aquaculture, purpose of use, and potential human health hazards. In addition, chemical use in U.S. aquaculture extends beyond disease treatments.[30,33,44,49] Table 2 lists selected aquaculture chemicals used in the U.S., along with potential worker hazards.

Human pathogens are present in aquaculture water, and aquatic organisms can harbor zoonotic organisms (Table 3).[36,44,61–64] Some infections have colloquial names, like "Crayfish handler's disease," which is caused by a species of *Vibrio* or "fish handler's disease," caused by *Mycobacterium marinum*.[44] Worker contact with the water used in aquaculture operations has also led to dermatitis[23,36] and warts.[53] Allergic reactions from mold, dust, and fish meal have also been reported.[23,33,53] Fish themselves can be an occupational hazard;[23] spines and fin rays can cause tissue damage and infection.[30,44,61]

Catfish and crayfish farmers in the southern U.S. are subjected to high heat and humidity, contributing to possible heat exhaustion or sunstroke.[53] Long-term unprotected sun exposure, especially from reflective water surfaces like ponds, can lead to skin cancer.[36,53] In northern states or in colder water temperatures, hypothermia and frostbite are more likely.[33,53] Nuisance animals present workplace hazards, including poisonous snakes, leeches, and alligators. Insects can also be a constant hazard,[33] especially wasps.[65] In South Dakota, an aquaculture worker received several wasp stings and became sensitized to the point of an allergic reaction.[66] Poisonous spiders, ticks, and other arachnids, and the numerous disease organisms they carry, can present a workplace hazard. Mammals, such as raccoons, skunks, or bats, can carry diseases like rabies or numerous parasites[67] transmittable to workers.[30]

Marine aquaculture (coastal or off-shore)

There are few references to occupational health in U.S. marine aquaculture. Turner (2018) analyzed workers' compensation claims in Washington State and reported that coastal shellfish harvesters had an injury rate of 12.5 per 100 fulltime employees. Harvesters most frequently reported struck-by/against

Table 1. Drugs approved by the U.S. food and drug administration for use in aquaculture.

Drug	General Use	Administration	Potential Human Hazards
Chloramine-T	Control external bacteria	Immersion	(1) Inhalation: irritation to the respiratory tract (2) Ingestion: burns in mouth, throat, esophagus, and stomach, nausea and vomiting (3) Eye: corrosive to eye (4) Skin: corrosive to skin and can cause allergic reaction
Formalin	Control external parasites and fungus (on eggs and fish)	Immersion	(1) Inhalation: potential drowsiness or dizziness, severe respiratory irritation (2) Ingestion: potential damage to organs (through prolonged or repeated exposure) (3) Eye: serious eye damage (4) Skin: irritation, may cause allergic reaction (5) Chronic: potential carcinogen
Hydrogen peroxide	Control external bacteria and fungus (on eggs and fish)	Immersion	(1) Inhalation: irritation to nose, throat, and lungs, even death (2) Ingestion: burn mouth, throat, and stomach, potential death (3) Eye: burns and potential blindness; effects may be delayed (4) Skin: irritation and burns
Oxytetracycline hydrochloride	Skeletal marking	Immersion	(1) Eye: serious eye damage/irritation (2) Suspected of damaging unborn children
Tricaine methanesulfonate	Anesthetic	Immersion	(1) Inhalation: potential respiratory irritation (2) Eye: potential serious damage (3) Skin: skin irritation
Chorionic gonadotropin	Spawning	Injectable	(1) Suspected of damaging unborn children
Florfenicol	Antibiotic	Medicated feed	(1) Inhalation: irritation and upper respiratory tract (2) Ingestion: potentially harmful (3) Eye: potential irritation (4) Skin: potential irritation (5) Chronic: suspected of damaging fertility or unborn child
Oxytetracycline dihydrate	Antibiotic	Medicated feed	(1) Inhalation: harmful (2) Ingestion: damage to lungs from repeated oral exposure at high doses (3) Eye: potential irritation (4) Skin: harmful (5) Chronic: may damage fertility or unborn child from repeated oral exposure
Sulfadimethoxine/ ormetoprim	Antibacterial	Medicated feed	(1) Inhalation: respiratory inflammation (2) Eye: irritation (3) Skin: allergic reactions (4) Chronic: may cause birth defects

injuries caused by knives and work-related musculoskeletal disorders such as strains, sprains, and tears caused by body positioning. Shellfish harvesters also reported non-viral conjunctivitis from shucking oysters, as well as *Vibrio vulnificus*-caused corneal ulcers and other eye trauma.[36]

Because of the dearth of published research on marine aquaculture occupational health in the U.S., we have included some brief information from other countries to illustrate the potential hazards and to guide future U.S. research efforts. In Norway, Holen et al. (2017) found that blows by objects, falls, entanglement or crush injuries, and pricks/cuts/punctures were the most common causes of injury, and open wounds, sprains, contusions, and fractures were the most frequently sustained injuries in Atlantic salmon net-pen culture from 2001 to 2014.[68] In a second report, Holen et al. (2017) reported 34 fatalities in Norwegian aquaculture from 1982 to 2015, with most fatalities caused by loss of vessel (n = 15), man overboard (n = 5), and blow from an object (n = 6).[69] The authors suggested that seafaring vessel use and crane use represent critical intervention points for future worker safety interventions. Both of these analyses conclude that marine aquaculture work in Norway poses many occupational safety hazards, and that aquaculture work

Table 2. Chemicals used in U.S. aquaculture.

Chemical	General Use	Potential Human Hazards
Formalin	Tissue sample preservation	(1) Inhalation: potential drowsiness or dizziness, severe respiratory irritation (2) Ingestion: potential damage to organs (through prolonged or repeated exposure) (3) Eye: serious eye damage (4) Skin: irritation, may cause an allergic reaction (5) Chronic: potential carcinogen
Ethanol	Equipment disinfection and tissue sample preservation	(1) Eye: serious eye irritation (2) Chronic: potential carcinogen (3) Highly flammable
Copper sulfate	Algaecide, fungicide	(1) Inhalation: potentially fatal (2) Eye: potential irritation (3) Skin: potential irritation (4) Flammable: fumes produced may be irritating or toxic
Potassium chloride	Mussel veliger control	(1) Ingestion: potentially harmful (2) Eye: serious irritation (3) Skin: irritation
Potassium permanganate	Pond oxygenation, disinfection	(1) Inhalation: gastrointestinal or respiratory tract irritation, burning, lung damage, death (2) Ingestion: harmful (3) Eye: serious irritation, possible corrosion (4) Skin: irritation, possible corrosion, burns
Iodine	Egg disinfection	(1) Eye: serious irritation (2) Skin: sensitizer
Silicone-based defoaming agents (food grade emulsions)	Live fish transportation	(1) Inhalation: prolonged or excessive inhalation may cause irritation (2) Ingestion: potential gastrointestinal upset (3) Eye: potentially slight irritation (4) Skin: potential irritation
Quaternary ammonia	Equipment disinfection	(1) Inhalation: respiratory irritation (2) Ingestion: harmful (3) Eye: serious damage (4) Skin: severe burns
Bleach (chlorine)	Equipment disinfection	(1) Eye: serious and severe damage (2) Skin: severe burns
Carbon dioxide	Anesthetic	(1) Inhalation: may cause rapid suffocation (2) Skin: possible frostbite
Sodium thiosulfate	Neutralize chlorine	(1) Inhalation: respiratory tract irritation, potentially harmful (2) Ingestion: digestive tract irritation, potentially harmful (3) Eye: irritation (4) Skin: irritation, potentially harmful if absorbed (5) Chronic: prolonged or repeated skin contact may cause dermatitis
Diquat	Aquatic herbicide	(1) Inhalation: toxic (2) Ingestion: harmful (3) Eye: irritation (4) Chronic: damage to organs through prolonged or repeated exposure
Rodeo	Aquatic herbicide	(1) Eye: slight temporary irritation
Malachite green	External anti-microbial treatment for aquarium fish only (illegal to use in food fish aquaculture)	(1) Inhalation: hazardous, irritation to gastrointestinal or respiratory tract, characterized by burning, sneezing, and coughing (2) Ingestion: hazardous (3) Eye: irritant, potential corneal damage, blindness (4) Skin: irritant, inflammation and blistering (5) Chronic: severe over-exposure produce lung damage, choking, unconsciousness or death, mutagenic
Sulfuric acid	Alkalinity	(1) Inhalation: potentially fatal (2) Ingestion: digestive and respiratory tract burns (3) Eye: burns (4) Skin: burns (5) Chronic: potentially carcinogenic

(*Continued*)

Table 2. (Continued).

Chemical	General Use	Potential Human Hazards
Phenolphthalein	Alkalinity	(1) Inhalation: potential drowsiness or dizziness (2) Ingestion: acute toxicity, organ toxicity following a single exposure (3) Eye: irritation (4) Chronic: carcinogenic, genetic defect suspect, damaging fertility or unborn child suspect
Methyl red	Alkalinity	(1) Inhalation: potential respiratory irritation (2) Ingestion: potential digestive tract irritation, potential central nervous system depression, potential kidney damage (3) Eye: irritation (4) Skin: irritation, prolonged or repeated contact causes defatting of skin with irritation, dryness, and cracking (5) Flammable, potentially explosive
Sodium hydroxide	Water quality testing and pH adjustment	(1) Eye: serious damage (2) Skin: corrosion
Phosphoric acid	Water quality testing	(1) Eye: severe damage (2) Skin: corrosion
Cadmium	Water quality testing	(1) Inhalation: respiratory irritation, fatal (2) Ingestion: harmful (3) Skin: harmful (4) Chronic: suspected of causing genetic defects, damaging fertility and unborn child, potentially carcinogenic, causes damage to organs through prolonged or repeated exposure (5) Flammable, combustible dust
Sodium nitroferricyanide dehydrate	Water quality testing	(1) Ingestion: toxic
Potassium antimony tartrate	Water quality testing	(1) Ingestion: toxic
Sodium dodecyl sulfate	Water quality testing	(1) Inhalation: respiratory tract irritation, potentially causes a respiratory reaction (2) Eye: irritation (3) Skin: irritation (4) Flammable
Ammonia chloride	Water quality testing	(1) Ingestion: harmful (2) Eye: serious irritation

Table 3. Fish and aquatic pathogenic microbes that have infected aquaculture workers in the U.S. (Sources: 20,41,58–61).

Type	Pathogen	Location/fish	Symptoms
Dinoflagellate	*Pfiesteria piscicida*	Estuaries/ Striped bass	Eye irritation, paraesthesia, nausea, respiratory problems, skin lesions, abdominal pain, kidney and liver dysfunction, weakness, joint pain, headache, myalgia, vomiting, memory loss, emotional changes, narcosis, decrease in speech fluency, severe cognitive impairment
Bacteria	*Aeromonas spp.*	Ubiquitous, mostly freshwater	Cellulitis, deep muscle necrosis, septicaemia, gastroenteritis
	Burkholderia pseudomallei	Ponds/ Catfish	Pneumonia, septicaemia, fever, internal abscesses, folliculitis, meningitis, hypoventilation, anuria, dysarthria, ataxia, cranial nerve defects
	Edwardsiella tarda	Ponds/ Catfish	Necrotic skin lesions, gastroenteritis, meningitis
	Erysipelothrix rhusiopathiae	Ponds/ Catfish	Skin infection, septicaemia, endocarditis
	Mycobacterium spp.	Ubiquitous, mostly marine	Osteomyelitis, septic arthritis, tenosynovitis, cellulitis "Fish Handler's Disease"
	Streptococcus iniae	Recirculation/ Tilapia	Cellulitis, joint pain, fever, dyspnoea, confusion
	Vibrio spp.	Ponds/ Catfish, shellfish, crustaceans	Blisters, ulcers, edema, purpura, haemorrhagic bullae, necrotic eschar, fever, ecchymotic haemorrhages, mental issues, enteritis "Crayfish Handler's Disease"

is second only to wild fisheries regarding the level of occupational risk. In addition, Holen and Utne (2018) point out that the regulatory and surveillance framework for this industry in Norway is fragmented, and gaps in the understanding of safety and health risk factors in aquaculture persist.[70]

In Brazil, Speck et al. (2015) identified electric shock, solar radiation, and drowning as priorities for hazard mitigation at a long-line mollusc farm.[71] Other identified hazards included noise exposure (up to 88.5 dB), biological hazards (bites, stings, zoonotic diseases), ergonomic hazards (materials handling and hazardous postures), and slip/trip/fall hazards (slippery conditions, boat travel, debris on floor).[71] Additionally, authors found that limited organizational structures, lack of personal protective equipment use, and lack of task-based training put workers at additional risk.[71] In Australia from 2012 to 2016, marine aquaculture represented approximately 17% of the aquaculture industry, but had 43% of reported serious injury claims and 61.5% of the serious disease claims for aquaculture workers (68). Most common claims for all aquaculture workers were ergonomic stress (n = 110), struck by objects (n = 85), and slips/trips/falls (n = 22).[72]

Self-contained underwater breathing apparatus (SCUBA) work is required for some types of aquaculture.[30,68] In addition to possible net entanglement and entrapment,[53,68] SCUBA-related decompression sickness[23,73] represents a serious and potentially lethal hazard.

Major U.S. laws relevant to aquaculture OSH

The Occupational Safety and Health Act created the OSHA in the U.S. Department of Labor (DOL). OSHA regulates worker safety in the U.S. by setting and enforcing workplace safety and health standards. Individual states that have OSHA-approved state safety-and-health plans can enforce OSHA standards, and may also set stricter standards than those used by OSHA. Tables 4 and 5 list and describe OSHA violations and injuries and fatalities reported to OSHA, relevant to U.S. aquaculture operations. Employers with 10 or fewer employees are partially exempt from keeping workplace injury or illness records.[74] Since 1976, the U.S. Congress has included an appropriations rider precluding OSHA from conducting enforcement actions in most farming operations with 10 or fewer non-family employees.[75] The mean number of employees at U.S. fish farms was fewer than four in 2005.[11] Therefore, workers at many aquaculture operations are not covered by OSHA workplace safety regulations. Additionally, minor children of agriculture and aquaculture farm owners are exempt from all labor regulations.[76] OSHA has a voluntary Consultation Program that allows businesses to have state agency or university employees review their workplace and suggest safety improvements; this program could be utilized by aquaculture businesses.[77] Finally, a policy analysis focused on environmental and public health issues associated with offshore aquaculture found that OSHA does not have jurisdiction in federal waters, partly due to pre-emption by the U.S. Bureau of Ocean Energy Management, which is in charge of worker safety on oil rigs and wind farms in federal waters.[78]

Chemicals used in U.S. aquaculture are regulated by the Environmental Protection Agency (EPA). The Federal Insecticide, Fungicide, and Rodenticide Act authorizes this agency to determine which pesticides can be used, and how they can be used.[79] In addition to enforcing pesticide regulations, the EPA works with state offices to train and certify workers applying these chemicals.

The U.S. Coast Guard, within the Department of Homeland Security, regulates boating and provides information on boating safety. Coast Guard regulations regarding life jackets, fire extinguishers, and other areas directly affect aquaculture worker safety and health, particularly in near-shore or off-shore aquaculture.[80]

In the U.S., workers' compensation is a government-mandated insurance program designed to protect workers injured on-the-job. States administer their workers' compensation programs, which may require participation in a public system or purchasing private coverage, so rules and benefits vary between states.[81] In general, the program covers medical expenses and lost wages for workers who are injured, regardless of whom is at fault.[82] Occupational illnesses may also be covered.[83] As part of the insurance program, employees are not

Table 4. Violations observed during OSHA or state agency inspections of U.S. aquaculture operations, 2009–2018. Ownership is denoted as either public (government-owned, typically producing fish for release into the wild) or privately owned (commercial aquaculture). Source: https://www.osha.gov/pls/imis/industry.html.

Year	State	Ownership	Description of Issues
2018	WA	Private	Inspection of fire extinguishers, Marking of exits
	WA	Private	Written accident prevention program, Safety meeting requirements, First-aid training requirements
	AK	Private	Hazard communication programs, Open flames or smoking near flammable liquid storage, Required portable fire extinguishment and control equipment, Reporting of injuries and illnesses
	OR	Private	Maintenance of powered industrial trucks, Portable fire extinguishers required to be operable and charged, Inspection of portable extinguishers
	MS	Private	Workplace not free from recognized hazards – electrical hazards, Electrical power must be locked out prior to maintenance or service of equipment
	WA	Private	Modification or additions to powered industrial truck not sourced from manufacturer
	WA	Private	Safety meeting requirements, Written hazard communication
	WA	Private	Protection of open-sided runways and platforms with railings
	WA	Private	Accessibility of emergency washing facilities, Industrial truck operator training, Written hazard communication, Safety data sheets, Hazardous chemical training
2017	MI	Public	Electrical energy control inspections, Use of compressed air for cleaning without proper controls, Close unused cables/openings
	NY	Public	Ladders, Machinery fixed with anchors, Safety guards on machinery, Close unused cables/openings, Flexible cords and cables connected to devices and fittings, Grounding of equipment, Labelling of hazardous chemicals, Inspection of hazardous energy control procedure
	CA	Private	Injury and illness prevention program, Hazardous storage of material, Heat illness prevention plan, Hazard communication plan
	NY	Public	Vermin control
	OR	Public	Hand protection
	TN	Private	Training on hazardous chemicals in work area
	NY	Public	Portable metal ladders, Wiring issues, Confined spaces
	WA	Private	Inspection of fire extinguishers
2016	ME	Private	Workplace not free from recognized hazards
	CA	Private	Seatbelt usage, Machinery guarding, Oxygen cylinder storage
	NY	Public	Portable ladders, MSDS hazardous chemical sheets, Exit routes, Formaldehyde, Railings
	ME	Private	Supervisor accident prevention training, Exceeded crane/derrick load ratings
	WA	Public	Vermin control, Anchoring of machines, Radial saw position, Safety guard for grinder, Chemical labelling
	OK	Private	Workplace not free from recognized hazards – electrical shock
	CT	Public	Evacuation routes, Equipment violations, Formaldehyde issues, Blood borne pathogen control plan
	MN	Private	Accident and injury reduction program, Machinery guarding, Machine controls/power shut-off
	AK	Public	Inspection records, Confined space, Electrical equipment, MSDS sheets, Overhead crane
	MI	Public	Eyewash station
2015	NY	Public	Eyewash station, Written records, Hazardous chemical communication program
	NY	Public	Exit routes, Circular saw, Altered plug-ins
	WA	Private	Personal protective equipment, Electrical wiring, Safety meeting documentation, Truck driver training, Fire extinguisher maintenance and records
	OR	Private	Railings, Vehicle audible warning device, MSDS sheets, Safety meeting documentation
	NY	Public	Workplace violence prevention, Railings and guarding of openings, Electrical wiring
	NY	Public	Workplace violence, Arc welding ray protection, Defective or damaged equipment
	NY	Public	Eyewash station needed, Exposure record keeping
	CA	Private	Injury/illness prevention program records, Yard surface opening guards, Illumination, Face and eye protection, Respiratory protection program, Guarding of machinery and equipment moving parts
	OK	Private	Workplace not free from recognized hazards – electrical shock
	MI	Public	Confined spaces signing, Asbestos warning signs, Hazard communication program
	MI	Public	Electrical lockout, Open sprockets and chains, Several electrical issues, Compressed air use violations
	AK	Private	Noise exposure, Need eyewash station, Hazardous materials labelling
	AK	Private	Noise exposure, Welding cables, Chemical training program
	AK	Private	Noise exposure, Fan blade guards, Oxygen cylinder storage, Hazard communication program, Welding cables, Respiratory protection program, Personal fall arrest systems
	AK	Private	Fan blade guards, Face piece respirators
2014	NY	Public	PPE available, Fire extinguisher annual check, Horizontal belt guards, Electrical equipment use and grounding, Lockout/tagout SOPs
	ME	Private	Oxygen cylinder issues, Electrical conductors unprotected
2013	AZ	Public	Electrical cords, Fire extinguisher issues, Electrical equipment installed and used as per instructions
	WA	Private	Toilet issues
	VA	Public	Exit signs, Respiratory written plan, Hepatitis B vaccine
	CA	Private	Railings, Floors and platform issues, Mold growth
	NY	Public	Emergency systems, Anchoring of fixed machinery, Electrical equipment issues, Electrical cords
	OK	Private	Workplace not free from recognized hazards – electrical shock

(*Continued*)

Table 4. (Continued).

Year	State	Ownership	Description of Issues
	KY	Public	First aid and medical services, Written chemical hazard communications program
	NV	Public	Workplace cleanliness and sanitary issues, Fire extinguisher issues
	NV	Public	Step bolts and manhole steps
	ME	Private	Material handling and storage, OSHA year-end logs
	MD	Public	Respirator program and administration, Confined space determination
	MD	Public	Ladders, Anchoring of fixed machinery, Woodworking machine issues, Electrical hazards, Chemical labelling, Exits, Personal protective equipment, Fire extinguisher issues, Chemical hazard communication
	HI	Private	Scuba gear issues, Container marking, Personal flotation devices
	AZ	Public	Industrial truck operator issues, Radial saw installation, Grinder guard, Welding chemical fume information, Oxygen cylinder storage, Formaldehyde issues, OSHA annual summary
2012	NY	Public	Eyewash station, Radial saw guard, Electrical equipment issues, Belt sander guards, Guards for grinding machines, Workplace violence program, Truck operator evaluations, Truck issues, Fire cabinet issues
	MN	Public	Employee training
	NY	Public	Exits, Electrical issues, Electrical equipment issues
	WA	Public	Hazardous chemical list, MSDS sheets
	WA	Public	Conveyor belt guards, Using extension cords in lieu of permanent wiring
	KY	Private	Chemical hazard plan, Employee chemical training, Medical services and first aid, Lack of respirators
	WA	Public	Ladders, Gas ventilation from stored batteries
	IL	Public	Grinder work rest
	OR	Private	Close electrical boxes, Extension cord use, Safety committee, Electrical service labelling
	NV	Public	Exits, Fueling vehicle issues, Fire extinguisher issues, Electrical service labelling, MSDS sheets
	CA	Private	Air tank permit, Safety program, Truck and tractor operations, Hazardous substance warning, Guard energized parts, Mark electrical service, Extension cords, Railings, Moving machinery and parts issues, Hand protection, Personal flotation devices, Heat illness prevention, First aid training, Grinding work rests, Belt and pulley drive guards, Storage of gas cylinders, Hazardous material labels, MSDS sheets, Hazardous chemical training, Fire extinguisher issues, Eyewash station
	ME	Private	Propane storage, Eyewash station, Machine guards, Annual crane testing, Workplace hazard assessment, Respirator issues, Lockout electrical training, Truck issues, Space for electrical components, Safe practices manual
2011	ID	Public	Safe workplace, Truck driver refresher training, Illness and injury documentation, OSHA log and annual survey
	WA	Public	Personal protective equipment (PPE) for face and eyes, Eyewash station, Lack of respirators
	WA	Public	PPE for face and eyes, Crane inspections, Compressed air issues, Ladders, Lack of respirators, Extension cords
	HI	Private	Respirator issues, Written hazard communication plan, Chemical listing and MSDS Training
	NY	Public	Eye and body wash, Formalin, Written hazard communication program, Chemical labeling and list, MSDS
	HI	Private	Truck driver training, Electrical equipment issues - electrical grounding, electrical boxes covered, extension cords
	HI	Private	Exposure to hyperbaric conditions, Safe dive practices, Dive preparation-physical fitness, Ladder below water surface, Means to assist injured diver, Dive profiles, Post-dive procedures, Decompression chamber, SCUBA diving issues
	AK	Public	Electrical equipment, MSDS, Chemical training/information, Fire extinguisher issues
2010	TN	Private	Electrical equipment free from hazards, Safety inspections – provide PPE
	WA	Private	SCUBA Diving – safe practices manual, Pre-dive procedures, During dive procedures, Post-dive procedures
	HI	Private	Woodworking machines issues, Electrical systems grounded, Truck driver training, Written chemical hazard communication program, MSDS sheets, Chemical hazard training
	ID	Public	Ladders, Slings, Guard mechanical power transmission shafts, Electrical equipment, Electrical receptacles, Electrical training, Waterproof electrical, De-energize electrical, Lockout/tagging, Use of electrical PPE, Inspect and maintain walkways, Maintain ladders/steps, Exit signs, Fan blade guards, Extension cords
	TN	Public	Horizontal shaft guards, Waterproof electrical outlets, Ignition sources by fuel locations, PPE training, Label chemicals, Annual retraining for hazardous chemicals
	CA	Private	Guard energized parts, Accident prevention program, Servicing equipment, Personal floatation devices, Heat illness prevention, Industrial truck operator training, Written hazardous communication program
	WA	Private	Marking disconnecting means, Fire extinguisher annual inspection, Protect conductors from abrasion, Retraining of powered industrial truck operators
	WA	Private	Employer chemical hazard communication issues
2009	AK	Private	Respirator maintenance procedures, Electrical grounding
	AK	Private	Provide fire extinguishers
	VT	Private	Eyewash/body wash stations, Provide respirator, Inform/train workers on chemicals
	AK	Private	Exit route with guard rails, Extension cords, Mark non-exits, Waterproof electrical boxes, Space around electrical equipment, Oxygen cylinder storage
	NY	Private	Record keeping issues
	CA	Private	Prevention program, Heat illness prevention, Provide water to prevent heat illness, Scaffold inspection/planking
	CA	Private	Heat Illness prevention, Close unused openings in boxes, raceways, auxiliary gutters and cabinets
	NY	Public	Circular saw hood, Grinder work rest, Blood borne pathogen exposure control plan and training, PPE training, label chemicals
	NJ	Public	Ladders, Electrical working space
	NJ	Public	Walkways free of hazards, Shop tool guards, Electrical equipment issues, Electrical wiring issues

(*Continued*)

Table 4. (Continued).

Year	State	Ownership	Description of Issues
	NY	Public	Exits unobstructed/signed, Mark non-exits, Grinder work rests, Electrical parts in good shape, Label chemicals, Inspect cranes, Exit signs
	HI	Private	Catwalk and walkway issues, Ladder issues, Guards on machines, Training for truck drivers
	HI	Private	Access and egress, Fire extinguisher, Provide PPE, Written workplace assessment, Lockout/tagout training, Not clean and orderly, Truck markings in place, Slings/hoisting inspections, Record keeping issues, Electrical marking, Electrical transformers
	CA	Private	Provide for safe exit of permanent pools, ponds, water tanks or reservoirs 4 feet or deeper
	NY	Public	Label electrical, Approved containers for flammable materials, Eyewash/body wash station, Electrical aquarium equipment permanently grounded, Electrical panels, Extension/flexible cords
	WA	Private	Wall openings must be guarded, Sprocket wheels/chains enclosed, Attachment plugs must be able to endure rough use, Standard railings, Fire extinguisher monthly inspections, Welding issues

Table 5. Injuries and fatalities in U.S. aquaculture reported to OSHA, 2007–2018. Ownership is denoted as either public (government-owned, typically producing fish for release into the wild) or privately owned (commercial aquaculture). Source: https://www.osha.gov/pls/imis/industry.html.

Year	State	Ownership	Description
2017	WI	Public	Diver was monitoring and collecting mussels and lost consciousness in the water due to low oxygen. Diver was resuscitated and placed in a coma at the hospital to assist with recovery.
2017	OR	Public	Hatchery employee died from pre-existing cardiovascular condition.
2017	CA	Private	Employee was killed by being hit on the head with a backhoe bucket while standing in a pond to sort fish prior to moving to another pond.
2016	ME	Private	Employee had fingers amputated while trying to access barges from a fish pen.
2015	LA	Private	Employee drowned while emptying crawfish traps. Employee was intoxicated with a mixture of drugs.
2011	HI	Private	Employee failed to surface after separating from his diving partner and was found unconscious on the ocean floor (approximately 34 m below the surface). Cardio-pulmonary resuscitation and treatment with an automatic external defibrillator in a hyperbaric chamber were unsuccessful.
2007	CA	Public	Employee had a thumb tip amputated. While driving a backhoe downhill, the employee hit a bump in the road and the cab window inadvertently closed.

allowed to sue an employer for work-related injuries. Many states exempt workers in agriculture and aquaculture from required participation in the state workers' compensation program.[84] In addition, several states exempt short-term or seasonal workers, commercial fisherman, harvesters, and agricultural businesses with only a small number of employees.

For coastal aquaculture operations, there is a lack of clarity and potential overlap regarding insurance coverage mandated by different laws. The Longshore and Harbor Workers' Compensation Act is a federal workers' compensation program administered by the U.S. DOL that covers maritime workers while on navigable waters and in coastal areas (e.g., docks, piers). The U.S. DOL states that the Longshore Act does not cover aquaculture workers that are covered by state workers' compensation programs, but there is some uncertainty around dual liability for operators.[85,86] The Jones Act, which is part of the Merchant Marine Act, covers injured "seamen", and relevance to aquaculture operations is not settled.

Policy landscape for U.S. aquaculture OSH

Several reports and journal articles have been published that assess the policy landscape relevant to expansion and competitiveness of U.S. aquaculture,[87–92] with an emphasis on building support among policymakers and the public for establishing a permitting process for aquaculture operations in federal waters. Many of these resources include a list of recommendations, including policy changes and increased coordination between agencies, but worker safety is not included or is mentioned only briefly.

Aquaculture operations located inland or near the coast in state waters may be subject to the same oversight as agricultural operations

in the state. However, oversight of agricultural operations is subject to exemptions and varies by the size of operation and state. We were unable to find resources describing state-based oversight of aquaculture worker safety, and have heard informally from stakeholders that state OSH agencies are not focusing on the aquaculture sector.

Non-regulatory resources for aquaculture OSH

The National Institute of Occupational Safety and Health (NIOSH) funds and conducts OSH research in the U.S. The NIOSH mission is to conduct OSH research and promote workplace safety through information transfer and interventions both within the U.S. and internationally through global collaborations. NIOSH recently founded the Center for Maritime Safety and Health Studies, with aquaculture workplace safety and health listed as one of seven research priorities.

One of the primary mechanisms for bringing worker safety and health information to agriculture operators and workers, including aquaculture, in the U.S. has been the Cooperative Research and Extension Services (CRES).[93] CRES is a partnership between the USDA and over 100 state land-grant universities that focuses on agriculture-related research and transfer of information to agriculture producers and consumers. Information on aquaculture safety is shared with local extension agents, who in turn directly advise fish farmers[94] and publish educational materials.

Discussion

The diversity of aquaculture settings and methods in the U.S. results in a wide variety of occupational hazards. This diversity presents a challenge to occupational health practitioners and researchers working to generate interventions and best practices recommendations. While the national estimates of injury and illness rates in U.S. aquaculture are informative, they are likely underestimates for several reasons. Many agricultural operations are excluded from OSHA reporting and BLS data. Additionally, underreporting is pervasive and severe, and has been found to be as high as 50% in OSHA-inspection-eligible workplaces.[95] Finally, the latency of work-related illnesses and non-acute injuries can obscure causal attribution.[96] For these reasons, injury and illness estimates are assumed to undercount actual cases. Heterogeneity in the aquaculture sector and widespread underreporting of occupational injuries and illnesses underscores the importance of increased surveillance and primary research focused on U.S. aquaculture OSH.

Data collection specific to the variability in the U.S. aquaculture workforce and production operations are necessary to identify specific characteristics associated with higher rates of injury and other indicators of worker vulnerability. For example, worker safety has been found to be negatively associated with part-time status and small farm size,[97] and workers under the age of 18 have high rates of occupational injury and death.[98,99] Lower wages and limited access to health services can also contribute to OSH issues.[100–102] Lastly, around the world and in the U.S., migrant workers or workers facing challenges related to documentation status and/or citizenship, experience higher rates of injury, illness, and death on the job. Reasons for this disparity include a higher proportion of these individuals working in hazardous jobs relative to the entire worker population, a lack of training and/or protective equipment, and power imbalances and language barriers that can result in not speaking out about unsafe conditions.[103]

This paper provides a detailed description of current knowledge regarding U.S. aquaculture OSH, including national surveillance data, peer-reviewed studies, industry reports, and policy resources. It includes both private (commercial) and public (governmental) hatcheries, the latter of which are often excluded from aquaculture literature reviews. This review is limited by a lack of U.S.-based marine aquaculture OSH research findings, reliance on case studies, a lack of recent epidemiologic evidence, and underreporting and other limitations associated with national statistics. Due to the important role of marine aquaculture in the U.S., and a lack of peer-reviewed OSH literature on this sector specific to the U.S., recent articles from other countries have been included to illustrate likely OSH hazards. Although it is possible that the search methods used in this study missed sources relevant to U.S. aquaculture OSH, it is

unlikely given the multiple search terms and databases examined.

Conclusion

Ample opportunities exist to generate robust research and resources which could improve health and safety among aquaculture workers in the U.S. Although workplace safety and health are not highly regulated in U.S. agriculture or the commercial fishing industry, evidence-based efforts using research, surveillance, stakeholder engagement, interventions, and development and dissemination of best practices in both of these sectors have successfully improved worker safety and health standards.[54,104] As the U.S. aquaculture industry expands and the number of aquaculture workers increases, partnerships between stakeholders working to expand the U.S. aquaculture sector and OSH professionals are imperative to ensure the development of a safe and sustainable aquaculture industry.

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References

1. National Institute for Occupational Safety and Health. CDC - agricultural safety - NIOSH workplace safety and health topic. https://www.cdc.gov/niosh/topics/aginjury/default.html. Published 2018. Accessed March 14, 2019.
2. Food and Agriculture Organization. The state of world fisheries and aquaculture. http://www.fao.org/documents/card/en/c/I9540EN/. Published 2018. Accessed November 9, 2018.
3. US Fish and Wildlife Service. Fish production at national fish hatcheries | U.S. fish & wildlife service. https://www.fws.gov/southeast/our-services/fish-production/. Published 2018. Accessed March 14, 2019.
4. NOAA. About aquaculture | fishwatch. https://www.fishwatch.gov/aquaculture. Published 2018. Accessed March 14, 2019.
5. Food and Agriculture Organization. SOFIA 2018 - State of fisheries and aquaculture in the world 2018; 2018. http://www.fao.org/state-of-fisheries-aquaculture/en/. Accessed December 9, 2018.
6. National Science and Technology Council Committee on Science IWG on A. National strategic plan for federal aquaculture research (2014-2019). Washington, DC; 2014. https://www.ars.usda.gov/IWGA/Documents/National Strategic Plan for Federal Aquaculture Research 2014 to 2019.pdf. Accessed July 12, 2018.
7. National Oceanic Atmospheric Administration. *Marine Aquaculture Strategic Plan FY 2016-2020*; 2016. doi:10.1017/CBO9781107415324.004
8. Love DC, Gorski I, Fry JP. An analysis of nearly one billion dollars of aquaculture grants made by the US federal government from 1990 to 2015. *J World Aquac Soc*. 2017;48(5):689–710. doi:10.1111/jwas.12425.
9. United States Department of Agriculture. USDA - NASS, census of agriculture - census of aquaculture; 2013. https://www.agcensus.usda.gov/Publications/Census_of_Aquaculture/. Accessed July 12, 2018.
10. Bureau of Labor Statistics. Table, NAICS 1125 aquaculture, all counties 2017 annual averages, all establishment sizes. Quarterly census of employment and wages. https://data.bls.gov/cew/apps/table_maker/v4/table_maker.htm#type=1&year=2017&qtr=A&own=5&ind=1125&supp=0. Published 2017. Accessed July 12, 2018.
11. USDA National Agricultural Statistics service. Census of aquaculture (2005). http://usda.mannlib.cornell.edu/usda/AgCensusImages/2002/02/07/Full Report-revised 2. 7.07.pdf. Published 2006. Accessed July 12, 2018.
12. USDA National Agricultural Statistics Service. Census of Aquaculture (2013). https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Aquaculture/Aqua.pdf. Published 2014. Accessed July 12, 2018.
13. Alaska SG. *Alaska sea grant: aquaculture*. University of Alaska Fairbanks. https://alaskaseagrant.org/our-work/aquaculture/. Published 2018. Accessed July 31, 2018.
14. NOAA UD of C. Aquaculture | NOAA Fisheries. https://www.fisheries.noaa.gov/topic/aquaculture. Published 2018. Accessed July 31, 2018.
15. U.S. Bureau of labor statistics. Farmworkers, farm, ranch, and aquacultural animals. https://www.bls.gov/

oes/current/oes452093.htm. Published 2018. Accessed March 12, 2019.
16. Hernandez T, Gabbard S Findings from the national agricultural workers survey (NAWS) 2015-2016: a demographic and employment profile of United States farmworkers. https://www.doleta.gov/naws/pages/research/docs/NAWS_Research_Report_13.pdf. Published 2018. Accessed March 12, 2019.
17. U.S. Bureau of labor statistics. Employed persons by detailed industry and age; 2018. https://www.bls.gov/cps/cpsaat18b.htm. Accessed March 14, 2019
18. U.S. Bureau of Labor Statistics. Occupational injuries and illnesses and fatal injuries profiles. https://data.bls.gov/gqt/InitialPage. Published 2016. Accessed July 12, 2018.
19. U.S. Bureau of Labor Statistics. Table SNR01. Highest incidence rates of total nonfatal occupational injury and illness cases, 2015; 2015. https://www.bls.gov/iif/oshwc/osh/os/ostb4736.pdf. Accessed July 12, 2018.
20. U.S. Bureau of Labor Statistics. News release, employer-reported workplace injuries and illnesses. Washington, DC; 2015. https://www.bls.gov/news.release/archives/osh_10272016.pdf. Accessed July 12, 2018
21. Bureau of Labor Statistics. 2017 SURVEY OF OCCUPATIONAL INJURIES AND ILLNESSES CHART DATA. Survey of injuries, illnesses, and fatalities. https://www.bls.gov/iif/soii-chart-data-2017.htm. Published 2018. Accessed April 5, 2019.
22. U.S. Bureau of Labor Statistics. Census of Fatal occupational injuries (CFOI) - current and revised data. https://www.bls.gov/iif/oshcfoi1.htm#2015. Published 2015. Accessed July 12, 2018.
23. Myers ML. Review of occupational hazards associated with aquaculture. *J Agromedicine*. 2010;15(4):412–426. doi:10.1080/1059924X.2010.512854.
24. Lee S, Radtke T. Applied occupational and environmental hygiene exposure to formaldehyde among fish hatchery workers case studies. *Appl Occup Environ Hyg*. 1998. doi:10.1080/1047322X.1998.10389536.
25. Wooster G, Martinez C, Bowser P, O'Hara D. Human health risks associated with formalin treatments used in aquaculture: initial study. *N Am J Aquac*. 2005;67(2):111–113. doi:10.1577/A04-026.1.
26. Voorhees JM, Barnes ME. Airborne formaldehyde levels during simulated formalin egg treatments in vertical-flow tray incubators at a production fish hatchery. *J Agric Saf Health*. 2016;22(3):199–207. doi:10.13031/jash.22.11791.
27. Bernstein PS, Digre KB, Creel DJ. Retinal toxicity associated with occupational exposure to the fish anesthetic MS-222. *Am J Ophthalmol*. 1997;124(6):843–844. http://www.ncbi.nlm.nih.gov/pubmed/9402834 Accessed August 3, 2018. doi:10.1016/S0002-9394(14)71705-2.
28. Page EH. A cluster of acoustic neuromas in fish hatchery workers. *Ear Nose Throat J*. 2000. https://search.proquest.com/docview/209400087/fulltextPDF/496A7C5007594E84PQ/1?accountid=11752. Accessed March 14, 2019.
29. Summerfelt ST, Sharrer MJ, Tsukuda SM, Gearheart M. Process requirements for achieving full-flow disinfection of recirculating water using ozonation and UV irradiation. *Aquac Eng*. 2009;40(1):17–27. doi:10.1016/J.AQUAENG.2008.10.002.
30. Maryland Aquaculture Coordinating Council. Best management practices: a manual for Maryland aquaculture. http://extension.umd.edu/sites/extension.umd.edu/files/_docs/programs/aquaculture/9_Managing_Maryland_Aquaculture.pdf. Published 2007. Accessed March 14, 2019.
31. Glanz K, Buller DB, Saraiya M. Reducing ultraviolet radiation exposure among outdoor workers: state of the evidence and recommendations. *Environ Heal*. 2007;6(1):22. doi:10.1186/1476-069X-6-22.
32. National Institute for Occupational Safety and Health. CDC - NIOSH 1988 OSHA PEL project documentation: list by chemical name: OZONE. OSHA PEL project. https://www.cdc.gov/niosh/pel88/10028-15.html. Published 1989. Accessed March 14, 2019.
33. Ogunsanya TJ, Durborow RM, Myers ML, Cole HP, Thompson SL. Safety on North Carolina and Kentucky Trout Farms. *J Agric Saf Health*. 2011;17(1):33–61. doi:10.13031/2013.36232.
34. Airgas. MSDS: oxygen, Refrigerated Liquid. https://www.airgas.com/msds/001190.pdf. Published 2018. Accessed March 14, 2019.
35. Florida U of. Liquid Oxygen. Environmental Health and Safety. http://www.ehs.ufl.edu/programs/lab/cryogens/oxygen/. Published 2016. Accessed March 14, 2019.
36. Turner K, Rabinowitz P, Anderson N, Cohen M, Pappaioanou M. Occupational injuries of aquaculture workers: Washington State. *J Agromedicine*. 2018;23(4):336–346. doi:10.1080/1059924X.2018.1501452.
37. Voorhees J, Barnes ME. Occupational noise levels in two fish rearing buildings at an aquaculture facility. *Occup Dis Environ Med*. 2017;5:58–66. doi:10.4236/odem.2017.52006.
38. Barnes ME, Hewitt CR, Parker TM. Fish hatchery noise levels and noise reduction techniques. *J Agric Saf Health*. 2015;21(3):187–195. doi:10.13031/jash.21.11072.
39. Passchier-Vermeer W, WF P. Noise exposure and public health. *Environ Health Perspect*. 2000;108(Suppl 1)):123–131. http://www.ncbi.nlm.nih.gov/pubmed/10698728. Accessed August 17, 2018.
40. Ising H, Kruppa B. Health effects caused by noise: evidence in the literature from the past 25 years. *Noise Health*; 6(22):5–13. http://www.ncbi.nlm.nih.gov/pubmed/15070524. Accessed August 6, 2018.
41. Nelson DI, Nelson RY, Concha-Barrientos M et al. The global burden of occupational noise-induced hearing loss the global burden of occupational noise-induced hearing loss.; 2005. http://www.who.int/quantifying_ehimpacts/global/6noise.pdf. Accessed August 13, 2018.
42. Selander J, Nilsson ME, Bluhm G, et al. Long-term exposure to road traffic noise and myocardial infarction. *Epidemiology*. 2009;20(2):272–279.doi:10.1097/EDE.0b013e31819463bd.

43. Stansfeld SA, Matheson MP. Noise pollution: non-auditory effects on health. *Br Med Bull*. 2003;68 (1):243–257. doi:10.1093/bmb/ldg033.
44. Durborow R. Health and safety concerns in fisheries and aquaculture. *Occup Med (Chic Ill)*. 1999. 142373–406https://www.researchgate.net/publication/12968619_Health_and_safety_concerns_in_fisheries_and_aquacultureAccessed March 14, 2019.
45. National Institute for Occupational Safety and Health. Municipal sewer maintenance worker drowns inside sewer wet well in illinois. fatality assessment and control evaluation program reports. https://www.cdc.gov/niosh/face/in-house/full9014.html. Published 2015. Accessed March 14, 2019.
46. Nikkanen HE, Burns MM. Severe hydrogen sulfide exposure in a working adolescent. *Pediatrics*. 2004;113:4. doi:10.1542/peds.113.4.927.
47. U.S. Fish and Wildlife Service. Handbook of aquatic animal health procedures and protocols, fish and wildlife service manual, U.S. fish and wildlife service. https://www.fws.gov/policy/AquaticHB.html. Accessed March 14, 2019.
48. Myers ML, Cole HP, Ibendahl GA, Stephens WB, Westneat SC. Exposure assessment of tractor-related tasks presenting potential overturn hazards on catfish farms in Mississippi, USA. *Hum Ecol Risk Assess An Int J*. 2013;19(4):959–971. doi:10.1080/10807039.2012.702537.
49. Myers ML, Cole HP. Simple solutions for reduced fish farm hazards. *J Agromedicine*. 2009;14(2):150–156. doi:10.1080/10599240902721024.
50. Myers ML, Durborow RM. *Aquacultural Safety and Health, Health and Environment in Aquaculture*. 1stCarvalho E ed. Rijeka Croatia: Intech Open; 2012. www.intechopen.com
51. Durborow RM, Myers ML, Cole HP, Semmens K, Thompson S Aquaculture safety for raceways. http://www.uky.edu/publichealth/sites/www.uky.edu.publichealth/files/Research/SCAHIP/Products/AquaSafetyforRaceways.pdf. Accessed July 6, 2018.
52. Stephens WB, Ibendahl GA, Myers ML, Cole HP. Risk analysis of tractor overturns on catfish farms. *J Agromedicine*. 2010;15(4):405–411. doi:10.1080/1059924X.2010.510438.
53. Douglas JDM. Salmon farming: occupational health in a new rural industry. *Occup Med (Chic Ill)*. 1995;45 (2):89–92. doi:10.1093/occmed/45.2.89.
54. Myers ML, Westneat SC, Myers JR, Cole HP. Prevalence of ROPS-equipped tractors inAquaculture US. *J Agric Saf Health*. 2009;15(2):185–194. doi:10.13031/2013.26804
55. MacCollum DV. *Crane Hazards and Their Prevention*. American Society of Safety Engineers; 1993. https://books.google.com/books/about/Crane_Hazards_and_Their_Prevention.html?id=aIYKAQAAMAAJ. Accessed March 14, 2019..
56. University of Kentucky. *Safety for fish farm workers*. www.aces.edu/farmsafety. Accessed March 14, 2019.
57. U.S. FWS. Mora national fish hatchery, sump walkways. https://www.fws.gov/Southwest/fisheries/mora/documents/August_2016_MR.pdf. Published 2016. Accessed March 14, 2019.
58. Nonnenmann MW, Hussain A, Shirley M, Shepherd S, Gilmore K, Levin JL. Risk factors for musculoskeletal symptoms among crawfish farmers in louisiana—a pilot study. *J Agromedicine*. 2010;15(4):386–393. doi:10.1080/1059924X.2010.510440.
59. Boyd CE, Massaut L. Risks associated with the use of chemicals in pond aquaculture. *Aquac Eng*. 1999;20 (2):113–132. doi:10.1016/S0144-8609(99)00010-2.
60. Plant KP, LaPatra SE. Advances in fish vaccine delivery. *Dev Comp Immunol*. 2011;35(12):1256–1262. doi:10.1016/J.DCI.2011.03.007.
61. Lowry T, Smith SA. Aquatic zoonoses associated with food, bait, ornamental, and tropical fish. *J Am Vet Med Assoc*. 2007;231(6):876–880. doi:10.2460/javma.231.6.876.
62. Cole DW, Cole R, Gaydos SJ, et al. Aquaculture: environmental, toxicological, and health issues. *Int J Hyg Environ Health*. 2009. doi:10.1016/j.ijheh.2008.08.003.
63. Swinker M, Tester P, Koltai Attix D, Schmechel D. Human health effects of exposure to Pfiesteria piscicida: a review. *Microbes Infect*. 2002;4(7):751–762. http://www.ncbi.nlm.nih.gov/pubmed/12067835 Accessed August 17, 2018. doi:10.1016/S1286-4579(02)01594-0.
64. Garrett ES, CL DS, Jahncke ML. Public, animal, and environmental health implications of aquaculture. *Emerg Infect Dis*. 1997;3(4):453–457. doi:10.3201/eid0304.970406.
65. Myers ML, Durborow RM, Cole HP. Inherently safer aquacultural work: hierarchical hazard controls. *Saf Manag*. 2012;57(7). (July).
66. Ewan PW. Venom allergy. *BMJ*. 1998;316(7141):1365–1368. http://www.ncbi.nlm.nih.gov/pubmed/9563993 Accessed March 14, 2019. doi:10.1136/bmj.316.7141.1365.
67. Rhode Island Department of Environmental Management. Infectious diseases of raccoons. http://www.dem.ri.gov/programs/bnatres/agricult/pdf/raccoons.pdf. Accessed March 14, 2019.
68. Holen SM, Utne IB, Holmen IM, Aasjord H. Occupational safety in aquaculture – part 1: injuries in Norway. *Mar Policy*. September 2017. doi:10.1016/J.MARPOL.2017.08.009.
69. Holen SM, Utne IB, Holmen IM, Aasjord H. Occupational safety in aquaculture – part 2: fatalities in Norway 1982–2015. *Mar Policy*. 2017. doi:10.1016/j.marpol.2017.08.005.
70. Holen S, Utne I. A framework based on a systems approach to developing safety indicators in fish farming. *Safety*. 2018;4(2):19. doi:10.3390/safety4020019.
71. Speck GM, Mannrich G, Guertler C. et al. Occupational health and safety management in oyster culture. *Aquac Eng*. 2015;70:63–72. doi:10.1016/j.aquaeng.2015.11.002.
72. Mitchell RJ, Lystad RP. Occupational injury and disease in the Australian aquaculture industry. *Mar Policy*. 2019;99:216–222. doi:10.1016/J.MARPOL.2018.10.044.
73. Douglas JD, Milne AH. Decompression sickness in fish farm workers: a new occupational hazard. *BMJ*.

1991;302(6787):1244–1245. http://www.ncbi.nlm.nih.gov/pubmed/2043848 Accessed August 6, 2018. doi:10.1136/bmj.302.6787.1244-a.
74. Occupational Safety and Health Administration. Partial exemption for employers with 10 or fewer employees. - 1904.1 | occupational Safety and Health Administration. Department of Labor. https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9632. Accessed August 3, 2018.
75. Galassi T. DEP small farms | occupational safety and health administration. memorandum, occupational safety and health administration. https://www.osha.gov/dep/enforcement/policy_clarification_small_farms.html. Published 2014. Accessed August 3, 2018.
76. US Department of Labor. Child labor bulletin 102 child labor requirements in agricultural occupations under the fair labor standards act. www.dol.gov/whd. Accessed March 14, 2019.
77. Occupational Health and Safety Administration. OSHA Small Business Assistance | on-Site Consultation | occupational Safety and Health Administration. https://www.osha.gov/dcsp/smallbusiness/consult.html. Accessed June 5, 2019.
78. Fry JP, Love DC, Shukla A, Lee RM. Offshore finfish aquaculture in the United States: an examination of federal laws that could be used to address environmental and occupational public health risks. *Int J Environ Res Public Health*. 2014;11:11. doi:10.3390/ijerph111111964.
79. US EPA. Pesticide regulation. http://npic.orst.edu/reg/epareg.html. Published 2019. Accessed March 14, 2019.
80. U.S. Coast Guard. Regulations, Policy and Guidance. https://www.dco.uscg.mil/OCSNCOE/Regulations-Policy-Guidance/. Accessed March 15, 2019.
81. National Federation of Independent Business. Workers' compensation law – state by state comparison; 2017. https://www.nfib.com/content/legal-compliance/legal/workers-compensation-laws-state-by-state-comparison-57181/. Accessed March 14, 2019.
82. State workers compensation sites: state and local government on the net. http://www.statelocalgov.net/50states-workers-compensation.cfm. Accessed March 14, 2019.
83. JUSTIA. Workers' Compensation Overview :: justia. https://www.justia.com/injury/workplace-accidents/workers-compensation/. Published 2019. Accessed March 14, 2019.
84. National Federation of Independent Businesses. Workers' compensation law – state by state comparison. https://www.nfib.com/content/legal-compliance/legal/workers-compensation-laws-state-by-state-comparison-57181/. Accessed March 14, 2019.
85. US Department of Labor. Division of longshore and harbor workers' compensation. https://www.dol.gov/owcp/dlhwc/FAQ/lsfaqs.htm. Published 2019. Accessed March 14, 2019.
86. Martone J What is the difference between state act and longshore. American equity underwriters. https://www.amequity.com/longshore-insider/article/state-act-versus-longshore. Published 2009. Accessed March 14, 2019.
87. Devoe MR Marine aquaculture regulation in the United States: environmental policy and management issues. http://nsgd.gso.uri.edu/tamu/tamuw95003/tamuw95003_part1a.pdf. Accessed August 6, 2018.
88. O'Connell T New Report Evaluating U.S. Shellfish Aquaculture Permitting Systems Now Available. https://www.fisheries.noaa.gov/news/new-report-evaluating-us-shellfish-aquaculture-permitting-systems-now-available. Published 2018. Accessed March 14, 2019.
89. Lester SE, Gentry RR, C V K, White C, Gaines SD. Opinion: offshore aquaculture in the United States: untapped potential in need of smart policy. *Proc Natl Acad Sci U S A*. 2018;115(28):7162–7165. doi:10.1073/pnas.1808737115.
90. Engle CR, Stone NM. Competitiveness of U.S. Aquaculture within the Current U.S. Regulatory Framework. *Aquacult Econ Manage*. 2013(90). doi:10.1080/13657305.2013.812158.
91. Cicin-Sain B, Knecht RW, Rheault R, et al. Development of a policy framework for offshore marine aquaculture in the 3-200 mile U.S. ocean zone. http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=EFD9A2AC1F1A3282973ED5581569E1D7?doi=10.1.1.121.5037&rep=rep1&type=pdf. Published 2004. Accessed February 28, 2019.
92. Knapp G, Rubino M The political economics of United States marine aquaculture. http://www.iser.uaa.alaska.edu/Publications/2010_10-PoliticalEconomicsUSMarineAquaculture.pdf. Published 2011. Accessed August 6, 2018.
93. National Institute for Food and Agriculture. Cooperative extension history | national institute of food and agriculture. https://nifa.usda.gov/cooperative-extension-history. Accessed August 3, 2018.
94. Durborow RM. Safety in Aquaculture. *J Extension*. https://www.joe.org/joe/2016june/tt7.php. Published 2016;54(3). Accessed March 14, 2019.
95. US Office of the Inspector General. *Report to the occupational safety and health administration: OSHA needs to improve the guidance for its fatality and severe injury reporting program to better protect workers*; 2018. https://www.oig.dol.gov/public/reports/oa/2018/02-. Accessed March 14, 2019.
96. U.S. Occupational Safety and Health Administration. Occupational injury and illness recording and reporting requirements | occupational safety and health administration. https://www.osha.gov/laws-regs/federalregister/2001-01-19. Accessed March 15, 2019.
97. Alli BO. *Fundamental Principles of Occupational Health and Safety*. *Second*; 2008. http://www.ilo.org/global/publications/books/WCMS_093550/lang–en/

index.htm. Accessed August 3, 2018. Geneva, Switzerland: International Labour Office.
98. Castillo DN, Landen DD, Layne LA. Occupational injury deaths of 16- and 17-year-olds in the United States. *Am J Public Health*. 1994;84(4):646–649. http://www.ncbi.nlm.nih.gov/pubmed/7755674 Accessed August 3, 2018. doi:10.2105/AJPH.84.4.646.
99. Wilk VA. Health hazards to children in agriculture. *Am J Ind Med*. 1993;24(3):283–290. http://www.ncbi.nlm.nih.gov/pubmed/8238028. Accessed March 14, 2019
100. Champoux D, Brun J-P. Occupational health and safety management in small size enterprises: an overview of the situation and avenues for intervention and research. *Saf Sci*. 2003;41(4):301–318. doi:10.1016/S0925-7535(02)00043-7.
101. Cooper CL, Marshall J. Occupational sources of stress: a review of the literature relating to coronary heart disease and mental ill health. *J Occup Psychol*. 1976;49(1):11–28. doi:10.1111/j.2044-8325.1976.tb00325.x.
102. Schulte PA, Wagner GR, Ostry A, et al. Work, obesity, and occupational safety and health. *Am J Public Health*. 2007;97(3):428–436.doi:10.2105/AJPH.2006.086900.
103. Moyce SC, Schenker M. Migrant workers and their occupational health and safety. *Annu Rev Public Health*. 2018;39(1):351–365. doi:10.1146/annurev-publhealth-040617-013714.
104. Lincoln JM, Conway GA. Preventing commercial fishing deaths in Alaska. *Occup Environ Med*. 1999;56:691–695. doi:10.1136/oem.56.10.691.