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Updated assessment of occupational safety and health hazards of climate change

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Abstract

Workers, particularly outdoor workers, are among the populations most disproportionately affected by climate-related hazards. However, scientific research and control actions to comprehensively address these hazards are notably absent. To assess this absence, a seven-category framework was developed in 2009 to characterize the scientific literature published from 1988–2008. Using this framework, a second assessment examined the literature published through 2014, and the current one examines literature from 2014–2021. The objectives were to present literature that updates the framework and related topics and increases awareness of the role of climate change in occupational safety and health. In general, there is substantial literature on worker hazards related to ambient temperatures, biological hazards, and extreme weather but less on air pollution, ultraviolet radiation, industrial transitions, and the built environment. There is growing literature

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Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

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on mental health and health equity issues related to climate change, but much more research is needed. The socioeconomic impacts of climate change also require more research. This study illustrates that workers are experiencing increased morbidity and mortality related to climate change. In all areas of climate-related worker risk, including geoengineering, research is needed on the causality and prevalence of hazards, along with surveillance to identify, and interventions for hazard prevention and control.

Keywords

Health equity; heat; mortality; productivity; work

Introduction

Climate and weather patterns are changing (Dahl et al. 2019b; Moda et al. 2019; IPCC 2021). As a result, the burden of climate change on workers is increasing (Kim and Lee 2020). However, the attention on this burden in the occupational safety and health (OSH) field, the media, and state and business action plans is limited (Constible et al. 2020; Toivanen and Uusitalo 2022). Identifying how all worker populations may be at increasing yet variable risk of adverse effects is essential to implementing preventive measures.

Workers are one of the first societal groups exposed to climate-related hazards. Their exposure may be longer and greater than for the rest of the population because often work environments are difficult to modify, work must continue, and tasks must be completed despite changes in climate and weather. Consequently, morbidity, mortality, and injury rates related to climate change hazards appear to be increasing, as is the economic burden (Gubernot et al. 2015; Dong et al. 2019; Kjellstrom et al. 2019; Pradhan et al. 2019; Dillender 2021).

Historically, no systematic, comprehensive means of identifying OSH hazards from climate change existed. To address this deficit, Schulte and Chun (2009) reviewed the scientific literature published from 1988–2008 to develop a framework that identified these seven categories of climate hazards: (1) increased ambient temperature; (2) air pollution; (3) ultraviolet exposure; (4) extreme weather; (5) vector-borne diseases and expanded habitats; (6) industrial transitions and emerging industries; and (7) changes in the built environment (Figure 1). Workers will likely be exposed to more than one of these hazards, at the same time or at various times, and cumulative effects will probably occur (US EPA 2003). In 2016, the literature on the framework was updated for 2008–2014 (Schulte et al. 2016), and additional topics related to OSH were considered, including mental health effects, economic burden, and geoengineering. These additional topics are related to the framework and crosscut each of the hazard categories. Additionally, Schulte et al. (2016) addressed key priorities for actions to better characterize and understand the relationship between climate change and worker health and safety issues. These priorities included research, surveillance, risk assessment, and management. A detailed review of research priority needs was also presented (Schulte et al. 2016). The current update presents further information from 2014–2021.

Methods

Building on the previous assessments during 1988–2008 and 2009–2014, this paper updates the literature further during 2014–2021 with new studies of climate change–related adverse effects that workers experience on the job (Figure 2). The literature update involved searching databases (PubMed, Scopus, PsychInfo, Social Services Abstracts, Sociology Abstracts, ABI Inform, Agricultural & Environmental Science Collection, Safety Lit, and GreenFILE) for English-language articles. The keywords were variations of the seven category names for climate-related occupational hazards. The authors used ad hoc searches and snowball techniques to supplement searches of scientific and gray literature. They reviewed the titles and abstracts from the searches and included literature that added new information to the climate hazard categories or the knowledge base for hazard protection and control. The searches also addressed crosscutting issues that the authors considered critical: mental health implications, economic burden, equity issues, and the potential impact on workers of geoengineering. Because of the vast, wide-ranging relevant literature, this article scans the horizon rather than presenting a systematic review (Streit et al. 2021). For each of the categories in the framework, the authors characterized the literature in terms of hazards and controls. In addition, they addressed new information illustrating the importance of the critical crosscutting topics listed above.

Results: occupational health hazards and effects related to climate change—2014–2021

Increased ambient temperatures

Hazard update—One of the most commonly identified and discussed effects of climate change is increasing ambient temperatures and the resulting additional heat burden placed on populations. Heat stress has long been a major concern for many worker populations, both outdoors and indoors (Kjellstrom et al. 2009; Schulte and Chun 2009; Arbury et al. 2014; Applebaum et al. 2016; Constible et al. 2020; Park et al. 2021). In the United States, outdoor workers are expected to experience a three- to four-fold increase in the number of days with a heat index of above 100 °F (38 °C) by the mid-2000s (Dahl et al. 2019a; Dahl et al. 2019b). The heat index is an indicator of heat discomfort and is also known as apparent temperature, which considers temperature and humidity interactions and the associated perceived equivalent (apparent) temperature. It feels hotter than its reported temperature on a thermometer when ambient humidity is high because increasing levels of humidity decrease the water vapor partial pressure gradient between the skin and air, restricting the evaporative process of sweat. Higher humidities and ambient temperatures that exceed the temperature of the skin (approximately 95 °F (35 °C)) result in a net heat gain because sweat does not readily evaporate, interfering with the body's ability for cooling via evaporation of sweat (Larrañaga and Wang 2012).

Outdoor workers such as those in construction, agriculture, and landscaping are at the highest risk of adverse effects from increased ambient temperatures. Many of those work activities are labor intensive, which can cause the body to generate excessive heat (NIOSH 2016). A substantial proportion of heat-related fatalities occur during the first day on the

job, which emphasizes the importance of acclimatization (Arbury et al. 2014). From 1992–2016, 285 construction workers died from heat-related causes, accounting for more than one-third of all U.S. occupational deaths related to heat exposure (Dong et al. 2019). A study of construction workers in Washington State found a 0.5% increase in the chances of experiencing traumatic injuries per 1 °C increase in maximum daily humidex (a mean of how hot it feels that combines temperature and humidity) (Calkins et al. 2019). A review of existing epidemiological research on heat stress and construction workers in the United States and internationally found that heat-related health effects among construction workers were a significant but understudied topic (Acharya et al. 2018).

Populations disproportionately affected by heat stress include foreign-born workers, particularly because many work outdoors and in industries such as agriculture, construction, and services. In a review of Nepali migrant construction workers in Qatar, investigators estimated that 200 of the 571 deaths during 2009–2017 could have been prevented if effective heat-protective measures had been implemented as part of local OSH programs (Pradhan et al. 2019). It can be difficult to determine whether a worker's death is heat-related (for example, causes of death are often poorly described, e.g., “cardiac arrest”) and whether the implementation of useful controls has been inadequate (Pradhan et al. 2019).

Agricultural workers are another group at high risk of experiencing adverse health effects caused by extreme heat. As the average ambient temperature increases, farmworkers have been shown to experience an increase in heat-related events leading to morbidity and mortality (Gubernot et al. 2015; Hesketh et al. 2020). Likewise, agriculture workers may be at increased risk for traumatic injury when working in elevated and extreme temperatures (Spector et al. 2016). However, more research is needed to understand the relationship between traumatic injury risks and higher temperatures.

Roughly 20% of heat-related deaths reported to the Occupational Safety and Health Administration (OSHA) are in the Agriculture, Fishing, and Forestry sector (Gubernot et al. 2015; Morris et al. 2019). A study of workers' compensation claims in Washington State during 2006–2017 found that Hispanic workers, as well as agriculture and public administration workers, were disproportionately represented in heat-related illness (HRI) cases. Furthermore, many of these cases occurred below the state's 89 °F (31.7 °C) heat rule (Hesketh et al. 2020). Langer et al. (2021) concluded that even when farm workers reported compliance with California OSHA (Cal/OSHA) regulations, worker training and hydration replacement were not sufficient to prevent HRI, especially during work at a fast rate.

Extreme heat exposure is linked to chronic kidney disease (CKD). The literature shows an increase in the prevalence of kidney disease among agricultural and construction workers, especially in hot regions (Pradhan et al. 2019; Shih 2023). Sugarcane work is known to be associated with this disease (Pundee et al. 2021). However, although the cause(s) of the disease are unknown, at least one group has suggested heat stress nephropathy may be a driver of CKD of unknown etiology as climate change contributes to rising temperatures (Glaser et al. 2016).

Control update—In 2016, the National Institute for Occupational Safety and Health (NIOSH) published an updated guidance document, the NIOSH Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments (NIOSH 2016). This document, along with stakeholder efforts and the recognition that heat continues to cause heat-related deaths, illnesses, and injuries in working populations, has led to a major push in the United States for a federally mandated occupational heat standard.

Currently, there is no OSHA federal heat standard requiring employers to abide by defined rules for heat safety at their workplaces. A few state OSHA programs, such as Cal/OSHA, have implemented heat standards for employers (Cal/OSHA 2005). In 2021, additional state OSHA programs, recognizing the increasingly extreme temperatures being experienced by workers, created temporary or emergency heat standards (Oregon 2021; Washington State Department of Labor and Industries 2021). In addition, OSHA announced plans to launch a rulemaking process to develop a workplace heat standard (OSHA. 2021). Setting a federal standard for occupational heat stress is an important step toward protecting workers. As previously recognized, many workers are at additional risk of HRIs, not only from environmental exposures (temperature, humidity, direct sun) but also from the exertion of work activities and from wearing necessary personal protective equipment and clothing (NIOSH 2016).

The need for acclimatization programs has been previously recognized in the literature (Arbury et al. 2014; Schulte et al. 2016; Morrissey et al. 2021). However, acclimatization provides little protection for workers during heat waves or other extreme heat events, when temperatures rise too quickly for them to physiologically adjust to working in suddenly hotter environments. For this reason, steps should be taken by employers to implement a heat alert plan that will increase the precautions taken to protect workers during heat waves (NIOSH 2016).

There are several factors associated with heat stress on the body, including clothing, physical fitness level, and activity. Other factors are environmental: relative air velocity, mean radiant temperature, air temperature, and air relative humidity (Pal et al. 2021). Modifiable factors include providing proper shade, drinking water, and other cooling mechanisms, as well as increasing awareness and prevention training. Agriculture workers have been found to benefit from taking regular breaks and having shifts adjusted to the coolest part of the day. However, shift adjustments must be balanced with controls for sleep disruption and deprivation. Piece-rate payment in agriculture has been associated with an increased risk for HRI (Spector et al. 2015). The effects of increased heat exposure are also disproportionately borne by foreign-born, migrant, seasonal, and rural workers, who are employed in sectors that work predominantly outside (Moyce and Schenker 2017).

The National Weather Service has created a Weather-Ready Nation Strategic Plan that includes a national early warning system for extreme heat, heat metrics developed with the support of public health research, and a national outline for the systematic tracking of reliable data on extreme heat and HRI (NWS 2020). Furthermore, the plan explains the importance of developing measures to enhance resilience and targeted interventions to manage extreme heat in the United States.

Air pollution

Hazard update—Although numerous studies have captured the negative health impact on the general population of ambient air pollutants, primarily ozone and PM_{2.5} (particles with a diameter of 2.5 mm or less), few have captured the long-term impact of air pollution due to climate change on worker health (Karita et al. 2001; Muhammad et al. 2014). Available studies show that the increasing impact of climate change on levels of air pollutants will disproportionately impact outdoor workers with increased exposure to PM_{2.5} (Kinney 2018), ozone (Vinikoor-Imler et al. 2014; Adam-Poupart et al. 2015; Carvalho et al. 2018; Schifano et al. 2019; Tang et al. 2021), and allergens (Lee et al. 2021). The impact of these exposures is often heightened by the physical demands related to many outdoor occupations (US EPA 2020). Exposure to nitrogen dioxide (NO₂), mainly in warm months, was associated with work-related injuries, and exposure to PM₁₀ (particles with a diameter of 10 mm or less), sulfur dioxide (SO₂), and NO₂ was associated with hyperuricemia in traffic police officers (Tang et al. 2021).

Ambient ozone exposures are expected to continue to increase in the United States, particularly affecting outdoor workers (Fann et al. 2015). The health impacts of ambient ozone are both acute and chronic (Applebaum et al. 2016). The effects of acute and ambient ozone exposure can occur in healthy adults at concentrations lower than the U.S. occupational limit of 100 parts per billion (ppb) (Applebaum et al. 2016; Kinney 2018; OSHA 2022). In 2020, the EPA completed its review of the body of available scientific evidence and exposure/risk information and decided to retain the existing ozone National Ambient Air Quality Standard (NAAQS) of 70 ppb (EPA 2020). This applies to tropospheric ozone, which is the ground layer closest to the earth, as opposed to upper-level or stratospheric ozone.

One of the most studied groups with increased adverse health risks due to climate change and air pollution is wildland firefighters. The primary exposure of concern to this cohort is PM_{2.5} (US EPA 2019), however, there are many additional pollutants of concern, including ozone, polycyclic aromatic hydrocarbons, and aldehydes (Adetona et al. 2016; Wu et al. 2020). Although there are many measures of wildland firefighter exposure and acute effects, the long-term impact of exposure is not well studied or understood (Adetona et al. 2016). A consistent trend across the limited studies shows declines in lung function when post-season and pre-season values are compared (Betchley et al. 1997; Miranda et al. 2012), but the long-term impact is uncertain. Further evaluation of significant clinical health endpoints in this population is needed.

Control update—Conventional workplace measures to prevent worker exposure to air pollution, such as engineering controls, encapsulation, and ventilation, are not applicable in the outdoor environment, and employers and workers may not have control over sources of air pollution (WHO 2018). Still, some measures can be taken to protect outdoor workers from ambient air pollution, such as reducing time spent outdoors; rotating workers; restricting work during times of severe air pollution; using a respiratory protection program, medical surveillance, and case reporting; and supporting the development of air quality standards (WHO 2018).

Various organizations and investigators have published guidance to protect wildland firefighters and workers in offices and commercial buildings (Broyles 2013; National Wildfire Coordinating Group 2013; Occupational Health and Safety 2019; CDC 2020; Washington State Department of Labor and Industries 2020; US EPA 2021c). A 2019 workshop sponsored by the American Thoracic Society recommended a unified federal response to wildland fires (Rice et al. 2021). The dynamic environment of wildland fires makes hazard prevention and control difficult. The workshop recommended multidisciplinary research, policy development, and communication to address hazards for those managing and fighting wildland fires as well as the general public. Semmens et al. (2021) identified specific wildland firefighter tasks related to direct suppression that could be targets for intervention aimed at wildland firefighters' perception of smoke exposure and minimizing smoke exposure.

Ultraviolet radiation

Changes in various constituents of the atmosphere, such as a decrease in stratospheric ozone, affect the intensity of ultraviolet (UV) radiation at the earth's surface and the exposure of workers (Bais et al. 2015). Stratospheric ozone works as a filter to absorb UV radiation before it comes into the lower atmosphere.

Hazard update—The health effects of UV radiation have been identified before the time period surveyed by this report and include cancer, eye effects, and disturbed immune function (Schulte and Chun 2009; Barnes et al. 2019; Parker 2021). The extent of outdoor workers' exposure to UV radiation varies at different places on the Earth. Despite indications from measurements in a few studies, no statistically significant decreases in UVB radiation attributable to the beginning of stratospheric ozone recovery have yet been detected (Bais et al. 2015). Nonetheless, the Montreal Protocol (an international treaty to phase out ozone-depleting gases) has “prevented global depletion of stratospheric ozone and consequently large-scale increases in solar UV-B radiation” and played an important role in preventing many adverse effects of high UV exposure (Barnes et al. 2019).

Control update—There are specific measures employers and outdoor workers can take to mitigate exposures, including the use of sunscreens and sun-protective clothing. Certain recommendations for sun-protective clothing may be at odds with choosing appropriate clothing for working in the heat, such as long sleeves, dark versus light colors, and a tighter fabric weave. However, the extent of their use depends on employers' and workers' perceptions and motivation or direction to implement them (Hault et al. 2016; Peters et al. 2020; Cherrie et al. 2021).

Extreme weather

Hazard update—The increase in global temperature has been linked to an increase in the frequency, severity, and impact of extreme weather such as heat waves, floods, landslides, drought, and wildfires (Pinkerton et al. 2019). Establishing such links is challenging because of combinations of factors, including natural variability (Knutson et al. 2017). A new type of research called “attribution science” is being developed to determine “not if climate change causes an event but if climate change made some events more severe and more likely to

occur, and if so by how much” (Cho 2021). In the United States from 1980–2021, 310 weather events caused at least \$1 billion in total damages (NOAA NCEI 2022). Workers died and were injured in these events, but comprehensive counts are not available for the scope of this update. Previously, it was reported that from 1992–2006, 317 workers died or were injured in these events (Schulte and Chun 2009). One population of workers—aptly named “storm chasers,” consisting largely of migrant workers involved in restoring buildings, towns, regions, and waterways—has experienced a range of hazards and adverse health effects (Stillman 2021). In addition, because of a lack of occupational health and safety programs, these workers suffer from concomitant deprivation of food, shelter, labor protection, and health insurance. These factors interact with workplace hazards to negatively affect worker health and safety.

Extreme weather directly affects agriculture workers, from landowners to laborers, resulting in a variety of acute and chronic adverse health outcomes such as traumatic injuries, fatigue, and mental stress. These extreme weather events include prolonged drought, flooding, hurricanes, and extreme El Niño/La Niña weather patterns, as well as severe storms, heatwaves, freezes, and wildfires. In commercial fishing, weather is an important risk factor in vessel sinkings and crewmember survival (Lucas et al. 2018). As extreme weather events increase and weather patterns change over time, research is needed on the best way to relay accurate, tailored, useful forecasts to fishing workers (Finnis et al. 2019).

Sea levels are rising, contributing to increased storm surges that will cause flooding and high humidity (Beggs 2014; Levy and Patz 2015a; D’Amato et al. 2016; Sheehan et al. 2017; D’Amato M et al. 2018; Demain 2018; Katelaris and Beggs 2018; Thien et al. 2018; Poole et al. 2019; American Academy of Allergy Asthma and Immunology 2020; D’Amato et al. 2020; Eguiluz-Gracia et al. 2020; Katelaris 2021). Rising sea levels can lead to damp buildings and mold growth. More moisture and higher temperatures are leading to fungal growth, which impacts indoor air quality (Katelaris and Beggs 2018; Poole et al. 2019; Deng et al. 2020).

Higher temperatures are integral in creating conditions for lightning. In 2021, 24 million more lightning strikes (an increase of 14%) occurred in the United States, compared with 2020 (Vaisala 2022). A drastic rise in lightning strikes was also seen in the Arctic, with 7,278 lightning strikes north of 80°N, almost double the total number for the previous 9 years (Vaisala 2022). The increasing number of workers projected to work in the Arctic will result in a larger population at risk for lightning strikes.

Control update—The protection of workers at the macro level will depend on global governments and economic policies. At the micro level of workers and employers, the amount of risk will depend on the response to risk. The primary responsibility for controlling these hazards falls on employers. One major type of response is adaptation, such as hardening physical infrastructure, relocating people and assets, and ensuring backup capacity, which may have an impact on workers who have to perform tasks in extreme weather conditions (Woetzel et al. 2020). Beyond adaptation, employers and workers need training in preventative practices. They also should be included in the development and implementation of climate mitigation plans that affect worker safety (Pinkerton et al.

2019). A McKinsey Company report on 105 countries found that “while companies and communities have been adapting to reduce climate risk, the pace and scale of adaptation are likely to need to significantly increase to manage rising levels of physical climate risk” (Woetzel et al. 2020).

Vector-borne diseases and other biological hazards

Infectious diseases, including zoonotic diseases, are affected by changing environments. Climate change can alter the habitat and geographic distribution of disease vectors and other biological hazards. Outdoor workers are at the highest risk of exposure. Table 1 provides additional details on selected at-risk worker populations for these hazards and associated diseases.

Hazard update

Vector-borne diseases.: The potential impact of climate change on vector-borne diseases continues to be a well-researched topic, although the available literature on specific workers or occupations remains limited (Beard et al. 2016; Ogden 2017; Levi et al. 2018; Caminade et al. 2019; Fouque and Reeder 2019; Adam-Poupard et al. 2021). Climate factors such as temperature extremes and precipitation patterns affect the seasonality and distribution of vector-borne diseases (Ogden and Lindsay 2016; Caminade et al. 2019; Fouque and Reeder 2019). A review of studies showed a positive correlation between higher air temperature and the expansion of vector habitats (Levi et al. 2018). Temperature affects the biting, survival, and reproductive rates of vectors, as well as the survival and development rates of the pathogens they carry (Campbell-Lendrum et al. 2015; Levi et al. 2018). Precipitation is an important factor for vectors with aquatic developmental stages, such as mosquitoes, and affects humidity, which impacts many vectors (Campbell-Lendrum et al. 2015).

Mosquitoes are one of the world’s deadliest animals (CDC 2019). In the United States in 2020, West Nile virus was the most common cause of domestic arboviral neuroinvasive disease, with 559 cases reported, for an incidence of 0.17 cases per 100,000 population (Soto et al. 2022). More than 150,000 cases of mosquito-borne diseases were reported from 2004–2016 in the United States (Rosenberg et al. 2018). During this time, West Nile Virus was the most common mosquito-borne disease in the continental United States (nearly 32,000 reported cases), while epidemics of dengue, chikungunya, and Zika viruses were reported, mainly in U.S. territories (Rosenberg et al. 2018). Increased rainfall or extreme rainfall associated with climate change is an important factor for mosquito-borne diseases (Campbell-Lendrum et al. 2015). Worksites (such as construction sites) with poor water drainage collect water from increased precipitation and provide breeding sites for mosquitoes, resulting in an increased risk of bites by infected mosquitoes (Applebaum et al. 2016; Wilke et al. 2018).

Tick-borne diseases (with the majority being Lyme disease) more than doubled in the United States and U.S. territories during 2004–2016, with more than 490,000 cases, made up more than 75% of all reported vector-borne disease cases (Rosenberg et al. 2018). In 2019, more than 34,900 confirmed and probable cases of Lyme disease were reported to CDC (CDC 2021a). Although the use of insurance databases is critical for determining the

actual number of cases treated each year, Lyme disease is under-reported due to reporting complexities. An analysis of insurance claims data during 2010–2018 estimated that Lyme disease was diagnosed and treated in about 476,000 patients annually (Kugeler et al. 2021).

Climate change has been associated with the geographic distribution, local abundance, seasonal tick activity, and expansion of ticks to higher altitudes and latitudes (Eisen et al. 2016; Semenza and Suk 2017; Ogden et al. 2021). Researchers projected that the average annual period of Lyme disease onset in endemic states will be 0.4–0.5 weeks earlier for 2025–2040 and 0.7–1.9 weeks earlier beyond 2065 (Monaghan et al. 2015), and the activity of nymphs in some areas is predicted to advance 8–11 days by the 2050s (Levi et al. 2018).

Poisonous plants.: Changes in temperature and precipitation can affect the distribution and growth rates of a variety of vegetation, including poisonous plants. Giant hogweed, a plant that was purposely imported as a unique ornamental, has become more invasive because of climate change and is spreading in parts of the United States and Europe (Klimaszyk et al. 2014; Schindler et al. 2018). Giant hogweed sap contains furanocoumarins, causing skin hypersensitivity to UV light, and resulting in rashes and blistering (Klimaszyk et al. 2014; Downs et al. 2019). Outdoor workers have reported serious injuries from blistering skin after mowing or other work after contact with giant hogweed (Klimaszyk et al. 2014; Downs et al. 2019). More outdoor workers will be at risk of exposure as this species continues to expand its range.

Allergens and molds.: With climate change-related high temperatures and precipitation, it is likely that the amounts of airborne fungal spores (aeroallergens and asthmagens) will increase (Grinn-Gofron et al. 2019). As climate change brings higher global temperatures and increased precipitation, flooding, storm damage, and indoor mold growth will likely become a more widespread problem, along with changing geographic distributions (Levy and Patz 2015a; D’Amato et al. 2016; Pugatch 2019; Buis 2020; Knutson et al. 2020; Du et al. 2021; Katelaris 2021). Both outdoor and indoor workers may experience higher fungal exposure and higher rates of fungal diseases.

Occupational exposure to mycotoxins (including aflatoxins) is a growing concern as climate change is expected to impact the ecology, adaptation, and proliferation of mycotoxins (Marroquin-Cardona et al. 2014; Viegas et al. 2016; Valencia-Quintana et al. 2020; Viegas et al. 2020). While mycotoxins are a public health concern when ingested, workers can be exposed to fungal toxins and carcinogens via respiratory, dermal, and mucosal routes (Marroquin-Cardona et al. 2014; Wangia et al. 2019).

As climate change causes drier and windier conditions in the southern and western United States, coccidioidomycosis (also known as Valley fever) continues to be a growing occupational health challenge (Wilken et al. 2015; Benedict et al. 2017; Freedman et al. 2018; de Perio et al. 2019; Pearson et al. 2019). By 2100, it is predicted that climate change will more than double the area where *Coccidioides* is present in the soil, and the number of cases will increase by 50% (Gorris et al. 2019). In California, construction employers in counties where coccidioidomycosis is highly endemic are required to provide annual

training to all employees before beginning work that may cause substantial dust disturbance (California Legislature 2019).

Other fungal allergic reactions and diseases may be caused by contact with trees or animal droppings. Maple bark disease is a hypersensitivity pneumonitis illness caused by a fungus, *Cryptostroma corticale*, found on maple trees infested with sooty bark disease (Braun et al. 2021). This fungus thrives in hot summers and on trees impacted by drought, and thus it is expected to spread in some areas placing more outdoor workers at risk of exposure. Histoplasmosis is a fungal infection often associated with working in areas with bird or bat droppings, or areas where there are spores in the soil (Benedict et al. 2017). Demolition or construction where the spores in the soil are disturbed may place workers at risk for exposure. The fungus is being found in new regions, and climate change is believed to be partially responsible (Benedict et al. 2017; Gnat et al. 2021).

There is a growing body of literature concerning increasing levels of aeroallergens, asthma, allergic rhinitis, and occupational exposures. As carbon dioxide levels and temperatures have increased, this has led to longer plant growing seasons with earlier flowering and pollen production, increased length of pollen season, higher levels of pollen production, increased allergenicity of pollen, and later frosts (Beggs 2014; Levy and Patz 2015a; Sheehan et al. 2017; Demain 2018; Poole et al. 2019; American Academy of Allergy Asthma and Immunology 2020; D'Amato et al. 2020; Deng et al. 2020; Eguiluz-Gracia et al. 2020; Choi et al. 2021; Katelaris 2021; Pawankar and Wang 2021; Schramm et al. 2021; US EPA 2021b). Outdoor workers are at increased risk of pollen exposure, as many jobs involve intense physical activity and resultant increased inhalation rates (D'Ovidio et al. 2016). Similarly, to the previously mentioned poisonous plants, climate change is expected to influence the geographic distribution of a variety of plants and pollens.

Control update—Recommendations for protecting workers from the potential impact of climate change on biological hazards have included robust disease and vector surveillance, vector control, training for workers about biological hazards and best preventive practices, and personal protective clothing and equipment for workers where appropriate (Tong et al. 2016; NIOSH 2021). One Health is a transdisciplinary approach that recognizes the interrelationships of human health, animal health, and environmental health to achieve optimal health outcomes (CDC 2021b). Due to its comprehensive approach to hazards, the One Health approach may best protect workers and help OSH and public health communities prepare, plan, and respond to the potential impacts of climate change on biological hazards. The expansion of habitats of vectors and biological hazards may lead to increased use of pesticides and herbicides (Gatto et al. 2016). Agricultural workers, landscape workers, and other outdoor workers may be at risk of exposure to these substances.

Industrial transitions and emerging industries

The greatest driver of climate change is rising planetary temperatures resulting from the production of greenhouse gases (IPCC 2021). A major cause of greenhouse gases is the burning of fossil fuels. The social and economic pressures involved in reducing fossil

fuel use and transitioning to renewable energy frame the view of the types of hazards workers will experience. Further, a growth in recycling (which may be one response to climate change and resource depletion) may increase workers' risk of exposure to hazardous materials and conditions (Anderson et al. 2020).

Hazard update—Phasing out fossil fuels has a direct impact on workers in the industries dealing with these energy sources, as well as on the workers in surrounding communities who depend on those industries. Coal is the primary fossil fuel that has been flagged for phasing out globally (UN Environment Programme 2019). High costs of coal extraction have led to an undercutting of coal prices by natural gas since the early 2010s (Neal 2020). Coal workers continue to suffer from the adverse health effects (such as pneumoconiosis, silicosis, traumatic injury, and hearing loss) they have experienced since the 1800s (Cho and Lee 1978; Khanzode et al. 2011; NIOSH 2011). However, the impact of industrial transitions may be more in the psychosocial realm. Claudia Strambo of the Stockholm Environment Institute stated, “History shows that when a mining transition is not well managed, the impacts to the environment, economy, and social fabric of former mining regions can be catastrophic,” (Casey 2019).

To reduce global carbon emissions, significant changes in energy production are expected. The number of renewable energy sources, primarily solar, wind, and hydrogen-generated energy (US EIA 2021). Ultimately, solar and wind energy production are expected to partially replace fossil fuel energy generation. However, nuclear power will likely serve as a growing intermediary energy supply for many decades until solar and wind energy provide ample supply and deliver power continuously (IAEA 2021). Occupational hazards in the nuclear industry, in terms of injuries and fatalities, are predominantly from the mining and milling of raw materials (Roscoe et al. 1995). During operations, a potential for ionizing radiation exposure exists, although even at less concerning levels they are likely still important (Richardson et al. 2015). Unresolved issues associated with the disposal of nuclear waste are potentially a more significant occupational and environmental concern; these may be resolved through the commercial development of nuclear fusion. Nuclear fusion, which is a promising energy source, uses radioactive materials with half-lives substantially less than those for fission, and the risk of a major accident is substantially less (Markandya and Wilkinson 2007; Ball 2022).

Solar photovoltaic systems and wind turbines are likely to be a major replacement for fossil fuels in the future. Various methods of manufacturing photovoltaic materials involve a variety of different materials, most of which are potentially toxic or hazardous (National Research Council 2010). Although most of these chemicals have been involved in a fair amount of basic toxicological research (Bakhiyi et al. 2014), very little quantitative or qualitative risk assessment research has been done on the occupational health issues arising during the mining of component materials, manufacturing, and recycling processes (Bradbrook et al. 2013; Bakhiyi et al. 2014). Furthermore, several physical and electrical hazards are associated with the installation and maintenance of photovoltaic systems, including falls and manual-handling concerns, as well as heat stress. However, little data are available for quantifying the rates at which these risks directly affect installers (Duroha et al. 2020).

In the wind energy–generation industry, manufacturers of wind turbines have hazards similar to those in the automobile and aerospace industries. Primarily, these involve exposures to epoxy-based resins, glassreinforced plastic, and noise. Installation and maintenance of wind turbines are associated with work in confined spaces, electrical risks, and falls from heights, potentially exacerbated by the unpredictability of wind gusts (Freiberg et al. 2018). Off-shore wind farm hazards include isolation, delay in emergency care for life-threatening injury, and the potential for longer work shifts (Mette et al. 2018). Similar to the lack of literature on risks in solar energy production, occupational health hazards in the wind energy industry have been addressed in only limited peer-reviewed scientific literature (Karanikas et al. 2021).

Hydrogen technologies may also provide renewable energy (Federal Ministry for Economic Affairs and Energy 2020), and the hazards will need to be assessed (Rivikin et al. 2015). Although hydrogen energy has the potential to replace fossil fuels, its impact on the atmosphere has yet to be fully assessed (Warwick et al. 2022).

Recycling is an important means of energy efficiency, but hazards have arisen in this industry (Anderson et al. 2020). More broadly, the transition to a circular economy may expose workers to new hazards, and OSH-relevant knowledge for dismantling old infrastructure may be lacking (Daheim et al. 2021).

Another area of transition is the Agriculture, Fishing, and Forestry sector. The agriculture industry is changing because of significant alterations in weather, including rainfall patterns, and more frequent weather extremes, such as high temperatures and longer droughts. The locations where crops have traditionally been grown are moving farther north. Land that has never supported crops is being purchased, anticipating a future opportunity to grow crops. This may result in a need for workers to be located potentially in further remote areas where infrastructure is lacking. In addition, traditional agriculture areas will need to transition to other crops or otherwise adapt.

Control update—In general, the prevention and control of adverse effects on workers from industrial transitions and emerging industries will involve anticipation of scenarios in a matrix of old and new hazards by traditional and future jobs (Schulte et al. 2020). For the most part, the hazards will be known ones but in new situations. A critical control measure will be the use of strategic foresight approaches to protect and promote worker safety, health, and well-being (Streit et al. 2021). Ultimately, the occupational safety and health field can be a resource to promote a “just transition” for workers who are displaced due to responses to climate change (UNFCCC Secretariat 2020).

Changes in the built environment

Hazard update—Much of the response to climate change may be changes in the built environment, which may present hazards to workers. Clearly, some of the new technologies, such as wind and solar, will involve building and construction with new or exacerbated hazards. Moreover, building and construction are responsible for 39% of carbon emissions globally (UN Environment Programme 2019). New construction scenarios or expanded construction demands may present hazards to workers beyond those in construction.

Additionally, buildings designed to save energy (“tight buildings”) may allow for the buildup of toxic substances, radon gas, and infectious agents, which might affect worker occupants and maintenance staff (Schulte and Chun 2009). Other potential impacts on workers could arise from commonly used built environment strategies to combat climate change, such as tree planting, road diets (roadway reconfiguration), bike lane installation, and cool roofs, but these have not been specifically characterized in the literature.

Control update—As with industrial transitions, anticipating hazards from climate change for construction and maintenance workers will benefit from strategic foresight (Streit et al. 2021). This may also be useful for identifying hazards for users of built environments, such as workers who are building occupants.

Crosscutting topics

The topics of mental health, health equity, economic burden, and geoengineering crosscut the seven-category framework, and the literature on these is growing.

Mental health effects of climate-related occupational hazards—Although the attribution of adverse mental health outcomes to climate-related hazards is challenging, exposure to climate- or weather-related disasters can cause or exacerbate mental health effects ranging from stress, anxiety, depression, and substance abuse to post-traumatic stress disorders and suicide (Tiesman et al. 2015; Dodgen et al. 2016; Wang et al. 2016; Bromet et al. 2017; Casas et al. 2017; Tallon et al. 2017; Tempest et al. 2017; Hanigan et al. 2018; Orui et al. 2018; Groot et al. 2019; Bundo et al. 2020; Cruz et al. 2020; Fitzgerald et al. 2020; Hrabok et al. 2020; Clayton et al. 2021). Climate impacts and influencing factors include not only health threats from air quality, wildfires, sea level rise, storms, heat, floods, and droughts but also vulnerability at larger community or societal scales, such as natural and built environments, governance and management, and institutions (Dodgen et al. 2016). Specific occupations, including first responders, farmers, forestry and fishing workers, public safety workers, and healthcare workers, are at higher risk for adverse mental health outcomes (Dodgen et al. 2016; Wang et al. 2016; Daghigh et al. 2019; Howard et al. 2020; Metregiste et al. 2020). Overwork, disaster relief work that interferes with personal lives, loss of family members or homes, and economic instability could increase the risk for adverse mental health, including depression and suicidal ideation (Lowe et al. 2016; Wang et al. 2016; Orui et al. 2018). The link between climate change–related occupational hazards and mental health does not appear to be a major consideration of employers. General recommendations have been published but few for employers and workers (Clayton et al. 2021). Various authors in trade publications have issued a call for employers to take action as climate change increasingly impacts health, productivity, and well-being (Gifford 2018).

Emerging issues include the impacts on the mental health of mass evacuation, inter- and intra-country migration, and relocation related to extreme weather events and the cumulative or mixed effects of hotter temperature, poor air quality, vector-borne risks, and/or extreme events (Dodgen et al. 2016; Burke et al. 2018; Maitre et al. 2018; Li et al. 2020). Multiple strategies must be undertaken by employers, workers, and communities to enhance adjustment and coping post-disaster, including enhancing access to care, interagency

cooperation, and adequate preparation (Marinucci et al. 2014; Dodgen et al. 2016; Hrabok et al. 2020).

Occupational health equity

Work conditions or work-related conditions.: Overall, the literature demonstrates that the nature of work and social determinants of health overlap to affect exposure to climate risks (Hayes et al. 2018; Benevolenza and DeRigne 2019). In high-income countries like the United States, economically disadvantaged workers (Levy and Patz 2015b; US EPA 2021a) are disproportionately affected by the negative health effects caused or exacerbated by climate change. Some of these poor health outcomes include respiratory and allergy disorders, vector-borne diseases, and heat-related disorders (Levy and Patz 2015b). These populations are also at high risk for the psychosocial impact of climate change, which can include the adverse mental health effects discussed earlier, as well as financial impact (US DOL 2022). For example, as a result of Hurricane Katrina, permanently displaced residents (who were largely African American single mothers) and workers experienced significantly higher levels of distress and perceived stress than those who were not uprooted by the disaster (Palinkas 2020).

Immigrant workers and those of lower socio-economic status are frequently employed in high-risk occupations (such as agriculture, construction, transportation, and emergency work) that are often subject to extreme weather conditions exacerbated by climate change (Spector and Sheffield 2014; Kiefer et al. 2016; Schulte et al. 2016). Immigrant workers face a combination of risk factors for HRIs, including lack of OSH knowledge and quality training, poverty, language barriers, seasonality of jobs, lack of decision-making autonomy, differences with treatment on the job, and extreme work conditions (Flynn 2014; Flynn et al. 2014; O'Connor et al. 2014; Stoecklin-Marois et al. 2015; Fan and Qian 2017; Ellis and Stam 2018). Immigrants and minorities are also overrepresented in outdoor jobs such as construction, farm work, landscaping, and roofing. For example, Latino farmworkers in the United States are disproportionately exposed to extreme heat waves and other climate risks because of the nature of their work (Mera et al. 2015). Limited access to resources (such as food, discretionary funds, and health care) at home and work can also complicate these workers' climate risk and ability to deal with work-related injuries or illnesses. Migrant farmworkers' exposure to excess heat is also influenced by other factors such as lack of access to healthcare and living in employer-provided housing that often lacks air conditioning (Arcury et al. 2015).

Changes to the workforce.: Climate change and human migration patterns are interrelated. It is anticipated that the increasing severity and frequency of catastrophic events (such as hurricanes), as well as the negative impact of shifting weather patterns (such as rainfall levels) on agricultural production, will continue to drive more individuals to migrate to the United States (Palinkas 2020). For example, analysis of state-level data showed a significant effect of climate-driven changes in crop yields on the rate of emigration from Mexico to the United States (Hunter et al. 2015). Increased migration to the United States will contribute to the increasing diversity within the U.S. workforce, which presents unique challenges to the future of OSH (Tamers et al. 2020). Due to unequal treatment and opportunity, as the

foreign-born proportion of the workforce grows, work-related injuries and illnesses along with the economic burden on society are anticipated to increase (Flynn 2014; Hargreaves et al. 2019).

Catastrophic events.: Low-wage workers, who are disproportionately racialized ethnic minorities and foreign-born individuals, often reside in neighborhoods and housing more susceptible to extreme weather events (Huang et al. 2011; Klinenberg 2015; Palinkas 2020). Additionally, these workers are more likely to be employed in clean-up and rebuilding efforts, which may expose them to unique and more hazardous or toxic conditions with less government oversight, supervision, and access to protective equipment (Donato et al. 2007; Delp et al. 2009). For example, during the Katrina disaster, people of color were the most impacted and also the most employed in the rebuilding of the city; residents of the Lower Ninth Ward in New Orleans, who were predominantly African American, and many Latino workers were involved in the rebuilding (Palinkas 2020). These OSH concerns will likely rise, given an expected increase in extreme weather events and a surge in foreign-born workers due to increased global climate-related migration to the United States (Palinkas 2020).

Future needs.: Future OSH attention to climate change should consider the interrelationships among health equity, environmental justice, and climate change. Environmental justice is defined by the CDC as the fair treatment and meaningful involvement of all people, regardless of race, color, national origin, or income, to develop, implement, and enforce environmental laws, regulations, and policies (ATSDR 2022). Economic activity and how it is structured in society are fundamental drivers of both workplace conditions and environmental degradation (pollution and climate change). As a result, the relationships between work, social inequity, and environmental justice must be better understood (Kingsolver 2011). The practice of externalizing risk (placing the burden of risk on a third party) has negative impacts on workers (Weil 2017). For example, individuals from groups and communities who are socially disadvantaged are overrepresented in dangerous and low-paying jobs. As a result, these workers are not only at increased risk of workplace injuries but also at increased risk of living near environmental hazards (such as toxic waste sites) (Klinenberg 2015; Palinkas 2020).

Economic burden of climate-related OSH hazards—Climate change has affected weather patterns, resulting in extreme temperatures. Both high and low temperatures are detrimental to workers' health, especially those working outdoors (Dillender 2021). These workers are mostly employed in the agriculture, construction, emergency response, commercial fishing, paramedic and firefighting, and transportation industries. Extreme temperatures impose costs on employers in the form of increased energy outlays and reduction in labor productivity or labor supply (Deschênes and Greenstone 2011; Auffhammer and Mansur 2014; Park et al. 2021). Few studies have focused on estimating the economic burden associated with occupational health and climate change. Limaye (2020) estimated the public health costs of 10 climate-sensitive events in 2012 in the United States as \$10 billion. According to the Natural Resources Defense Council, the annual health costs of air pollution and climate change are more than \$800 billion and are expected to

increase over the years (Limaye 2021). The International Labor Organization reported that heat stress is gradually becoming an obstacle to economic activities (Kjellstrom et al. 2019), reducing the productivity of workers in four sectors (agriculture, construction, industry, and services). Even if appropriate resources are utilized to limit global warming to 1.5 °C above pre-industrial levels by the end of the century, the accumulated financial loss due to heat stress is expected to reach \$2.4 trillion by 2030 (Kjellstrom et al. 2019). According to estimates, the impact of heat stress on reducing worker productivity is expected to be 0.91% of total working hours (the equivalent of 800,000 full-time jobs) in 2030 (Kjellstrom et al. 2019). Licker et al. (2022) estimated that with a modest greenhouse gas emissions reduction, outdoor workers will be exposed to extreme heat conditions in the mid-twenty-first century which is triple that of the late twentieth century, with earnings of approximately \$39.3 billion at risk annually. Neidell et al. (2021) assessed that workers' annual wage loss due to a reduction in time spent working on days with temperatures above 90°F across the United States will range from \$36.7 to \$80.0 billion in 2090 under intermediate and high emissions, respectively.

Studies incorporating economic models have shown that the climate change effects on workers are among the most important drivers of the total economic costs of climate change (Orlov et al. 2019; Dasgupta et al. 2021; Somanathan et al. 2021). Dillender (2021) examined 6 months of medical costs for workers' compensation claims associated with extreme temperatures in Texas in 2015. Higher temperatures were associated with worse health outcomes. He found that a majority of the claims resulting from low temperatures involved above-median medical costs, whereas the claims resulting from high temperatures were more evenly split above and below the median costs. He extrapolated his results, using the assumption that claims arising from temperature have an average work-related injury cost of \$20,500 in 2014 dollars (Leigh 2011). Each day with a high temperature above 90 °F (32.2 °C) leads to costs from incidents of \$0.08 per worker, and each day with a high temperature below 40 °F (4.4 °C) leads to costs from occupational health incidents of \$0.15 per worker. Since roughly 10% of workers work outdoors at least one day per week and have an average hourly wage of \$18 in 2014 dollars, the implied cost of the reduction in hours worked from each day with a high temperature below 40 °F is about \$1.82 per worker in warmer climates, when averaged across all U.S. workers (Dillender 2021). Total annual costs in Texas were estimated to be \$69.7 million for days above 90 °F and \$97.6 million for days below 40 °F (Dillender 2021).

Orlov et al. (2019) used an interdisciplinary approach, combining meteorological, epidemiological, and economic analyses, to assess the cost of heat-induced reductions in outdoor worker productivity in Europe caused by the heat waves in August 2003, July 2010, and July 2015 (Orlov et al. 2019). They estimated that for the top 10 most affected European countries, average direct economic losses (estimated as the productivity losses in specific sectors) in agriculture accounted for \$59–\$90 per worker. In construction, these losses were \$41–\$72 per worker in 2015 U.S. dollar values. According to these authors, the average social costs of these events (estimated as the loss in productivity of other sectors as a result of the heat-induced impacts in agriculture and construction) ranged from \$1.6 to \$2.7 per capita.

Geoengineering—Geoengineering, also known as “climate intervention” or “climate engineering,” is defined as the intentional, large-scale human manipulation or alteration of the environment (Effiong and Neitzel 2016; Jones et al. 2017; Abatayo et al. 2020). Potential geoengineering interventions to address the changing climate are diverse and could include such approaches as the following: the chemical capture of carbon from the atmosphere; the facilitation of the growth and use of carbon-eating plankton; and using large mirrors to reflect sunlight into space and/or creating and injecting a reflective haze (usually chemicals such as carbon black [soot], various sulfate compounds, fine aluminum particles, aluminum oxides, and nanoparticles like barium titanate) to reflect sunlight into space. To date, the use of geoengineering to mitigate climate change is based on predictive models and, as such, remains highly controversial because it carries a strong possibility of unintended consequences (Ocean Studies Board 2015a, 2015b).

The extent to which geoengineering would create risks and hazards or decrease climate-related risks and hazards for workers is unknown. Outdoor workers, especially those of low socio-economic status such as manual laborers, farmworkers, nursery workers, ranch workers, construction workers, and wildland fire-fighters, would be at greatest risk from the effects of climate change and the potential effects of geoengineering. Few studies have been done to determine the human health impacts of exposure to atmospheric aerosols (inorganic sulfates, carbon black, powdered aluminum, aluminum oxides, nanoparticle barium titanates, etc.) proposed for use in geoengineering and the environmental changes that may result from geoengineering. Developing scenarios for different types of geoengineering may help identify potential hazards for workers and would be the first step in identifying prevention and control measures.

Discussion

This review is an update of two earlier reports that established and increased awareness of workers’ risk of exposure to, and adverse effects from, climate change-related hazards (Schulte and Chun 2009; Schulte et al. 2016). This current horizon-scanning effort discussed new information in all seven categories of climate-related hazards presented in the original framework. These findings support the importance of the complementary, crosscutting topics of mental health, occupational health equity, economic burden, and geoengineering.

The framework initiated in the earlier reviews served as the basis for two reports (NIEHS 2015, 2022) that described a climate change vulnerability assessment to determine how the impacts of climate change affect workers and how to prepare for these impacts. The findings discussed here imply that workers are at increased risk of exposure to climate-related hazards and that investigators, authorities, employers, trade associations, unions, and workers must make a concerted effort to identify the extent of exposure to these hazards and ways to control them.

Conclusions

The literature on the relationship between climate change and OSH hazards has continued to grow since 1988. However, many gaps persist, particularly regarding mental and

physical health effects on worker exposure to air pollution, UV radiation, risks in the built environment, and inequities. Scenarios must be developed for identifying hazards in geoen지니어ing, and more interventions should be developed to prevent and control the hazards related to vector-borne diseases. Since employers are not accustomed to dealing with climate-related hazards, programs that address employer and worker behaviors will be critical.

Anticipating potential futures and regional variations is necessary for preventing and controlling climate-related occupational hazards. Foresight techniques that predict climate-related OSH hazards can help establish priorities and responsibilities for workers' safety and health (Daheim et al. 2021; Streit et al. 2021).

Although there is a growing literature on health equity and climate change, the surveillance data are insufficient for addressing equity issues related to worker exposures and adverse outcomes with regard to race/ethnicity, nativity, immigration status, and language. Researchers must continue assessing the economic costs of climate-related hazards on workers and employers, assess the impact of such hazards on indoor workers, and find new hazard control and risk management interventions employers can use to protect workers. A bolder front must be opened up for surveillance and research to address the needs of workers exposed to climate-related hazards.

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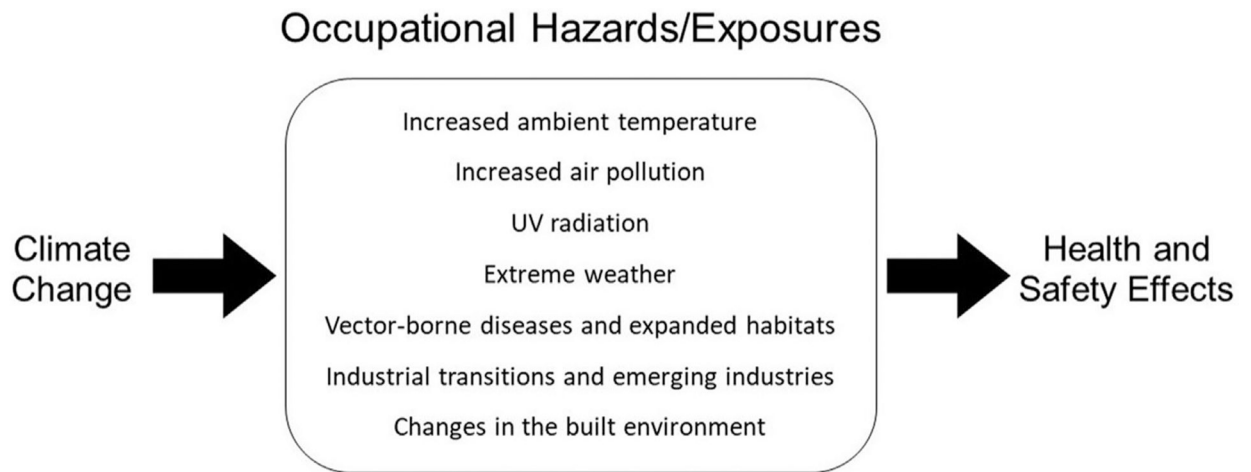


Figure 1.

Summary schematic of the Schulte and Chun (2009) conceptual framework of the relationship between climate change and occupational safety and health.

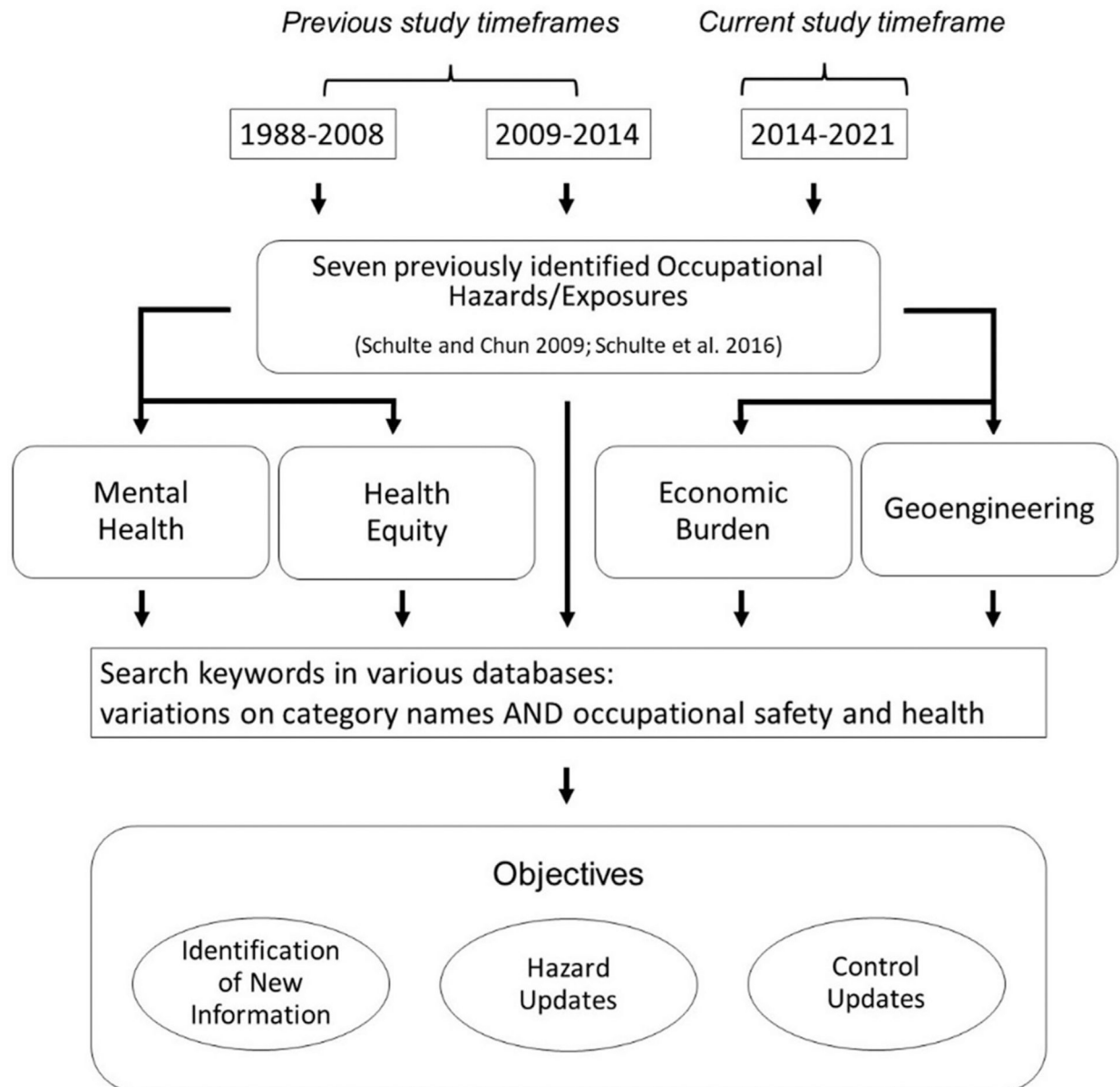


Figure 2.
Overview of search strategy and study objectives.

Table 1.

Populations disproportionately affected by select biological hazards.

Biological hazards	Workers at risk	Occupational health effects
Giant hogweed Molds	Outdoor workers Indoor and outdoor workers, remediation and construction workers (Johanning et al. 2014; Poole et al. 2019), teachers, and school staff (US EPA 2014; Claudio et al. 2016)	• Phytodermatitis • Fungal diseases, asthma, and hypersensitivity pneumonitis (Sheehan et al. 2017; D'Amato et al. 2020)
Mycotoxins/Aflatoxins	Cereal and feed production, storage, and transportation; animal husbandry, including dairy farming, poultry, and swine; bulk food imports; sugar factory workers; grain milling; textile production; bakeries; composting plants; tanneries; museums (Gutarowska et al. 2014; Viegas et al. 2016; Skóra et al. 2017; Wangia et al. 2019; Valencia-Quintana et al. 2020; Viegas et al. 2020; Habschied et al. 2021)	• Mycotoxicoses, liver/kidney damage, immune suppression, cancer, and respiratory issues (Freire and da Rocha 2016)
<i>Coccidioides</i> fungus	Outdoor workers who perform work that involves ground disturbance in construction, archeology, prison employment, wildland firefighting, outdoor film making, solar panel farm building, military, mining, quarrying, and oil and gas extraction (Wilken et al. 2015; Freedman et al. 2018; de Perio et al. 2019; Pearson et al. 2019)	• Coccidioidomycosis (Valley Fever)
<i>Cryptosporidium</i> fungus	Woodsmen, foresters, sawyers, and paper mill workers (Braun et al. 2021)	• Hypersensitivity pneumonitis (Maple Bark Disease)
<i>Histoplasma</i> fungus	Bridge inspectors or painters; chimney cleaners, construction workers; demolition workers; farmers; gardeners; heating and air-conditioning system installation/repair workers; microbiology laboratory workers; pest control workers; historic building restorationists; roofers; and water tower maintenance workers (NIOSH 2004; Benedict and Mody 2016)	• Histoplasmosis
Aeroallergens, pollen	Outdoor workers	• Increased exacerbation of existing allergic rhinitis and asthma (Shusterman 2014; Levy and Patz 2015a) • Newly developed pollen allergies (Lee et al. 2021)