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Non-heat related impacts of climate change on working populations

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Environmental and social changes associated with climate change are likely to have impacts on the well-being, health, and productivity of many working populations across the globe. The ramifications of climate change for working populations are not restricted to increases in heat exposure. Other significant risks to worker health (including physical hazards from extreme weather events, infectious diseases, under-nutrition, and mental stresses) may be amplified by future climate change, and these may have substantial impacts at all scales of economic activity. Some of these risks are difficult to quantify, but pose a substantial threat to the viability and sustainability of some working populations. These impacts may occur in both developed and developing countries, although the latter category is likely to bear the heaviest burden.

This paper explores some of the likely, non-heat-related health issues that climate change will have on working populations around the globe, now and in the future. These include exposures to various infectious diseases (vector-borne, zoonotic, and person-to-person), extreme weather events, stress and mental health issues, and malnutrition.

Keywords: *climate change*; *workers*; *vector-borne diseases*; *zoonoses*; *mental health*; *malnutrition*; *emergency workers*; *farmers*

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Climate change most obviously entails rising temperatures and heat exposure, and working populations (especially outdoor workers) are likely to be at particular risk from heat stress (1). As the ambient temperature reaches—and then exceeds—the human core temperature of 37°C, there are well-documented physiological effects on the human body, with increasing heat exposure posing risks to some organ systems and also making it progressively harder to work productively (physically and cognitively) (2, 3).

The ramifications of climate change for working populations are not restricted to increases in heat exposure. This paper explores some of the other likely, non-heat-related health problems that climate change will have on working populations around the globe, now and in the future. The risks include exposures to various infectious diseases (vector-borne, zoonotic, and person-to-person), extreme weather events, stress and mental health issues, and malnutrition.

Vector-borne diseases in outdoor workers

Most microbial pathogens, their vectors and host 're-servoir' species are sensitive to climatic conditions, which impose limits on the geographic range, seasonality, and transmission efficiency of infectious disease. Climate thus determines where and when a particular infectious disease *could* occur; but a diversity of other, often localised, factors – environmental, social, cultural, and technological factors, along with public health practices – determine where the infectious disease *will* actually occur. Outdoor workers are especially at risk of vector-borne disease and, as the global climate changes, they may be exposed to vector-borne diseases in areas and at times where transmission was previously not possible. In addition, changes in daily work activities due to increased heat, such as longer rest periods in the middle of the day and increased work at dawn and dusk, may coincide with the times when insect vectors are most active thus increasing the likelihood of disease transmission (4–6).

There is already suggestive scientific evidence that the geographic range and prevalence of some vector-borne diseases are changing in response to regional changes in climate, especially rises in temperature and changes in rainfall. In China, schistosomiasis – long a scourge of rural communities and farm-workers – has recently re-emerged in areas where it was previously eradicated, thought to be associated with the spread of suitable habitats for the intermediate host snail *Oncomelania hupensis* in response to regional warming (7–9). Schistosomiasis is predicted to spread northwards into currently

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non-endemic areas as the 0–1°C isotherm moves further north due to climate change and, thus, expands the potential habitat range of the intermediate host snail (8–10). Domestic water buffalo and cattle are an important reservoir host for schistosomiasis and are commonly used for ploughing and carrying loads by farmers in China. The animals often forage freely in areas where schistosomiasis is endemic, so re-infection commonly occurs in treated animals, which then excrete the parasite back into the water for uptake by the snails. In most endemic areas, over 70% of the environmental contamination can be traced back to bovine defecation (11). Farmers, therefore, have an increased risk of exposure to schistosomiasis, via the parasite life-stage released by the snails in the water and soil of their paddocks, which is amplified by contamination of drinking water and irrigation supplies by their livestock.

In Japan, the distribution of *Aedes albopictus* (the mosquito species that transmits dengue fever) has been advancing northwards over recent decades, thought to be associated with higher autumn mean temperatures that promote larvae development and warmer annual mean temperatures that encourage expansion of adult mosquitoes during summer (12). Meanwhile, dengue itself has been recently reported to be spreading in Taiwan in association with local climatic trends (13). The prevalence of leishmaniasis (a sandfly-transmitted parasite with many animal reservoirs) in Colombia has been previously shown to differ by season, but more recently, prevalence has been shown to also vary between El Niño and La Niña events (14). Another recent observation is the presence of a tropical fungus, *Cryptococcus gattii*, in the temperate Pacific Northwest region of North America – a fungus that causes meningitis, pneumonia, and tumour-like lesions in humans with a reported case-fatality rate of 9%. Analyses indicate that this was a case of emergence in a totally new geographic range for the fungus, suggesting that a warming climate may have created suitable conditions in a previously unsuitable habitat that have allowed the spores to persist and propagate (15, 16).

Local environmental conditions are important determinants of vector-borne disease distribution through their action on the host species, intermediate vertebrate hosts (where applicable), and vector organisms, especially mosquitoes. As temperature rises, pathogens such as the malaria plasmodium and dengue virus mature more quickly within the mosquito, while the mosquitoes themselves breed more prolifically and feed more often, thus increasing the likelihood and speed of transmission to humans. Vectorial capacity (a measure of how fast an outbreak can spread) also increases exponentially throughout the transmission season. Therefore, a small change in temperature that brings forward the beginning of the transmission season or lengthening of the rainy season (which is the breeding period for mosquitoes) could have a great effect on mosquito numbers and, therefore, on the resultant risk of disease occurrence (17).

Changes in the geographic ranges and seasonality of vector-borne infectious diseases will thus have important health and productivity consequences for many working populations. Outdoor workers are already at a higher risk of vector-borne infections than most other workers because of their proximity to vector species and their habitats. The risk of transmission will also increase under climate change as the number of vectors increases and transmission becomes more efficient.

Vector-borne diseases are already responsible for considerable losses in economic productivity every year, primarily in those regions where a vector-borne disease is endemic such as malaria in Africa. The impacts of endemic vector-borne disease begin with a workforce that is less healthy and less physically capable of working, increasing the number of work days lost to ill health. This reduces primary economic productivity, with flow-on effects on other important economic sectors such as tourism and trade at local, regional, and national scales. Endemic vector-borne disease has been associated with substantial negative impacts on long-term economic development in many regions in Africa and Asia, with macroeconomic studies estimating the growth rate of the gross domestic product (GDP) in malaria-endemic regions to be 0.25–1.3% per year lower than regions without malaria. Over 25 years this can amount to almost half of the per capita GDP in poor countries (18).

In addition, some vector-borne diseases have lingering health effects that will reduce the ability of an individual to work, and work productively, over extended time-frames (perhaps permanently). In particular, childhood infection can often have major effects on health and well-being in adult life, with reduced physical and cognitive abilities that may further reduce the potential workforce size and thus future production.

Malaria provides a major and instructive example. This ancient vector-borne disease is endemic to much of Africa and has had a profound impact on local social and economic development. Studies in sub-Saharan Africa have shown that, in addition to high mortality rates (of around 20%), childhood malaria is also associated with long-term neurological and cognitive impairments in around 25% of those who survive (19–21), including physical handicaps, hearing loss, and impaired higher order cognitive functions (such as planning and decision making) (21). Further impairments may emerge later in life as a result of brain injury during early developmental stages. Physical handicaps reduce a person's ability to contribute to domestic tasks such as cooking, cleaning and planting crops, whilst increasing the burden on caretakers, and minor cognitive deficits may become increasingly profound as children mature and the tasks required of them become more complex

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and demanding (21). Furthermore, chronic infection, frequent illness, and malnutrition will exacerbate the negative impacts of childhood malaria, with additional loss of adult function and abilities (21).

In adults, chronic malaria results in anaemia, which markedly reduces worker productivity and output (18, 22). Various mining, agriculture, and manufacturing industries have been seriously impaired by worker populations with a high disease burden. In addition, companies are wary of investing and working in areas where malaria is endemic (for fear of catching the disease) and when imported workers from malaria-free areas have no acquired immunity to the more severe effects of malaria (22). Beyond these immediate impacts (including medical costs, lost incomes, and decreased productivity), malaria imposes economic effects via two other broad mechanisms. First, the social costs include high childhood mortality rates (which leads to changes in the population-age structure), lower education levels (including deficits in cognitive function), decreased personal accumulation of capital, and the potential for population migration. Second, at the macroeconomic scale, malaria indirectly imposes substantial losses through decreased trade, tourism, and foreign investment. In turn, the health of the workforce at large is influenced by both of these impact pathways and, thus, the potential spread of malaria (and other vector-borne diseases) under future climate change poses a substantial threat to many developing nations around the globe.

Diarrhoeal disease and lost work days

Climatic conditions also affect the patterns of occurrence of many non-vector-borne infectious diseases. Campylobacter infections, derived from animal species and often then transmitted via contaminated water, show seasonal differences in transmission rates, with warmer winters advancing the spring transmission peak to earlier in the year (23). Climate-induced changes in water quality, availability, and salinity, as well as local temperature and humidity are also closely linked to the spatial and temporal patterns of vector-borne and water-borne diseases, and environmental changes may be reflected in changing epidemics and outbreaks of endemic diseases, such as cholera in India and Bangladesh (24) and haemorrhagic fever with renal syndrome in China (25, 26). Some diseases may also become endemic in new geographic regions.

The prevalence of diarrhoeal diseases in developing countries is high and is responsible for an estimated 7% of all deaths in developing countries, second only to malnutrition (27). It also impairs productivity at work and accounts for many lost work days. Diarrhoeal diseases are strongly linked to poor hygiene and sanitation practices, and lack of infrastructure, especially the contamination of food and water supplies through unregulated disposal of human excreta. Direct contact with an infected person is also an important disease transmission route. Environmental transmission is less common as many of these microorganisms are not robust enough to survive for long outside the host (28). However, future climate change is likely to generate circumstances and events that markedly increase the transmission of disease.

Climate change is likely to affect the replication, survival, persistence, and transmission of various microorganisms that cause diarrhoeal disease. Cholera, shigella, salmonella, campylobacter, noroviruses, enteroviruses, rotaviruses, cryptosporidium, and giardia often show seasonal infection patterns that strongly suggest underlying environmental influences that include rising temperatures, changing rainfall, and movements in the geographic ranges of host or reservoir species (29). In addition, extreme weather events enhanced by climate change, such as widespread flooding, substantially increase the risks of drinking water and food crops being contaminated with human faecal matter. These circumstances are likely to pose risks particularly to working populations in low-income settings with minimal hygiene facilities.

Cholera is endemic in many developing countries and is especially sensitive to changes in aquatic environments (water temperature, salinity, pH, and amount of rainfall), which are strongly affected by changes in local climate. Rising temperatures are also important, as the optimal temperature for microorganism growth is 30–40°C (24, 30).

Outbreaks and endemic diarrhoeal disease are already a major source of lost work days, especially in developing countries. Diarrhoeal disease imposes a significant financial impact on households through the direct costs of medical treatment and lost work days. Furthermore, these costs are incurred regardless of which family member is sick, through the costs of health care, infection of other family members, and loss of income when caring for a sick child or relative (28, 31). Morbidity and mortality from diarrhoeal disease is heavily focused on children. In South Africa, approximately 70% of cases and 90% of deaths from diarrhoeal disease are infants and children (28). Typically, the household income is then reduced when parents stay home from work to care for sick children. A single infection can thus remove two or three people from the work force.

The indirect costs of diarrhoeal disease include declines in long-term health and ability to work due to recurrent adult disease, physical and cognitive impairments associated with childhood infection and school absenteeism, rising household debt when loans are needed to pay for treatment, social disruption (especially from high childhood mortality rates), and lost economic opportunities for household income from work, as well as macroeconomic costs from lost trade and tourism (27, 28, 31). In the future, under conditions of climate change and especially if superimposed on persistent poverty, developing countries will continue to carry a high burden of unwell and poorly educated workers who are unable to contribute to their full potential.

The potential threat from diarrhoeal diseases in developed countries (with, currently, clean water supplies, good public hygiene, and sanitation infrastructure) is also likely to be increased by future climate change. In particular, extreme weather events may be enhanced in frequency and/or severity by climate change, leading to the overload of municipal stormwater and sewage systems and to reduced public hygiene – via, for example, the overflow of effluent into drinking supplies and recreational facilities such as pools, lakes, and rivers (32). Emergency response workers, especially those connected with sanitation and water infrastructure, are particularly at risk of infection due to their close proximity to the source and their immediate response to the emergency before testing for the presence of microbes is conducted. The removal of emergency response personnel from the workforce in emergency situations may have strong detrimental effects on the health and well-being of all residents and also increase the demand on public health sectors at a critical time.

The impacts of extreme weather events on diarrhoeal diseases may not be confined to a single city. For example, following the evacuation of New Orleans (Louisiana, USA) during Hurricane Katrina, outbreaks of gastroenteritis were seen in evacuees and relief workers across four states (not including Louisiana) (33). Furthermore, the interconnectedness of modern society means that diarrhoeal diseases from distant locations where pathogens thrive and there is minimal sanitation and hand-washing facilities for workers can be transmitted to unsuspecting populations elsewhere. For example, about 200 cases of *Escherichia coli* across the United States were linked to bagged fresh spinach from a single farm, where unusual weather conditions had contaminated the groundwater (which was used for crop irrigation) with animal faeces (15).

Zoonotic infections in livestock workers

Infectious diseases intermittently emerge from animal species and spill over into human populations. It is estimated that 60–80% of emerging pathogens are zoonotic in origin (34–37). The incidence of these events is often influenced by climate-related changes in the density and movement of reservoir animal species due to habitat disruption and population displacement. Ongoing climate change may be accompanied by more frequent zoonotic infections as well as the emergence and spread of new zoonotic infections.

Many existing and emerging zoonotic diseases can be traced back to human-induced ecological disturbances. In particular, deforestation (for crop and livestock farming), road construction, water control systems (dams, irrigation systems, and reservoirs), and human settlements disrupt the ecological niches of infectious agents, their hosts, and vector species (38). Workers involved in these industries are particularly at risk of novel zoonotic infection as they are literally 'on the front line' where contact, and conflict, between humans and wild animal species is most likely to occur. Emerging zoonotic infections are also more likely in poor and refugee populations who may turn to bushmeat hunting for food and income (15).

Although the links to climate change are indirect, the example of Nipah virus is a strong warning of the potential for new zoonotic disease outbreaks as future climate change alters animal habitats and human activities intrude. The previously unknown Nipah virus emerged in Malaysia in the late 1990s after large tracts of rainforest were cleared for commercial forestry, agricultural crops, and large-scale intensive pig farming (39). The outbreak infected more than 300 workers who had direct contact with infected pigs and more than 100 died. Over one million pigs were culled and the local swine industry almost collapsed (39). The cases were primarily men indicating the occupational nature of exposure. The most likely reservoir was discovered to be fruit bats or flying foxes from neighbouring forests that may have been displaced by some combination of human activities and unusually dry conditions during the severe El Niño event of 1997–1998, which also brought wide-scale forest fires (39, 40).

Projected increases in the frequency and severity of quasi-cyclical climatic events such as the El Niño (ENSO) oscillation under future climate change conditions, with the associated changes in habitats and food supplies for animal species, may increase the risk of displaced animal populations coming into contact with human activities. Livestock workers in regions close to wild animal habitats may be particularly at risk due to close contact with domestic animal hosts and contact with wild animal reservoir species. For example, wild elk and bison in Yellowstone National Park (USA) are reservoirs of Brucellosis (41), a highly contagious zoonotic infection that is transmitted through contact with, or consumption of, unsterilised milk and meat from infected animals. These wild animal populations are considered a potential threat to domestic cattle (and their handlers), which are grazed at the park boundaries (41).

Climate change may, in the future, influence some other categories of infectious disease risks in working populations in ways that, currently, seem marginal or uncertain. With changes in temperatures, wind patterns,

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water, and vegetation, the local flight paths and longer-distance migratory routes of birds and bats may alter. This could have implications for a range of viral diseases including influenza and various bat-borne viral zoonoses.

The emergence of new influenza strains has already been accelerated by battery-fed production of poultry alongside intensified interspecies contacts in many Asian backyards, villages, and local markets. Initially, these new disease strains appeared in the workers and owners who had close contact with infected animals. Influenza strain H5N1 ('Avian' flu) likely evolved from flocks of chickens in Hong Kong, with the first human infections in 1997. It has now spread to infect other poultry flocks as well as wild bird populations throughout Southeast Asia and human-to-human transmission has been documented in Thailand (34). The more recently identified influenza strain H1N1 ('Swine' flu) belongs to a category that is usually species-specific and only infects pigs. In March 2009, it was identified in people in Mexico (42, 43). Within days, hundreds of human cases were identified in Mexico, the United States, Canada, and Costa Rica, with high mortality rates (especially in Mexico, with 97 documented deaths from just over 5,000 cases) (42). These outbreaks resulted in the substantial loss of work days due to sickness, loss of income due to quarantined products, and severe restrictions on future production due to the culling of livestock (to help stop the outbreaks). The rapid spread of these influenza strains beyond the livestock workers into the general population was enabled by high density human settlements with poor public sanitation and hygiene and the global interconnectedness created by air travel soon spread the diseases internationally.

Under future climate change conditions, there will therefore be heightened need to monitor livestock workers more closely for signs of emerging zoonotic infections. The recent outbreaks of 'Avian' and 'Swine' flu have already demonstrated the potential for a new zoonosis that is initially confined to occupationally exposed persons to rapidly become global. The global loss of economic productivity directly and indirectly associated with these two influenza strains alone is probably incalculable.

Workers should also be monitored for less common zoonotic diseases, some of which can be devastating to individual workers and specialised industries. In Australia, cases of the deadly Hendra virus (also known as equine morbillivirus) have, so far, been confined to equine handlers and veterinarians. Hendra virus is related to rabies and is spread by infected bat urine that contaminates pasture and stock feed. Horses are vulnerable to infection and it is easily passed from horse to handler. It is invariably fatal to both (35, 40).

Extreme weather events and health care workers

Climate change is predicted to increase weather variability, thereby bringing more frequent and more intense extreme weather events such as floods and hurricanes (cyclones). During extreme weather events there are dramatic surges in demand on various sectors, especially in the medical, emergency response, and essential services sectors. These workers are expected to work harder, for extended periods, in difficult (and often dangerous) circumstances, and with limited resources. For example, during Hurricane Katrina (USA in 2005), emergency physicians were among the last to evacuate from a devastated New Orleans (44). Lead nurses were expecting to 'work hard for several days and return home, hot and tired, to life as usual' (p. 9) (45), not realising that the 'emergency' situation would persist for weeks and months afterwards. Hospital staff also faced unexpected challenges during Katrina such as finding a space to rest in an overcrowded hospital, facing armed looters in the hospital pharmacy, and finding ways to feed patients when the hospital kitchen was not operational (45). The significant stresses of these working conditions were exacerbated by the lack of communication with family and friends outside the workplace (45). Extreme events like Katrina are likely to occur with increasing frequency in a future with climate change, and will represent 'life-changing experiences' (p. 9) (45) for all workers involved, rather than being an inconvenience.

Generally, planning for extreme weather events focuses on *how* to respond to the event. Little consideration has been given to whether or not the necessary people are *willing* to work in such circumstances. Studies have shown that health care workers and paramedics were reluctant to work during emergency situations if they perceived a threat to their own safety, that of their colleagues, and/or their families at home. Further, willingness to work also decreased the longer an event continued (46, 47). The greatest barriers to their *ability* to work were personal illness and injury, communication problems, and difficulties in getting to and from the workplace (due to infrastructure damage and disruption), and personal obligations to child care, elderly relatives, and pets (46, 48). Requests to work longer hours, different shifts, with reduced breaks, and/or at a different location to the usual place of work also decreased the willingness and ability of people to work during an emergency (46).

Emergency workers often place substantial psychological pressure on themselves to work in exceptional circumstances: 'this job comes with a responsibility to turn up,' 'it's what we are trained for' (p. 24, paramedics quoted in (47)) and put their own well-being at risk in the process. Society also places high expectations on the willingness and ability of these workers to put their own needs and concerns aside, and work at maximum capacity for extended periods until services are restored and the 'emergency' has subsided.

The predicted increase in both frequency and severity of weather events under future climate change scenarios also poses a threat to the long-term well-being of these workers. The repeated trauma and stress of multiple emergency events and the ongoing management of the injured, ill, and displaced may leave these workers physically and emotionally fatigued and unable to contribute as strongly during later events.

In addition to emergency responses, it is expected that a more variable climate will bring more frequent and larger surges in 'non-emergency/normal' demands such as the amplification of patterns in weather-related diseases and injuries, including dehydration and heatstroke in summer, or broken bones after slipping on ice in winter. Shifts in the geographic ranges of vector-borne diseases and zoonoses and the re-emergence of previously eradicated (or well-controlled) diseases may also challenge staff unfamiliar with those diseases. Increased clinical workloads may also reduce disease surveillance activities so that new diseases or outbreaks are not detected as quickly. The identification of West Nile disease in the United States in 1999 was initially hampered by a lack of capacity (15, 44). A changing climate may also place more clinical demands on specific medical specialities as human physiologies struggle to adapt, including psychiatry, infectious disease, urology, cardiovascular, and critical care sectors.

Furthermore, health care workers and the operation of health care facilities will face multiple challenges related to climate change mitigation and adaptation strategies. Demands and pressures to reduce energy consumption, decrease greenhouse gas emissions, and increase building efficiency will place additional strain on an already stressed workforce (44).

Environmental change and mental health impacts in farming communities

Farming is an inherently stressful occupation, given the perennial need to cope with unpredictable environmental conditions (49–52). Agriculture is especially vulnerable to climate change, with significant risks of both short-term crop failures and long-term declines in productivity. In many agricultural regions, especially in mid-latitude (subtropical) regions, climate change will entail less rainfall and drying trends that are exacerbated by greater evaporation at higher temperatures. In many locations, the seasonal patterns of rainfall will change and rainfall events will often intensify. These changes will have significant effects not only on the success of the crops themselves (and the implications for food supplies from those crops) but on the ability to make a living on the land. This applies to both large-scale, modernised agricultural industries, as well as small-scale subsistence farmers with both micro- and macroeconomic ramifications.

In subsistence cultures, the loss of agricultural productivity decreases the ability of a society to feed themselves and increases their reliance on external food supplies including international aid programmes. The loss of crops also reduces opportunities for agricultural trade, an important source of both food and income for many around the world.

Extended dry periods not only damage the landscape and render land unproductive, but the resulting loss of income translates into great psychological stress for the farmers whose livelihoods depend on the land. The impairment of mental health by long-term stressful events, like droughts, is often gradual and accompanied by pervasive feelings of weakness, despair, and hopelessness. Climate-based stressors are particularly threatening due to their 'uncontrollable' and 'unpredictable' nature and the growing sense of uncertainty that they bring (49, 53, 54). In many rural societies, a stoic nature in the face of adversity is a highly desirable trait, and many who are affected by mental health disorders keep their symptoms well hidden and do not seek treatment (even if it is available) (53). Mental health disorders are characterised by emotional distress and impaired cognitive function, which may lead to workplace accidents, aggression, substance abuse, eating disorders, anxiety, and depression, all of which impair one's ability to work.

Rates of suicide mortality tend to increase in such circumstances (53, 55, 56), as has been documented in the UK, Europe, United States, Canada, Australia, Japan, India, and Kenya (49–51, 57–59). In Australia, the suicide rate in male farmers is approximately triple the rate of suicide in urban males and 4–5 times the rate of suicide in women (52, 53, 60). In India, an estimated 100,000 farmers committed suicide between 1993 and 2003 (58). These deaths were partly attributed to water shortages that decreased crop yields, but there were also significant additional stressors in this farming industry, including social inequality, debt accumulation, changing farming practices and crops, and government controls on crop prices and commodities trading (57, 58).

More recently, there have been marked increases in suicide rates in East Kenya after farmers were hit with unusual weather. A prolonged drought reduced crop yields and unseasonal rains during harvest led to widespread contamination of crops with a fungal toxin released by the wet grain. The toxin also remains in the soil afterwards, thus threatening future production as well. Again, these factors combined to exacerbate debt levels, producing extreme psychological stress, and suicide rates in the last year have soared to around 2,000 deaths/year (compared to the average rate of roughly 300 suicides/year) (59). Furthermore, these numbers appear to be underestimates of the true suicide toll, as suicide is treated as a crime in India and Kenya and so many deaths go unreported (58, 59). Farming men tend to be more susceptible to extreme mental health issues such as suicide, but women and children are also negatively affected especially in developing countries due to gender inequalities (49, 53).

As productivity becomes economically unviable, people may abandon the land in search of a more secure economic future, triggering the decline of rural communities and infrastructure. Declines in both physical and social environments are important drivers of mental health problems (55, 56). In the face of long periods with little or no farm income, financial debt escalates (causing further emotional distress), and many are forced to seek employment off the farm to provide some income. This burden tends to fall on the women, who are generally already most responsible for managing the farm finances, running the home, and raising children. Off-farm employment that is close to home also becomes harder to obtain as the rural infrastructure declines due to population loss and economic stress (49). More young people tend to leave the land as well, perceiving farming as a less appealing way of life (61). The resultant loss of people, property, services, livelihoods, and history (especially for those whose ancestors farmed the same land for generations before) can trigger powerful feelings of chronic loss and fatigue, hopelessness, helplessness, despair, and generalised anxiety in those who remain and in those who are displaced.

Climate change will also affect seasonal and transient farm workers such as fruit pickers and sheep shearers. Increasingly stressful environmental conditions when working outdoors and increasingly unpredictable crop yields will have major impacts on their livelihoods, especially if they are paid according to productivity. As farms cease production or change their crops, the availability of work will decrease. Low farm incomes may also reduce hiring of short-term workers during busy periods in the farm cycle. Many transient farm workers base their livelihoods around the synchronicity of different crops, moving from one crop to the next as each matures at different points in the season. Climate change may seriously disrupt this synchronicity, with workers no longer able to sustain employment across the growing season.

Farming communities are often overlooked by government policies in response to climate change, which tend to focus on the preservation and enhancement of urban centres and their associated infrastructure. Yet the products of agricultural industries such as food crops and building materials underpin many economies, and the implications of declining agricultural populations and productivity may have critical impacts on global food supplies and the nutrition status of billions of people. The impacts of declining agricultural activity may also be exacerbated by the looming threat of increasing livestock and crop diseases, many of which are linked to environmental changes and climate-sensitive vectors and pathogens (62, 63). In addition to the detrimental impacts on food production, nutrition and potential livestock-to-human disease transmission, a substantial threat to worker health from agricultural diseases may come from the increased use of pesticides and other agricultural chemicals in response to disease outbreaks. As such, ongoing climate change will pose a continuing – and growing – threat to the health of workers in the agricultural industry.

Malnutrition and an underfed workforce

The importance of nutrition in the determination of numerous health outcomes, particularly protein, carbohydrate, and micronutrient intake, has been well studied and clearly linked (64). The ramifications of global food shortages and endemic malnutrition on working populations are not well understood and difficult to quantify, with significant short- and long-term consequences for both individuals and the societies they live in.

Scenario-based modelling consistently indicates that global food yields may be severely impaired by rising temperatures and drought conditions associated with climate change. It is projected that climate change will have a negative overall impact on global cereal grain yields. However, those impacts will occur unevenly. Countries in the tropics and subtropics, where both warming and reduced rainfall are likely to occur, are at greatest risk. Many studies indicate that South Asia is particularly vulnerable and likely to experience declines in cereal grain yields of the order of 10–20% by later this century (65, 66). The IPCC predicts that food yields in sub-Saharan Africa will decrease by about a third by the middle of the century (66).

Water shortages and the cost, quantity, and quality of feed will impair livestock production, lowering milk yields, body weights, and fertility. This will have consequences for rural family incomes and for nutritional status, especially if protein intake in young children becomes inadequate for normal development. The spread of infectious diseases such as bluetongue virus and influenza will also decrease the overall health of livestock (43, 67, 68).

The world's fisheries provide over 2.6 billion people with one-fifth of their average annual protein intake. On top of the documented decline in ocean fisheries by the international Millennium Ecosystem Assessment (69), a 2008 report by the World Fish Centre (70) concludes that climate 'shocks' such as coral reef damage, warmer ocean waters, acidification (due to the increasing uptake of carbon dioxide), and decreased river flows (a crucial source of recycled nutrients for both freshwater and ocean fisheries) will exacerbate the already serious problem of over-fishing. Along with nutritional deprivation, many livelihoods will be lost.

As crop yields drop and prices rise, malnutrition will increase in the most vulnerable groups. Again, the effects will not be equally distributed, with young children in developing countries most adversely affected. Development *in utero* and during the first 3 years of life is especially vulnerable to nutritional deficiencies, and most survivors of childhood malnutrition continue to suffer from poor health as adults (71). Studies have shown that adults who survive childhood malnutrition are physically small with reduced muscle development and reduced aerobic capacity, resulting in decreased strength and endurance, and leading to less productive adult lives (71, 72).

The Food and Agriculture Organisation of the United Nations (FAO) now estimates that around one billion persons are currently undernourished – a number that has actually increased by around 20% during this decade (73). Modelling by the International Food Policy Research Institute (IFPRI) has predicted that by 2050, worldwide, there will be approximately 138 million malnourished children under the age of five (65).

Malnutrition will undermine the strength, health, and productivity of current and future working populations. The consequences of malnutrition in early life are usually severe and often irreversible. They include physical deformity and weakness; delayed motor, cognitive, and behavioural development; increased susceptibility to infection and disease; and premature mortality. These effects lead to less productive lives as adults and a reduction of the potential workforce in future years. Malnutrition also reduces intellectual development and capacity so that children are less capable of benefitting from education (even if it is available) and, in the long-term, may result in declines in the skill and mental capacities of underfed populations in poorer countries (67, 71).

Outdoor workers will be strongly affected by current and future malnutrition as the physical demands of their jobs increase, but entire populations may be at risk if there are major food shortages as well as endemic malnutrition. Climate change will also increase the already heavy workload of women in developing countries who tend to bear the burden of high fertility rates, childcare, and household tasks (such as cooking), as well as contributing to farming activities. Cultural influences may exacerbate the effects of climate change on women's workloads, such as in the Sahel and Horn of Africa, where men often migrate during droughts and leave women alone at home to continue raising the children, working the fields, tending to livestock, and managing the home. Such demands will substantially decrease the ability of women on their own to provide proper care and nutrition to infants (74).

Conclusions

The potential impacts of climate change on working populations extend far beyond the more overt risks associated with direct exposure to greater extremes of heat. These non-heat-related impacts of climate change on working populations are many and varied with substantial impacts at all economic levels. Adverse impacts may be observed in both developed and developing countries, although it is likely that the latter will bear more of the burden due to endemic poverty and disadvantage. These impacts of climate change on working populations will vary greatly by location. Increases in vector-borne diseases may be significant in one location, while another population experiences food shortages and malnutrition. Elsewhere, some populations may be adversely affected by multiple non-heat-related challenges to worker health. Non-heat-related impacts of climate change are wide-ranging and will often have serious health and economic consequences. They should be taken into account in the future planning of adaptive strategies in working populations.

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