NARRATIVE REVIEWS

The Impact of Climate Change, Pollution, and Biodiversity Loss on Digestive Health and Disease

Desmond Leddin

Department of Medicine, Dalhousie University, Halifax, Nova Scotia, Canada

The environment is changing rapidly under pressure from 3 related drivers: climate change, pollution, and biodiversity loss. These environmental changes are affecting digestive health and disease in multiple ways. Heat extremes can cause intestinal and hepatic dysfunction. Access to adequate amounts of food of high nutritional content and to clean water is under threat. Extreme weather is associated with flooding and enteric infections and affects the delivery of care through infrastructure loss. Air, water, and soil pollution from chemicals and plastics are emerging as risk factors for a variety of intestinal diseases including eosinophilic esophagitis, metabolic dysfunction associated fatty liver disease, digestive tract cancers, inflammatory bowel disease, and functional bowel disease. Migration of populations to cities and between countries poses a special challenge to the delivery of digestive care. The response to the threat of environmental change is well underway in the global digestive health community, especially with regard to understanding and reducing the environmental impact of endoscopy. Individuals, and peer societies, are becoming more engaged, and have an important role to play in meeting the challenge.

Keywords: Environmental Change; Global Warming; Environmental Pollution; Biodiversity; Hepatology

Introduction

We live in a time of rapid environmental change driven by global warming, increasing pollution, and declining biodiversity. These 3 processes are interconnected and are impacting in compound ways on digestive health and disease. The purpose of this comprehensive review is to discuss the background to environmental change, the intersection with digestive health, to identify gaps in knowledge, and actions which may be taken. Table lists some key definitions and resources for readers interested in learning more and taking action, especially with regard to reducing the impact of endoscopy.

Global Warming, Pollution, and Biodiversity Loss

Global Warming

In 1856, Eunice Foote published her work on the effect of carbon dioxide (CO_2) on warming of air.[9] She described a series of experiments using sealed glass tubes containing thermometers. One was filled with CO_2 and another with air. The tubes were placed in sunlight, and she made the following observations: *"The receiver containing the gas (CO_2) became itself much heated—very sensibly more so than the other—and on being removed it was many times as long in cooling."* Foote had demonstrated that an increased concentration of CO_2 in air increases the temperature change caused by sunlight acting on a model of the atmosphere. She had discovered the basis of the greenhouse effect. Her second observation was that once the CO_2 enriched air warms up, it is slower to cool down than normal air. Both observations are fundamentally important to the situation we find ourselves in nearly 170 years later. CO_2 is just one of several greenhouse gases (GHGs), which include methane, ozone, nitrous oxide, water vapor, and synthetic hydrofluorocarbons.[5] The non-CO_2 gases differ in their warming potential and are often expressed in CO_2 equivalents (CO_{2e}).[2]

The greenhouse effect is shown in Figure 1. Incoming short wave solar radiation heats the surface of the Earth and oceans, which then radiate heat into the atmosphere in the infrared spectrum. Some of this heat goes back into space. GHGs, produced from a variety of sources, like those shown in the lower part of the figure, hold a proportion of this radiated energy in the atmosphere by increasing their molecular kinetic energy. This leads to atmospheric warming.

By the time the first Model T rolled off the assembly line in 1908, the science behind how GHG might cause warming had been worked out.[10] In 1938, the first report was published validating the theory of how GHG might cause atmospheric warming.[11] Fifty years later, in 1988, the testimony of James Hansen to the US Senate sounded the alarm that this warming might be a problem. While this may have been news to the public,[12] the connection between burning oil, and other fossil fuels, and a warming atmosphere was already well known to the petrochemical industry.[13]

Abbreviations used in this paper: **CO2e, carbon dioxide equivalent; COP, conference of the parties; GHG, greenhouse gas; GMST, global mean surface temperature; IBS, irritable bowel syndrome; IPCC, intergovernmental panel on climate change; MAFLD, metabolic dysfunction associated fatty liver disease; PM, particulate matter.**

Most current article

2772-5723
https://doi.org/10.1016/j.gastha.2024.01.018

Table. Key Definitions of Terms Used in Environmental and Climate Change Literature Links to Resources Which Show What can Be Done

Asylum seekers and refugees.[1]	Asylum seekers are refugees, who have left their own country and are seeking protection in another, while waiting for their claim to be decided. Refugees are people who have been forced to flee their country because of a fear of violence or persecution or because of natural disaster.
Carbon dioxide equivalent (CO_{2e})[2]	Carbon dioxide is the most abundant greenhouse gas, about 80%. Other greenhouse gases, like methane and nitrous oxide, differ in their warming ability relative to CO_2. To allow comparisons of combinations of multiple different gases, they are standardized to CO_2, and expressed as carbon dioxide equivalents, CO_{2e}.
Carbon footprint[2]	The carbon footprint is the total amount of greenhouse gases generated by all our actions, including our professional and personal lives. It is made up of several components, including the energy used in our homes, the food that we eat, the clothes that we wear, and the travel that we undertake.
Climate change[2]	Climate change is the long-term shift in the average patterns of weather in regions and globally. It is not the same as weather, which is much more short-term; climate change is measured over decades.
Conference of the parties (COP)[3]	This is an annual meeting of the parties who signed up to the Kyoto protocol. COPs occur annually with a goal of setting new policies and reviewing progress to date.
Cryosphere[4]	The cryosphere is the frozen part of the world's water resources. This is very important in modulating heat, and in controlling ocean levels and in providing water to large numbers of the global population.
Greenhouse gas (GHG)[5]	There are multiple greenhouse gases. Carbon dioxide is the most ubiquitous and comprises about 80%. Others include methane, nitrous oxide, and synthetic gases such as those used in anesthesia. What they have in common is the ability to hold heat in the atmosphere, which would otherwise be lost back into space. The retention of heat leads to progressive atmospheric warming and a shift in the mean temperature of the planet.
Global warming and global mean surface temperature (GMST)[2]	Global warming is the long-term shift in the temperature of the planet. It is often expressed as global main surface temperature change (GMST). GMST includes all areas of the planet including land masses and oceans. A rise of 1°C in GMST does not mean that every place will experience that temperature rise. Some will experience much more and some less.
International panel on climate change (IPCC)[6]	The IPCC is a United Nations body charged with informing the world's community on best scientific evidence with regards to the effects of climate change, how to mitigate it, and how to adapt to the challenge. The IPCC produces regular reports involving hundreds of international scientists, which are comprehensive summaries of the evidence.
Particulate matter (PM)[7]	Particulate matter, also known as particle pollution, is a term applied to the mixtures of solid particles and liquid droplets, which are sometimes found suspended in air. They are made up of hundreds of different chemicals and vary in size and structure. The particles that are less than 10 μm and diameter may be inhaled and there is particular concern over particles that are less than 2.5 μm and the subclass known as black carbon. This is the sooty material which is released from burning fossil fuels. When it is deposited on ice, it increases the absorption of solar energy. It is associated with important adverse health effects.
Paris Agreement[8]	In 1997, a protocol was signed in Kyoto, Japan by 192 parties to limit GHG emissions. The Paris agreement was signed in 2015 and set a target to keep warming below 2°C.
Sustainability	Sustainability means living within our means and not compromising the health and wealth of future generations by destroying critical ecosystems now. In practical terms, it means getting to carbon neutrality as quickly as possible. There are several sites in the digestive health community, which have excellent resources, showing how to move to sustainable practice. Some of these are listed here. The American society for gastrointestinal endoscopy (ASGE sustainable endoscopy at https://www.asge.org/home/resources/key-resources/sustainable-endoscopy) The British society of gastroenterology (BSG climate change and sustainability at https://www.bsg.org.uk/strategic-areas/climate-change-and-sustainability/) The world gastroenterology organization has a series of 18 short talks, which outline various aspects of the intersection between climate change and digestive health. https://www.worldgastroenterology.org/education-and-training/webinars/wgo-climate-course-for-global-gastroenterology

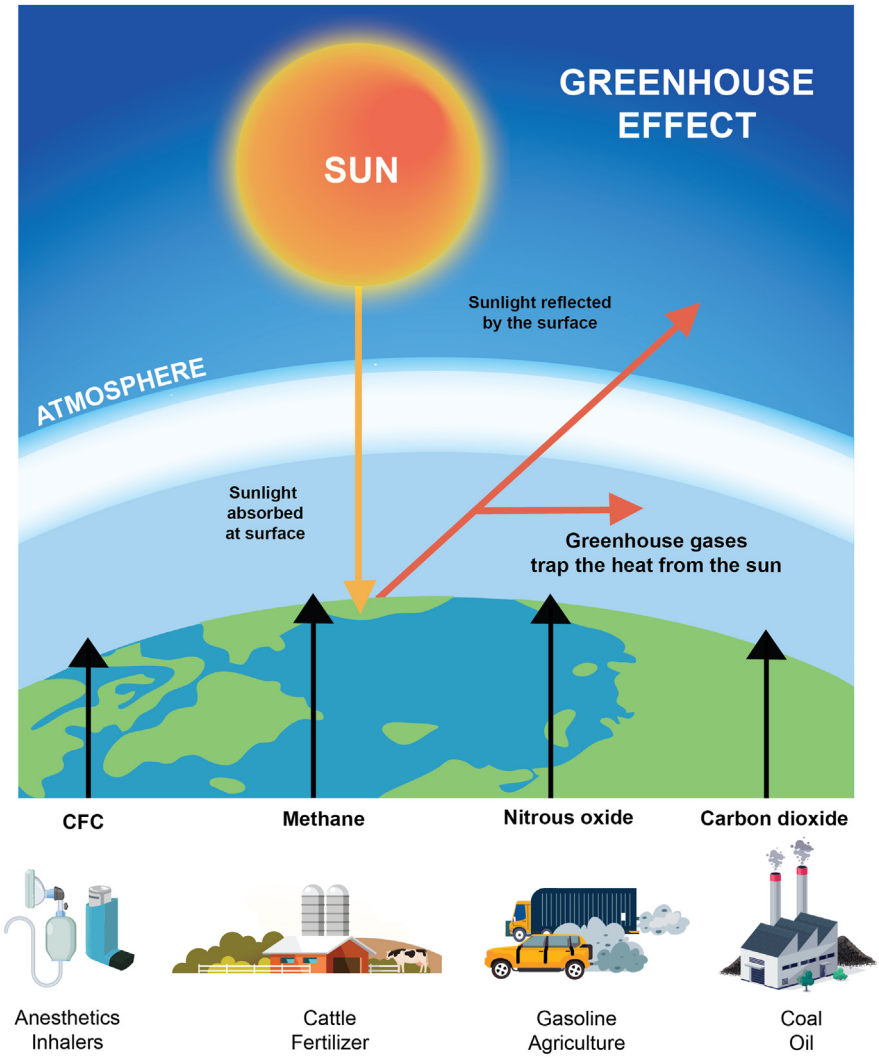

Figure 1. The Greenhouse Effect. Greenhouse gases (GHGs) reduce the amount of energy radiated from the Earth being lost into space. Some of the sources of GHG are shown in the lower figure. CFCs are ChloroFluoro-Carbons, commonly used in aerosol sprays, as solvents and refrigerants.

In the same year, 1988, the United Nations and the World Meteorological Organization founded the Intergovernmental Panel on Climate Change (IPCC).[6] The IPCC brings together scientists with a focus on climate and is the definitive source for data, projections, modelling, and guidance on adaptation and mitigation. In 2015, the United Nations negotiated an international treaty, the Paris Agreement, which aimed to keep global warming below 2°C, and preferably below 1.5°C.[8] It was estimated that to achieve this, global emissions of GHG needed to peak by 2025 and decrease by nearly half by 2030.

The target of limiting warming to less than 2°C was based both on scientific evidence and political pragmatism. It is, after all, not possible to conduct a controlled experiment on the earth to see what level of warming is safe. We now know that even with warming of less than 2°C, multiple tipping points, conditions under which self-perpetuating positive feedback loops begin, may be reached with catastrophic effects.[14] Tipping points can be visualized as dominoes, stable until a certain critical point is reached beyond which even a small change can cause the domino to fall. First described in 2008,[15] currently 9 global, and 7 regional, regional tipping points are described. One example is the Greenland ice sheet. Normally ice reflects some sunlight back into space. As ice melts, the reflective effect is lost, the exposed sea surface absorbs solar energy, and this leads to further warming and increased ice loss. Failure of these critical systems can have global effects and may occur relatively abruptly. Even leaving tipping points aside, it is becoming clear that the rise in Global Mean Surface Temperature (GMST) to date is already a problem as evidenced by more frequent reports of extreme climate events which now occur on a regular basis.

The less than 2°C target refers to GMST. This is the average temperature of the earth as whole, including the oceans and the poles. With an average global rise of 2°C, many regions will warm much more than 2°C with implications for local ecosystems and habitability. A third concern regarding the Paris agreement is that the treaty cannot be enforced, and countries are not meeting their obligations. So far not a single country has reached the level of reduction in emissions needed to keep warming within the goals of the agreement. Current pledges, even if they were delivered, will result in a rise of global temperature

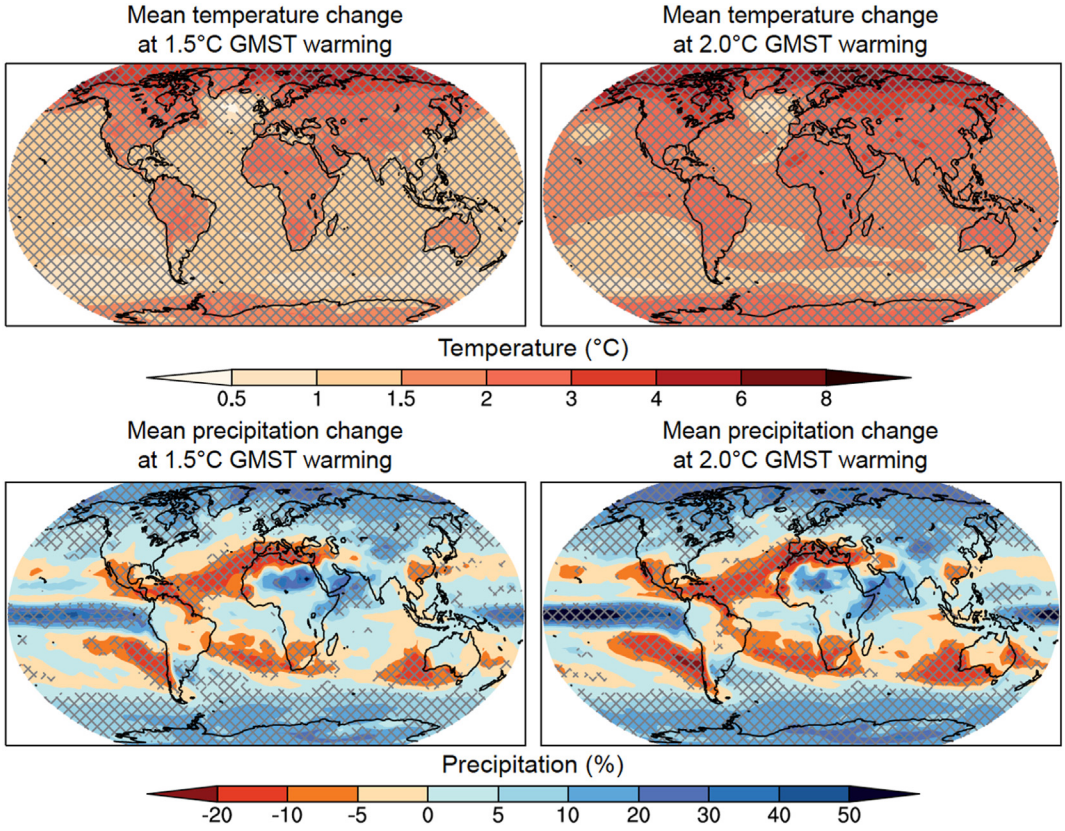

Figure 2. Top panels show the changes in surface temperature as GMST reaches 1.5°C and 2.0°C above preindustrial. The lower panels show the corresponding change in precipitation.[19] Reproduced with permission from Intergovernmental Panel on Climate Change (IPCC).

of +2.4°C–2.6°C by 2100,[16,17] a level which will have severe consequences for all life on earth.

The carbon footprint is the amount of CO_2 attributable to each person and activity. It is sometimes expressed in CO_{2e} where the $_e$ stands for equivalent. GHGs other than CO_2 such as methane, which differ in warming potential, are referenced to CO_2 and the combined value is expressed in equivalents.[2] It is closely related to Gross Domestic Product, which is a measure of national wealth. In 2022, the carbon footprint was 14.9 tonnes (t) of CO_2 per person per year in the United States, in China it was 8.0 t, India 1.9 t, and for comparison in Ghana it was 0.6 t. However, this does not consider population number. When that is factored in, China was the world's largest producer of CO_2, emitting 11.4 Giga Tonnes (Gt), followed by the United States at 5.01 Gt, and India at 2.83 Gt. Yet another way to look at it is to consider the national cumulative share of emissions to date. In this case, the United States was responsible for 24.1%, China 14.7%, and India 3.4%.[18] Global average per capita emissions were 4.7 t of CO_2 in 2019.

GMST is already more than 1°C above preindustrial temperature. The IPCC has produced maps of what the world will look like as the planet warms further.

The maps in Figure 2 are a future vision of which parts of the planet will experience severe water and temperature stress as the planet moves though a 1.5°C and then a 2.0°C GMST rise, and which parts will remain relatively unscathed, at least in the short term. As GMST continues to rise past 1.5°C all land areas, and especially the Arctic, will see increases in temperature. The oceans, which up to the present have buffered much of the rise in land temperature, will also show increasing temperatures. Two bands of decreasing precipitation (lower panels), already apparent at 1.5°C, will become more pronounced. These changes will profoundly affect the growth of food, access to water, rainfall, storm events, and the habitation of billions of people.

Climate change is closely linked to 2 other processes namely biodiversity loss and pollution. For example, when forests are cut down to produce pastureland for cattle, there is a loss of the ability of the forest to sequester CO_2. Cattle produce methane, which is a potent GHG. Manure from cattle herding pollutes rivers which results in decreased quality and usability of water. The loss of forest habitat reduces biodiversity with all the negative implications which come from that, including increased exposure to pathogens, decreased production of crops, and decreased quality of water.[20]

Pollution

Pollution can be defined as the presence in, or introduction into, the environment of a substance or any form of

energy at a rate faster than it can be handled in a harmless form.[21] Pollution can occur from natural causes, such as wildfires, but the term is usually applied to air, water, and land contamination by anthropogenic action, often involving chemicals. A recent inventory of chemicals on the market suggested that as many as 350,000 chemicals and mixtures of chemicals have been registered for use. The identities of many are unknown.[22] An estimated 9 million deaths are attributable to the health effects of well-studied pollutants, that is the ones we know about.[23] The production of novel entities has greatly exceeded our ability to measure their impact.[24] The digestive tract is vulnerable to pollution given its physiologic role in ingestion and metabolism. Ingestion is not a prerequisite for pollution to affect the digestive tract; some inhaled pollutants are circulated in the body systemically and reach the intestine and liver through the circulation. Children may be especially vulnerable to the effects of pollutants.[25] There is a concern that pesticides such as the herbicide glyphosate may be involved in the etiology of neurodegenerative disease such as Parkinson's and that the effects may be mediated via the gut microbiome.[26] Although some progress has been made in reducing deaths from household air pollution and water pollution, these have been offset by increased deaths from ambient air pollution and toxic chemicals.[23,27]

Biodiversity Loss

Biodiversity is the variety of life on Earth; it includes all organisms, species, and populations; the genetic variation among these; and their complex assemblages of communities and ecosystems.[20] There may be as many as 9 million types of plants and animals, protists, and fungi on the earth.[28] Increased biodiversity is beneficial; it improves crop yield, fisheries yield, contributes to biocontrol of pests, resistance to plant invasion, disease prevalence in animals, carbon sequestration, pollination, and water purification.[28] Biodiversity loss increases the risk of the emergence of novel infectious disease, as species and habitat loss increases.[29] Biodiversity is in rapid decline due in part to climate change and pollution. In addition, invasive alien species are being introduced to all regions and biomes of the world.[30] Invasive species can cause irreparable damage and extinction to native species and biodiversity of systems. This affects the ability of ecosystems to function optimally with negative implications for water and food security, and disease transmission to humans,[30] and threatens the achievement of the United Nations Sustainable Development goals.[31]

Compound Events

Compound weather events are those in which more than 1 hazard occurs simultaneously.[32] For example, a dry spring combined with a hot, dry summer in 2010 led to wildfires causing more than 50,000 deaths and destroying 25% of Russian crops.[33] These compound events may become more frequent as climate change advances. Similarly, climate, pollution, and biodiversity events often occur together as compound environmental interactions.

Implications of a Changing Environment for Health

The health implications of our changing climate are increasingly appreciated.[34,35] Climate change is increasingly seen as a health crisis demanding a public health response.[36] Climate change will exacerbate global inequities since the effects of climate change on health will be felt most severely in low-income countries, which have contributed least to the problem, and in vulnerable populations such as children,[25] older adults, in pregnancy, in people with chronic illness or disability, and in lower socioeconomic groups.[36,37] Climate change threatens to derail the progress which has been made on virtually all the United Nations Sustainable Development Goals. However, the situation is by no means hopeless. There is a great deal which health systems can do to reduce emissions, break the cycle of healthcare-induced environmental harm, and build resilience.[38]

Impacts of Environmental Change on Digestive Health

The direct and indirect health effects of environmental change will affect every organ system, including the digestive tract.[39–41] Figure 3 shows the relationship between a changing environment and effects on the digestive system.

Direct and Indirect Effects of Heat on Intestinal Tract and Liver

Direct Effects

GMST has increased by at least +1.1°C since 1880 and the planet is continuing to warm at +0.15°C–0.2°C per decade. This may not seem like a lot, but it is. A 1°C–2°C drop in the past was enough to produce an ice age.[42] Future temperature change depends on how aggressively we pursue carbon reduction. It is still possible to hold global warming to less than 2°C by the end of the century but if we carry on as at present temperatures as high as +5°C above those measured between 1850 and 1900 are possible.[43] Humanity may be facing extinction if GMST reaches that level.

Temperature change is more complex than simply a change in GMST. Humidity, the amount of radiant heat, access to shade, and the health status of people and animals exposed are also very important. From a physiologic perspective it may be that metrics other than mean temperature, such as days with temperatures exceeding 40°C, are more important than simple mean temperature rise. The IPCC has produced an interactive atlas which allows users to

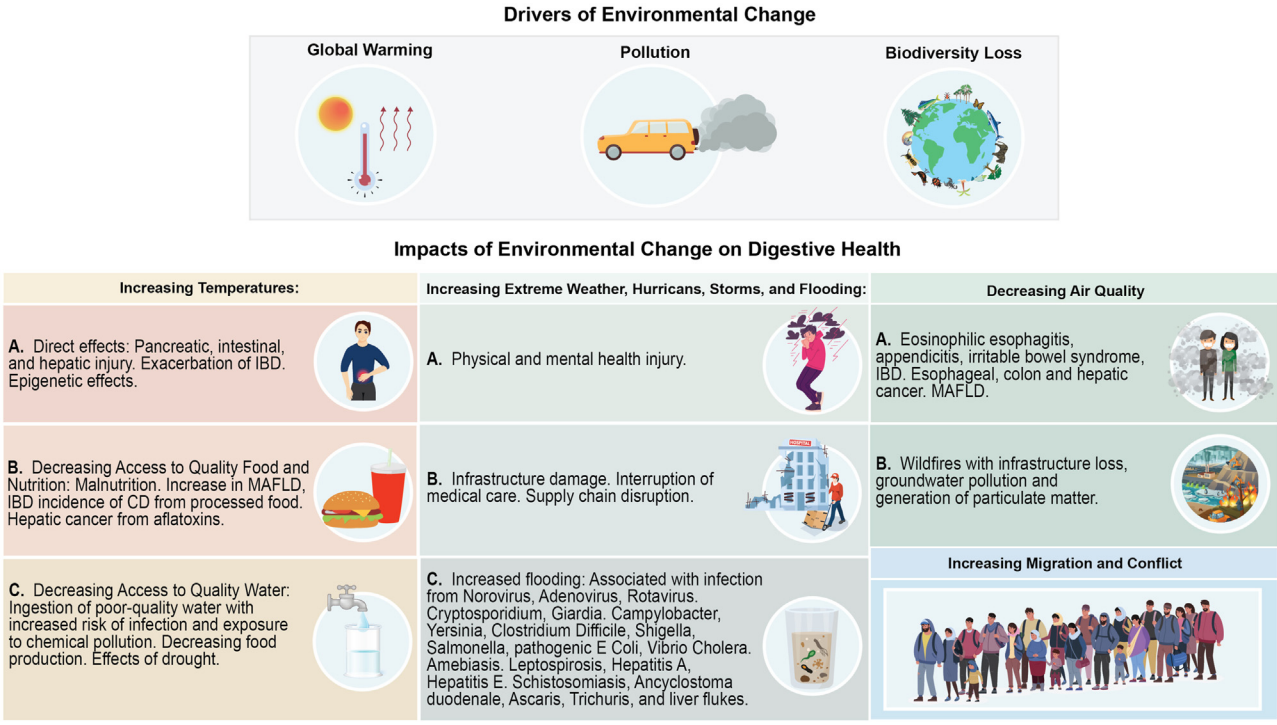

Figure 3. The effects of a changing environment on digestive health. Global warming, pollution, and biodiversity loss are raising temperature, increasing extreme weather, and decreasing air quality. These effects are linked to a variety of digestive health disorders.

explore climate datasets and projections by region.[44] This simplified tool lists 12 heat-related parameters.

Acute heat stress causes intestinal lesions in mice[45] and has been linked to the development of pancreatic, intestinal, and liver damage in humans.[46] Changes in intestinal permeability may be an important factor in the systemic inflammatory response associated with heat stroke.[47] The liver is also susceptible to heatstroke.[46,48] The mechanism may be a combination of changes in perfusion because of vasoconstriction and a systemic inflammatory response. The pathology of heat-induced liver damage has been described; centrilobular necrosis is prominent.[49] In animal models, exposure to elevated environmental temperature changes intestinal morphology and growth rates.[50] A retrospective study suggested that there may be a link between heatwaves, flares of inflammatory bowel disease (IBD), and infectious gastroenteritis.[51] There are no data on the effect of a shift in mean temperature of moderate degree on intestinal or liver health but there are reports of even short-term temperature change affecting DNA methylation, raising the possibility that environmental change may alter epigenetics.[52]

Decreased Access to Food and Nutrition

Even before the onset of the most severe effects of environmental change, more than 700 million people are undernourished, 2.4 billion are moderately or severely food insecure, and 258 million are experiencing crisis-level food insecurity.[53] While many in the world experienced food insecurity, nearly 2 billion people were overweight and 650 million were obese in 2016.[54]

More than a quarter of the world's GHG emissions come from food.[55] Agricultural activities release CO_2, methane, and nitrous oxide. Methane is a potent GHG released by enteric fermentation of ruminant animals and from manure storage sites. Nitrous oxide accounts for about half the warming effect of agricultural emissions and is produced by microbial metabolism of soil nitrogen[56] which is added to soil as manure or fertilizer to increase crop yield. Agriculture requires large amounts of water; agricultural runoff contributes to pollution and eutrophication. Half of the world's landmass is used for agriculture with resultant loss of wilderness and biodiversity. The food industry is certainly part of the problem but conversely, it can be an important part of the solution.

Increased CO_2 in the atmosphere may promote the growth of some crops and a warming climate may increase the length of the growing season in some regions. However, higher temperatures may lead to more rapid crop maturation, reducing the maximum potential yield and nutrition value of crops. Overall, the effect of climate change on agriculture, fisheries, and aquaculture is negative.[57] The net effect of climate change will be to put further pressure on global food production from both land and oceans.

Changing diet can be part of the solution. GHG emissions per kilogram of food produced vary from nearly 60 kg of

CO_{2e} per kg of beef, to 0.4 kg of CO_{2e} per kg of root vegetables.[58] Increased consumption of meat is associated with an increased risk of cardiovascular disease. It may be possible, therefore, to improve both human and planetary health by switching to a more plant-based diet. In 2019, the EAT-Lancet Commission proposed a diet which would meet nutrition needs, improve health, and reduce the climate impact of agriculture.[59] The Commission concluded that substantial dietary shifts are needed with a more than 50% reduction in red meat and sugar and a 100% increase in consumption of foods such as nuts, fruits, and vegetables. In addition, food losses will need to be reduced and combined with improvements in food production. Climate change may force dietary habits in the wrong direction, resulting in a reduction as much as 4% reduction in fruit and vegetable consumption, which will be linked to increased mortality.[60]

Food insecurity is not confined to low-income countries.[61] It is common even in high-income countries. This may become more problematic as climate change advances due to decreases in areas available for cultivation and variability in the growing season. This may result in higher prices in some regions. Famine from drought likely will increase in frequency. Food insecurity may be associated with an increased risk of nonalcoholic fatty liver disease.[62,63] Food insecurity and a change from traditional diet may result in consumption of more processed food, which has been linked to a higher risk of Crohn's disease.[64]

Pollution of soil can occur through industrial or domestic activities and results in an estimated 1 million deaths per year even if lead toxicity is excluded.[23] More than 1 billion pounds (454 million Kg) of pesticide are used in the United States each year and 2.5 billion Kg globally.[65] Pesticides include herbicides, insecticides, and fungicides. These chemicals are biologically active and can alter the gut flora in animal models.[66] Their role in the possible pathogenesis of human enteric or liver disease is unclear, although concerns have been raised about the involvement of herbicides in neurodegenerative disease possibly mediated through gut microbiome change.

Plastics are ubiquitous pollutants of water, soil, and air. Global plastic production is now estimated at 400 million tonnes per year.[67] More than 4200 chemicals are associated with plastic packaging, 69 of which rank highest for human or environmental health hazards.[68] Plastics may exert biological effects.[69,70] They can mimic hormones, attract, and concentrate other chemicals.[71,72] Phthalates can induce hepatic biochemical change[73] and microplastics have been postulated to be involved in the pathogenesis of IBD.[74]

Decreased Access to Water and Lower Water Quality

Half of the world's population is experiencing severe water scarcity for at least 1 month per year.[57] As the climate crisis builds momentum, it threatens to make the global situation regarding water even worse. Figure 2 (lower panels) shows the projected changes in precipitation as temperature rises. Clearly, many parts of the world, some of which are already under severe water stress, will experience increasing difficulties in accessing adequate amounts of high-quality water for agriculture and human habitation. In addition, in some coastal areas, access to freshwater will be decreased by rising sea levels, and encroachment of the freshwater table by seawater. Many areas of the world will become uninhabitable because of water shortages.

Annual rainfall amounts may remain stable, or even rise, in a region but if the precipitation occurs at the wrong time for crops, irrigation, aquaculture activities, human consumption, and transport, the effects may be severe. Drought and flood risks will increase as warming increases with the likelihood of extreme agricultural droughts doubling as GMST reaches $+1.5^{\circ}C$ above preindustrial levels.[57]

Water insecurity, as with food insecurity, affects vulnerable populations and regions more severely than those with more resilience, resources, and ability to adapt.[75] Income is a major determinant of health. The impact of climate change on water is projected to decrease global domestic product with the most severe effects in low-income and middle-income countries.[57] This will make a challenging economic situation even worse. Decreasing availability of water will be associated with enteric infections[76] as populations are pushed to consume water of lower quality, which may be tainted by pollutants or microbiological agents.

In addition to water quantity, water must be of good quality, and free of chemical and biological contaminants. Climate change, by altering the regional availability of water, will combine with reduced water quality from pollution to exacerbate water scarcity.[77] Drought is associated with malnutrition, bacterial, and algal bloom–related illness, migration, mental health disturbances, and wildfires.[78] Eutrophication is the overabundant growth of organisms such as algae from excess nutrients. The growth of cyanobacteria and exposure to microcystins is associated with hepatic toxicity and possibly with an increase in liver cancer.[79]

Progress has been made in reducing water pollution and waterborne disease. From 1990 to 2012, the number of children dying from diarrheal illness decreased by 60%.[23] However, an estimated 2.4 billion people are still using unimproved sanitation facilities, and nearly a billion still practice open defecation with obvious threats to water supply from infection. The World Health Organization estimates that globally at least 2 billion people use a drinking water source contaminated with faeces.[80]

Pharmaceuticals in drinking water are a potential concern.[81] Other chemicals may, or may not, have a biological effect, but pharmaceuticals are designed to be biologically active. Their potency and effects can vary between species. Fortunately, unlike many of the chemicals used in industrial processes, the biological action and toxicity of pharmaceuticals is generally well understood as is required for therapeutic approval, and there are methods available to

test for the presence of their concentrations in water. Some studies, including a World Health Organization review, have concluded that appreciable adverse health effects to humans are unlikely from exposure to trace concentrations of pharmaceuticals, which could potentially be found in drinking water.[81,82] However, there continues to be concern since a wide variety of drugs, many with the potential to affect gut flora, are detectable in waste water.[83] Their effect on gut flora and intestinal function is not known.

Oceans and Cryosphere

The oceans cover more than 70% of the Earth's surface and the cryosphere an additional 10%.[4] These water bodies play a critical role in shaping global weather and rainfall distribution, food production, water supply, economics, culture, and transportation. The oceans have thus far taken up more than 90% of the excess heat, and most of the CO_2, in the climate system and have buffered the rise in land and air temperature. The energy released by the Hiroshima bomb, an obscene metric but one which can be visualized, is estimated at 63×10^{12} J. The oceans are currently absorbing the equivalent of 5 Hiroshima bombs per second.[84] Putting this amount of energy into the oceans, which are a major driver of global weather and climate, has produced significant changes and contributed to the development of more extreme weather including droughts, heavy precipitation, and tropical cyclones.[85]

The cryosphere includes the Arctic, Antarctic, glaciers, high snowpacks, and permafrost and is an important source of water, and GHG sequestration. Mountains are considered the water towers of the world. They are vulnerable to climate change and the water access of as many as 1.9 billion people may be negatively affected as a result of environmental change.[86] Mountain areas also contain a third of the entire species of terrestrial diversity.

Global mean sea level is projected to continue to rise regardless of how aggressively emissions are reduced. Under a medium-low emissions scenario, the sea will rise by 0.43 m, by 2100, compared to 1986–2005.[4] One billion people currently live on land less than 10 m above the high tide mark, 230 million live less than 1 m above.[87] As a result of rising seas, many of the world's inhabitants and major cities are at risk from sea level rise. The oceans contain complex ecosystems[88] and are susceptible to pollution and biodiversity loss. Fish is an important part of nutrition; it supplies at least 16% of global protein intake.[89] Warming and acidification of the oceans is projected to decrease fish stocks, putting further strain on global access to nutrition.[4]

Extreme Weather, Hurricanes, Storms, and Flooding

Hurricanes, cyclones, and typhoons are the very visible face of global warming. There were hurricanes before there was global warming, of course, and this makes attribution of a shift due to climate change difficult with certainty.[90] The effect of warming is not so much to create novel phenomena, although that has been described for wildfires, but to make weather events more extreme and possibly more frequent. Warmer oceans are leading to the formation of more powerful storms with higher wind speeds and more rainfall.

The adverse health effects of hurricanes include physical and mental illness, flooding, infections, infrastructure damage, supply chain disruption, interruption of care, and pollution.[91–94] In addition, the economic impacts of hurricanes and cyclones are enormous. Hurricane Katrina resulted in 1200 deaths, and an estimated USD 75 billion in damages in the New Orleans area alone.[95]

Flooding

Flooding, in conjunction with hurricanes or simply from severe rainfall, poses a significant risk of enteric infections[92] as drinking water, sanitation, and waste disposal systems may be disrupted.[96] Enteric infection post flooding can occur from direct water contact, consumption of flood water, or from ingestion of contaminated groundwater. Even in developed countries, many people depend on groundwater for supplies, 23 million households rely on private wells for drinking water in the United States.[97] Norovirus, Adenovirus, Rotavirus, Cryptosporidium, Campylobacter, and Yersinia infections have been reported from groundwater contamination in developed countries.[96] In the mid-western US exposure to floodwater was associated with an increase in gastrointestinal symptoms, especially in children, and this was not related to the public water supply.[98] A connection between Clostridium difficile and flooding has been reported in Massachusetts[99] where flooding was associated with an increase in emergency room visits for digestive complaints.[100] A wide range of enteric and hepatic pathogens should be considered post flooding including Shigella, Salmonella, Campylobacter, Cryptosporidium, Giardia, Leptospirosis, pathogenic E Coli, Amebiasis, Hepatitis A, and Hepatitis E.[100–105] The conditions in shelters following climate events are favorable for the spread of enteric viruses. More than 1000 patients were treated for gastroenteritis at a shelter in Texas following Hurricane Katrina.[106] Norovirus was the sole pathogen and multiple different strains were identified. In lower income countries, the risks from flooding are even more severe. Floods in Bangladesh in 2004 resulted in more than 350,000 cases of diarrhea and more than 200,000 wells were damaged.[107] Cholera and typhoid are a particular concern from contaminated water and food.

Infrastructure and Supply Chain Disruption

Provision of digestive healthcare, liver care, and endoscopy is reliant on human resources, technical resources, intact infrastructure and supply chains, patient access to facilities, and the provision of emergency services. All of

these steps can be disrupted by severe storm events[91] and wildfires. Health systems may not be prepared for future climate challenges. For example, it has been estimated that in nearly one-third of the metropolitan statistical areas in the Atlantic and Gulf coasts of the United States, 50% or more of the hospitals are at risk of flooding.[108] Increasing the resilience of supply chains to extreme weather is important in maintaining the ability to deliver care[109] and supplies of medications.[110]

Air Quality

Air pollution can occur from gases, liquids, or solids. Particulate matter (PM) solids are a particular concern. They vary in size, composition, and source and include pollen, nitrates, organic carbon, mineral dust, metals, ions, black carbon, and biological particles such as bacterial fragments.[7] They are classified by size in microns. Car tires and brake pads are an important source. The particles are small enough to cross alveolar membranes and reach the systemic circulation where they can cause inflammation in various organs. The risk associated with exposure to some forms of air pollution, such as PM, can be determined from excess mortality data after exposure.[111] However, linking the effects of air, water, and land pollution to changes in digestive health is challenging. Levels of exposure may be uncertain; there are variations in exposure level and individual susceptibility, long latency times, exposure to multiple different components in differing concentration, geographic variation,[112] and the effects may vary with age of exposure.[113]

There is evidence from both animal and human studies that inhalation of PM can change gut flora.[7] There are possible associations between air pollution and eosinophilic esophagitis,[40] peptic ulcer disease, appendicitis, hospitalization with abdominal pain, irritable bowel syndrome, and IBD.[7,114] IBD shows both a positive association of air pollution with flares[115] and a negative association with incidence.[116] The relationship between air pollution and IBD is complex and awaits further clarification. Exposure to PM $< 1\mu$, PM2.5μ, PM10μ, and NO_2 has been associated with an increase of metabolic dysfunction associated fatty liver disease.[117]

Wildfires

Wildfires are increasing in frequency and severity. The main burden of illness associated with fires is on cardiac, respiratory,[118] and mental health[119] and there is no clear signal for digestive illness. However, given the potential for products of wildfires, and the chemicals used to treat them, to contaminate air, drinking water,[120] and food supplies, it is possible that digestive health will be affected. In recent years, major urban cities have needed to be evacuated because of encroaching fires resulting in health system disruption.[121] The Australian fires of 2019 and 2020 may have killed or displaced 3 billion animals (143 million mammals, 2.46 billion reptiles, 180 million birds, 51 million frogs). It is unclear if the biodiversity of the affected areas can recover. Wildfires are emerging as a significant contributor to black carbon and $PM_{2.5}$-related mortality.[122]

Effects on Existing Digestive Disease

Digestive Cancer

Climate change and pollution can affect cancer incidence through air pollution, changes in nutrition, exposure to chemical pollutants, and possibly changes in infectious disease.[123] Colorectal, gastric, and liver cancer are important contributors to global morbidity and mortality.[124] Gastric cancer incidence has been linked to environmental factors,[125] air pollution to small intestinal and anal cancer,[126] and sulfur dioxide and ultraviolet blocking aerosols to the risk of colon cancer.[127] A dose-dependent increase in the hazard ratio for esophageal cancer has been shown for exposure to PM2.5[128] which may also contribute to an increased risk of colorectal and liver cancer.[129]

Water can be contaminated with chemical or biological material. Naturally occurring chemicals such as arsenic are linked to the development of intestinal cancer.[130] Many more chemicals reach the water supply through industrial processes or mining. Their contribution to the development of intestinal and liver cancer is not known with certainty. Aspergillus flavus thrives in a warm, most environment, the kind of conditions which are projected to increase in distribution. The fungus produces aflatoxin, which causes hepatocellular injury and hepatocellular carcinoma and may increase the carcinogenic risk from Hepatitis B.[131] The toxin can be found in several crops including maize, peanuts, pistachio nuts, and cotton seeds.[132] Modelling studies suggest an increase in exposure to the toxin as the climate warms.[133] Climate change and pollution are not only increasing the risk of some cancers but may also be impacting screening, diagnostics, and the ability of facilities to function in cancer care.[134]

Infections

Climate change will affect the prevalence and incidence of infectious disease[135] and some human helminth infections including schistosomiasis, Ancyclostoma duodenale, Ascaris, Trichuris, and liver flukes.[136] Changes in water temperature in the North American Pacific and Atlantic Ocean have been linked to the appearance of Vibrio species.[137]

Functional Bowel Disease

Irritable bowel syndrome (IBS) in children has been associated with a variety of air pollutants[138] as has hospitalization for nonspecific abdominal pain.[139] It is possible that toxins may trigger IBS symptoms. Another possible pathway is that climate anxiety is prevalent[140] and anxiety is associated with functional gut disorders.

Migration and Conflict

Migration, both between and within countries, is an adaptive response to a changing environment. Climate change, pollution, and biodiversity loss will drive populations to move in search of a more habitable environment. Already more than 1 billion people are on the move, of whom 281 million are international migrants, and 84 million are forcibly displaced. Among these are 35 million children, 26 million refugees, and nearly 5 million asylum seekers.[1] Many voluntary migrants move under planned conditions. However, forced or involuntary climate migrants are at risk of worse health outcomes because of difficulty in accessing care in the countries of transit and destination.[141–143] Also at increased risk are those who, by virtue of their personal or national circumstances, are unable to migrate. These are termed immobile. Children, the elderly, and the ill may be left behind as younger members of the community leave. Cities will come under increasing pressure as migration from rural areas to cities will increase. By 2050, 143 million people in Sub-Saharan Africa, South Asia, and Latin America will be internally displaced.[144] This will place enormous strain on transportation, sanitation, delivery of water and nutrition, and delivery of intestinal and liver care. As populations move and compete for resources, the potential for conflict increases.[145]

The Response to the Challenge

The Political Response

The progress which humanity has made in the era of petrochemicals has been extraordinary but at a terrible cost to the environment and future generations.[146] The transition away from a fossil fuel–based economy will require a profound transformation in the way we all live and that is a tough task. Decoupling economic growth from GHG emissions remains a challenge even in high-income countries.[147] Very much at the heart of the political problem is that each country and each economy is starting from a different place, and each wants to achieve a comparably high level of income and living. Developing economies argue that they did not create the problem and that they have the right to prosperity as well as high-income countries. The global political response to meet the challenge requires a degree of cooperation and trust which is not evident, it is clearly failing. Current output of all greenhouse gases is higher than when the Paris agreement was signed in 2015.[18] It is possible that technological change,[148] geoengineering, or the lawsuits against governments and corporations will help solve the crisis but it seems unwise to rely on technologies, which have not yet been developed, or the courts for a solution. There are some signs of movement in the right direction. Congresses of the Parties (COP) to the Paris agreement are held annually. At COP27, it was agreed that a fund should be established for loss and damage in vulnerable countries,[3] and at COP28, there was agreement on the need to transition away from, even if not phase out, fossil fuels.

Why Digestive Healthcare Providers Should Engage

Even if politicians are not yet able to grapple with the issue, it does not mean that healthcare providers should stand by. We have an ethical duty not to harm patients.[149] We know that healthcare, and digestive care as part of that, is a significant contributor to GHG emissions, contributing more than 5% of national totals in many countries[150,151] and more than 8% in the United States.[152] We also know that GHG emissions are damaging health. While we cannot eliminate the carbon footprint of care, we have an ethical duty to reduce emissions as much as possible to minimize harm to patients. There is also an ethical issue of intergenerational justice. It is unjust to pass on the burden of our unsustainable behavior to future generations.[153] In addition, physicians have professional duties of advocacy and leadership.[154] If those arguments are not persuasive, there is evidence that action on climate change makes economic sense.[155] Environmentally responsible practice, like segregating waste, is not only good for the environment but it saves healthcare costs as well.[156] Leaving professional obligations and economics aside there is the issue of self-interest. If emissions continue at the present rate, our families, and societies, will be facing an existential crisis by the end of this century, if not sooner.[2] Silence from healthcare providers on this issue may be interpreted as a signal that there is no cause for concern so it is important to engage.

Digestive Health Response

Physicians tend not to act if they feel that they lack competence. One good starting point to gain confidence, and competence, is to educate oneself on the issue. An online course for digestive health providers has been conducted by the World Gastroenterology Organization;[157] short summaries of the 20-minute talks have been published as a series and are easily readable.[158]

There are then many actions which can be taken in both personal and professional lives.[25,159] While it is true that the impact of any single person is very small, but so is the impact of any one vote. Individual action sends a signal to family, friends, patients, community, professional societies, and politicians that this issue is important. Individual action in the workplace can help change facility culture and contribute to system change.[160] Climate activism is not without potential professional risks, which need to be appreciated and discussed.[161]

Professionally, endoscopy is an obvious way to engage either on one's own or with fellow clinicians. Many practical steps can be taken a more sustainable practice, which even have the potential to save money. Endoscopy unit leaders

are best placed to make changes, but individual practitioners can also drive the process. Endoscopy is practiced by most gastroenterologists and hepatologists, is associated with significant use of disposables and waste,[156] and lends itself to quality improvement.[162] The carbon footprint of endoscopic practice is being measured[163–166] and will allow evidence-based sustainability decisions. Segregating and reducing waste from endoscopy will not save the planet but it may trigger change in a unit or hospital system with bigger ramifications. The British Society of Gastroenterology, the European Society Gastrointestinal Endoscopy, and the American Society of Gastrointestinal Endoscopy have published guidance for endoscopy practitioners, which make it easy to begin the process of reducing emissions.[167–169] About two-thirds of the carbon emissions of healthcare are generated not by direct clinical care but by the supply chain[170] which reinforces the need to engage with industry.[171] Individuals in a leadership position in endoscopy, including nursing and management colleagues, can raise the issue with industry and factor sustainability into procurement decisions.[172]

Digestive healthcare providers in education leadership roles can educate trainees, influence national accreditation organizations to make this issue part of the curriculum, and emphasize the health co-benefits of climate action.[173] For researchers, the quote attributed to Einstein that "in the midst of every crisis lies opportunity", could not be more true. The issue of how environmental change is affecting digestive health, and of how mitigation, adaptation, and resilience building can best be achieved, needs increased research study.[174]

Once educated and acting physicians can be effective advocates for change and influence their personal networks, professional colleagues and peer societies, the public, patients, and politicians.

Professional societies have a key role to play since practitioners rely on them for education, advocacy, research support, and leadership.[174] They are also in a good position to influence politicians.[175] They can use their influence to change practice, to help practitioners reduce emissions, outline best practice on adaptation, and help build system-wide resilience. Without an educated gastrointestinal (GI) workforce, advocacy efforts for change will be limited. In a survey of global Gastroenterology leadership, leaders indicated that they personally believe that climate change is close to crisis, but the issue is not a priority for their GI society. A minority of professional societies has education programs for members, and 80% believe that their societies have more pressing priorities.[176] Barriers to engagement included financial concerns (such as loss of revenue from annual meetings), structural (a lack of administrative or educational support), and psychological blocks, which are characteristic of the response to the climate crisis.[177] Clearly there is much to be done before the full resources of professional societies are engaged in meeting the challenge. All these barriers can be addressed if GI society leadership understands the threat of environmental change, the implications for digestive health, and can build membership support.

Conclusion

The response to the challenge of environmental change is underway globally in digestive health. Sustainability committees have been formed in many health facilities and societies. Sustainability plans have been developed in several national and international professional organizations.[178] The topic is increasingly appearing on the agenda for professional society educational meetings. Globally carbon emissions have peaked and begun to decrease in many countries; the cost of renewable energy continues to fall and is competitive, or less expensive, than fossil fuels in many areas. The tide is beginning to turn but Eunice Foote's second observation, that atmospheric CO_2 not only heats the air but holds the heat, means that the time for ignoring this problem is long gone. We can meet this challenge but not by ignoring it. The digestive health community, both individually and collectively, has an important role to play.

References

1. World Health Organisation. Refugee and migrant health, 2022. Available from: https://www.who.int/news-room/fact-sheets/detail/refugee-and-migrant-health. Accessed January 2, 2024.
2. Leddin D, Montgomery H. The fundamentals: understanding the climate change crisis. Gut 2023;72(12):2196–2198.
3. Five key takeaways from COP27: United Nations Climate Change. [cited 2023 December]. Available from:. 2022 https://unfccc.int/process-and-meetings/conferences/sharm-el-sheikh-climate-change-conference-november-2022/five-key-takeaways-from-cop27. Accessed March 20, 2024.
4. IPCC. IPCC, 2019: Summary for policymakers. In: Pörtner H-O, Roberts DC, Masson-Delmotte V, et al, eds. IPCC special report on the ocean and cryosphere in a changing climate. Cambridge, UK and New York, NY, USA: Cambridge University Press, 2019:3–35.
5. US Environmental Protection Agency. Overview of greenhouse gases, 2023. Available from: https://www.epa.gov/ghgemissions/overview-greenhouse-gases. Accessed January 2, 2024.
6. IPCC. History of the IPCC. Available from: https://www.ipcc.ch/about/history/#:~:text=The%20Intergovernmental%20Panel%20on%20Climate%20Change%20(IPCC)%20was%20established%20by,UN%20General%20Assembly%20in%201988. Accessed January 2, 2024.
7. Vignal C, Guilloteau E, Gower-Rousseau C, et al. Review article: epidemiological and animal evidence for the role of air pollution in intestinal diseases. Sci Total Environ 2021;757:143718.
8. United Nations. The Paris Agreement. What is the Paris agreement?, 2023. Available from: https://unfccc.int/process-and-meetings/the-paris-agreement. Accessed January 2, 2024.
9. Foote E. Circumstances affecting the heat of the sun's rays. Am J Sci Arts 1856;22:2.
10. Arrhenius S. On the influence of carbonic acid in the air upon the temperature of the ground. Phil Mag J Sci 1896;41(251):237–276.

11. Callendar GS. The artificial production of carbon dioxide and its influence on temperature. Q J R Meteorol Soc 1938;64(275):223–240.
12. Shabecoff P. Global warming has begun, expert tells Senate. New York: New York Times, 1988.
13. Mann M. The New Climate War: the fight to take back the planet. New York, New York: Hatchette Book Group, 2021.
14. Armstrong McKay DI, Staal A, Abrams JF, et al. Exceeding 1.5°C global warming could trigger multiple climate tipping points. Science 2022;377(6611):eabn7950.
15. Lenton TM, Held H, Kriegler E, et al. Tipping elements in the Earth's climate system. Proc Natl Acad Sci U S A 2008;105(6):1786–1793.
16. Carbon Action Tracker. CAT emisisons gap. Available from: https://climateactiontracker.org/global/cat-emissions-gaps/. Accessed January 2, 2024.
17. United Nations Environment Program. Emissions gap report 2022, 2022. Available from: https://www.unep.org/resources/emissions-gap-report-2022. Accessed January 2, 2024.
18. Our World in Data. Greenhouse gas emissions, 2023. Available from: https://ourworldindata.org/explorers/co2?facet=none&country=~OWID_WRL&Gas+or+Warming=All+GHGs+%28CO2eq%29&Accounting=Production-based&Fuel+or+Land+Use+Change=All+fossil+emissions&Count=Per+country.
19. Hoegh-Guldberg O, Jacob D, Taylor M. Impacts of 1.5°C of global warming on natural and human systems, 2018. Available from: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Chapter3_High_Res.pdf. Accessed January 2, 2024.
20. United Nations Environment Program. What is biodiversity, 2010. Available from: https://www.unesco.pl/fileadmin/user_upload/pdf/BIODIVERSITY_FACTSHEET.pdf. Accessed January 2, 2024.
21. Nathanson J. Pollution: encyclopedia Brittanica, 2023. Available from: https://www.britannica.com/science/pollution-environment. Accessed January 2, 2024.
22. Wang Z, Walker GW, Muir DCG, et al. Toward a global understanding of chemical pollution: a first comprehensive analysis of national and regional chemical inventories. Environ Sci Technol 2020;54(5):2575–2584.
23. Landrigan PJ, Fuller R, Acosta NJR, et al. The Lancet commission on pollution and health. Lancet 2018;391(10119):462–512.
24. Persson L, Carney Almroth BM, Collins CD, et al. Outside the safe operating space of the planetary boundary for novel entities. Environ Sci Technol 2022;56(3):1510–1521.
25. Philipsborn R, Manivannan M, Sack TL. Climate change, paediatric health and ways that digestive health professionals can engage. Gut 2023;72(12):2216–2218.
26. Bloem BR, Boonstra TA. The inadequacy of current pesticide regulations for protecting brain health: the case of glyphosate and Parkinson's disease. Lancet Planet Health 2023;7(12):e948–e949.
27. Fuller R, Landrigan PJ, Balakrishnan K, et al. Pollution and health: a progress update. Lancet Planet Health 2022;6(6):e535–e547.
28. Cardinale BJ, Duffy JE, Gonzalez A, et al. Biodiversity loss and its impact on humanity. Nature 2012;486(7401):59–67.
29. Tollefson J. Why deforestation and extinctions make pandemics more likley. Nature 2020;584:2.
30. Roy HE, Pauchard A, Stoett P, et al. IPBES invasive alien species assessment: summary for policymakers (Version 2), 2023. Available from: https://zenodo.org/record/8314303/export/csl. Accessed January 2, 2024.
31. Kreienkamp J. The UN SDGs on biodiversity, climate change and health: towards a shared agenda, 2021. Available from: https://www.ucl.ac.uk/global-governance/news/2021/jun/un-sdgs-biodiversity-climate-change-and-health-towards-shared-agenda. Accessed January 2, 2024.
32. Zscheischler J, Martius O, Westra S, et al. A typology of compound weather and climate events. Nat Rev Earth Environ 2020;1(7):333–347.
33. Understanding and modeling compound weather events, 2022. Available from: https://damocles.compoundevents.org/index.php. Accessed January 2, 2024.
34. Haines A, Ebi K. The Imperative for climate action to protect health. N Engl J Med 2019;380(3):263–273.
35. Costello A, Abbas M, Allen A, et al. Managing the health effects of climate change: Lancet and University College London Institute for Global Health Commission. Lancet 2009;373(9676):1693–1733.
36. Public Health Canada. Mobilizing, public health, action and climate change in Canada. A message from Canada's chief public health officer, 2022. Available from: https://www.canada.ca/en/public-health/corporate/publications/chief-public-health-officer-reports-state-public-health-canada/state-public-health-canada-2022.html. Accessed January 2, 2024.
37. Makharia GK, Sadeghi A, Leddin D, et al. Impact of climate change on vulnerable populations. Gut 2023;72(12):2201–2204.
38. Setoguchi S, Leddin D, Metz G, et al. Climate change, health, and health care systems: a global perspective. Gastroenterology 2022;162(6):1549–1555.
39. Leddin D, Macrae F. Climate change: implications for gastrointestinal health and disease. J Clin Gastroenterol 2020;54(5):393–397.
40. Lee YY, Roslan NS, Tee V, et al. Climate change and the esophagus: speculations on changing disease patterns as the world warms. Curr Gastroenterol Rep 2023;25:280–288.
41. Donnelly MC, Talley NJ. Effects of climate change on digestive health and preventative measures. Gut 2023;72(12):2199–2201.
42. NASA Earth Observatory. Global temperatures: NASA, 2023. Available from: https://earthobservatory.nasa.gov/world-of-change/global-temperatures. Accessed January 2, 2024.
43. IPCC. Climate change: a threat to human wellbeing and health of the planet. Taking action now can secure our future, 2022. Available from: https://www.ipcc.ch/2022/02/28/pr-wgii-ar6/. Accessed January 2, 2024.
44. IPCC. WG1 Interactive Atlas. Available from: https://interactive-atlas.ipcc.ch/regional. Accessed January 2, 2024.
45. Liu Z, Sun X, Tang J, et al. Intestinal inflammation and tissue injury in response to heat stress and cooling treatment in mice. Mol Med Rep 2011;4(3):437–443.
46. Mora C, Counsell CWW, Bielecki CR, et al. Twenty-seven ways a heat wave can kill you: deadly heat in the era of

climate change. Circ Cardiovasc Qual Outcomes 2017;10(11):e004233.
47. Leon LR, Helwig BG. Heat stroke: role of the systemic inflammatory response. J Appl Physiol 2010;109(6):1980–1988.
48. Martínez-Insfran LA, Alconchel F, Ramírez P, et al. Liver transplantation for fulminant hepatic failure due to heat stroke: a case report. Transplant Proc 2019;51(1):87–89.
49. Bianchi L, Ohnacker H, Beck K, et al. Liver damage in heatstroke and its regression: a biopsy study. Hum Pathol 1972;3(2):237–248.
50. Mitchell MA, Carlisle AJ. The effects of chronic exposure to elevated environmental temperature on intestinal morphology and nutrient absorption in the domestic fowl (Gallus domesticus). Comp Biochem Physiol A Comp Physiol 1992;101(1):137–142.
51. Manser CN, Paul M, Rogler G, et al. Heat waves, incidence of infectious gastroenteritis, and relapse rates of inflammatory bowel disease: a retrospective controlled observational study. Am J Gastroenterol 2013;108(9):1480–1485.
52. Xu R, Li S, Guo S, et al. Environmental temperature and human epigenetic modifications: a systematic review. Environ Pollut 2020;259:113840.
53. Food and Agricultural Agency of United Nations. Putting a number on hunger: FAO. Available from: https://www.fao.org/interactive/state-of-food-security-nutrition/en/. Accessed January 2, 2024.
54. World Health Organisation. Obesity and overweight, 2021. Available from: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight. Accessed January 2, 2024.
55. Our World in Data. Food production is responsible for one-quarter of the world's greenhouse gas emissions. Available from: https://ourworldindata.org/food-ghg-emissions. Accessed January 2, 2024.
56. Government of Canada. Greenhouse gas emissions and agriculture. Available from: https://agriculture.canada.ca/en/environment/greenhouse-gases. Accessed January 2, 2024.
57. IPCC. Fact sheet food and water. Available from: https://www.ipcc.ch/report/ar6/wg2/downloads/outreach/IPCC_AR6_WGII_FactSheet_FoodAndWater.pdf. Accessed January 2, 2024.
58. Our World in Data. Food: greenhouse gas emisions across the supply chain. Available from: https://ourworldindata.org/food-choice-vs-eating-local. Accessed January 2, 2024.
59. Willett W, Rockström J, Loken B, et al. Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. Lancet 2019;393(10170):447–492.
60. Springmann M, Mason-D'Croz D, Robinson S, et al. Global and regional health effects of future food production under climate change: a modelling study. Lancet 2016;387(10031):1937–1946.
61. Government of Canada. Household food insecurity in Canada: overview, 2020. Available from: https://www.canada.ca/en/health-canada/services/food-nutrition/food-nutrition-surveillance/health-nutrition-surveys/canadian-community-health-survey-cchs/household-food-insecurity-canada-overview.html. Accessed January 2, 2024.
62. Tamargo JA, Sherman KE, Campa A, et al. Food insecurity is associated with magnetic resonance-determined nonalcoholic fatty liver and liver fibrosis in low-income, middle-aged adults with and without HIV. Am J Clin Nutr 2021;113(3):593–601.
63. Golovaty I, Tien PC, Price JC, et al. Food insecurity may Be an Independent risk factor associated with nonalcoholic fatty liver disease among low-income adults in the United States. J Nutr 2020;150(1):91–98.
64. Narula N, Chang NH, Mohammad D, et al. Food processing and risk of inflammatory bowel disease: systematic review and meta-analysis. Clin Gastroenterol Hepatol 2023;21(10):2483–24895.e1.
65. Alavanja MC. Introduction: pesticides use and exposure extensive worldwide. Rev Environ Health 2009;24(4):303–309.
66. Yuan X, Pan Z, Jin C, et al. Gut microbiota: an underestimated and unintended recipient for pesticide-induced toxicity. Chemosphere 2019;227:425–434.
67. UN Environmental Program. Drowning in plastics, 2021. Available from: https://wedocs.unep.org/xmlui/bitstream/handle/20.500.11822/36964/VITGRAPH.pdf. Accessed January 2, 2024.
68. Groh KJ, Backhaus T, Carney-Almroth B, et al. Overview of known plastic packaging-associated chemicals and their hazards. Sci Total Environ 2019;651(Pt 2):3253–3268.
69. Halden RU. Plastics and health risks. Annu Rev Public Health 2010;31:179–194.
70. Campanale C, Massarelli C, Savino I, et al. A detailed review study on potential effects of microplastics and additives of concern on human health. Int J Environ Res Public Health 2020;17(4):1212.
71. Rochman CM, Browne MA, Halpern BS, et al. Classify plastic waste as hazardous. Nature 2013;494(7436):169–171.
72. Daltry A, Merone L, Tait P. Plastic pollution: why is it a public health problem? Aust N Z J Public Health 2021;45(6):535–537.
73. Ganning AE, Brunk U, Dallner G. Phthalate esters and their effect on the liver. Hepatology 1984;4(3):541–547.
74. Ji J, Wu X, Li X, et al. Effects of microplastics in aquatic environments on inflammatory bowel disease. Environ Res 2023;229:115974.
75. Mbow C, Rosenzweig C, Barioni LG, et al. Food Security. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Geneva, Switzerland: IPCC, 2019.
76. Guzman Herrador BR, de Blasio BF, MacDonald E, et al. Analytical studies assessing the association between extreme precipitation or temperature and drinking water-related waterborne infections: a review. Environ Health 2015;14:29.
77. Ma T, Sun S, Fu G, et al. Pollution exacerbates China's water scarcity and its regional inequality. Nat Commun 2020;11(1):650.
78. Stanke C, Kerac M, Prudhomme C, et al. Health effects of drought: a systematic review of the evidence. PLoS Curr 2013;5.
79. Shi L, Du X, Liu H, et al. Update on the adverse effects of microcystins on the liver. Environ Res 2021;195:110890.

80. WHO. Drinking Water: Key facts 2022. Available from: https://www.who.int/news-room/fact-sheets/detail/drinking-water#:~:text=Water%20and%20health,individuals%20to%20preventable%20health%20risks. Accessed January 2, 2024.
81. WHO. Pharmaceuticals in drinking water, 2012. Available from: https://www.who.int/publications/i/item/9789241502085. Accessed January 2, 2024.
82. Bexfield LM, Toccalino PL, Belitz K, et al. Hormones and pharmaceuticals in groundwater used as a source of drinking water across the United States. Environ Sci Technol 2019;53 6:2950–2960.
83. Petrie B, Barden R, Kasprzyk-Hordern B. A review on emerging contaminants in wastewaters and the environment: current knowledge, understudied areas and recommendations for future monitoring. Water Res 2015;72:3–27.
84. CNN. Oceans are warming at the same rate as if five Hiroshima bombs were dropped in every second. Available from: https://www.cnn.com/2020/01/13/world/climate-change-oceans-heat-intl/index.html#. Accessed January 2, 2024.
85. Weather and climate extreme events in a changing climate. In: Intergovernmental Panel on Climate Change, ed. Climate change 2021 – the physical science basis: working group I contribution to the sixth assessment report of the intergovernmental panel on climate change. Cambridge: Cambridge University Press, 2023:1513–1766.
86. Immerzeel WW, Lutz AF, Andrade M, et al. Importance and vulnerability of the world's water towers. Nature 2020;577(7790):364–369.
87. Kulp SA, Strauss BH. New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. Nat Commun 2019;10(1):4844.
88. Hoegh-Guldberg O, Bruno JF. The impact of climate change on the world's marine ecosystems. Science 2010;328(5985):1523–1528.
89. Tacon AG, Metian M. Fish matters: importance of aquatic foods in human nutrition and global food supply. Rev Fish Sci 2013;21(1):22–38.
90. Landsea C, Knutson T. Can we detect a change in Atlantic hurricanes today due to human-c aused climate change?: NOAA Climate.gov, 2022. Available from: https://www.climate.gov/news-features/blogs/beyond-data/can-we-detect-change-atlantic-hurricanes-today-due-human-caused. Accessed January 2, 2024.
91. Waddell SL, Jayaweera DT, Mirsaeidi M, et al. Perspectives on the health effects of hurricanes: a review and challenges. Int J Environ Res Public Health 2021;18(5):2756.
92. Liang SY, Messenger N. Infectious diseases after hydrologic disasters. Emerg Med Clin North Am 2018;36(4):835–851.
93. Horney JA, Casillas GA, Baker E, et al. Comparing residential contamination in a Houston environmental justice neighborhood before and after Hurricane Harvey. PLoS One 2018;13(2):e0192660.
94. Ohl CA, Tapsell S. Flooding and human health. BMJ 2000;321(7270):1167–1168.
95. National Hurricane Center. Hurricanes in history. Available from: https://www.nhc.noaa.gov/outreach/history/#katrina. Accessed January 2, 2024.
96. Andrade L, O'Dwyer J, O'Neill E, et al. Surface water flooding, groundwater contamination, and enteric disease in developed countries: a scoping review of connections and consequences. Environ Pollut 2018;236:540–549.
97. USEPA. Private drinking water wells. Available from: https://www.epa.gov/privatewells. Accessed January 2, 2024.
98. Wade TJ, Sandhu SK, Levy D, et al. Did a severe flood in the Midwest cause an increase in the incidence of gastrointestinal symptoms? Am J Epidemiol 2004;159(4):398–405.
99. Lin CJ, Wade TJ, Hilborn ED. Flooding and clostridium difficile infection: a case-crossover analysis. Int J Environ Res Public Health 2015;12(6):6948–6964.
100. Wade TJ, Lin CJ, Jagai JS, et al. Flooding and emergency room visits for gastrointestinal illness in Massachusetts: a case-crossover study. PLoS One 2014;9(10):e110474.
101. Waring SC, Brown BJ. The threat of communicable diseases following natural disasters: a public health response. Disaster Manag Response 2005;3(2):41–47.
102. Chhetri BK, Takaro TK, Balshaw R, et al. Associations between extreme precipitation and acute gastrointestinal illness due to cryptosporidiosis and giardiasis in an urban Canadian drinking water system (1997-2009). J Water Health 2017;15(6):898–907.
103. Jones FK, Ko AI, Becha C, et al. Increased Rotavirus prevalence in diarrheal outbreak precipitated by Localized flooding, Solomon Islands, 2014. Emerg Infect Dis 2016;22(5):875–879.
104. Pal S, Juyal D, Sharma M, et al. An outbreak of hepatitis A virus among children in a flood rescue camp: a post-disaster catastrophe. Indian J Med Microbiol 2016;34(2):233–236.
105. Alderman K, Turner LR, Tong S. Floods and human health: a systematic review. Environ Int 2012;47:37–47.
106. Yee EL, Palacio H, Atmar RL, et al. Widespread outbreak of Norovirus gastroenteritis among evacuees of hurricane Katrina residing in a large "megashelter" in Houston, Texas: Lessons learned for prevention. Clin Infect Dis 2007;44(8):1032–1039.
107. OCHA. Bangladesh: floods situation report - 13 Oct 2004. Available from: https://reliefweb.int/report/bangladesh/bangladesh-floods-situation-report-13-oct-2004 2004. Accessed January 2, 2024.
108. Tarabochia-Gast AT, Michanowicz DR, Bernstein AS. Flood risk to hospitals on the United States Atlantic and Gulf coasts from hurricanes and sea level rise. Geohealth 2022;6(10):e2022GH000651.
109. National Academies of Sciences E, Medicine, Policy, Global A, Office of Special P, et al. Strengthening post-hurricane supply chain resilience: observations from Hurricanes Harvey, Irma, and Maria. Washington (DC): National Academies Press (US) Copyright 2020 by the National Academy of Sciences, 2020.
110. Mazer-Amirshahi M, Fox ER. Saline shortages - many causes, No simple solution. N Engl J Med 2018;378(16):1472–1474.
111. Dockery DW, Pope CA 3rd, Xu X, et al. An association between air pollution and mortality in six U.S. cities. N Engl J Med 1993;329(24):1753–1759.

112. Briggs D. Environmental pollution and the global burden of disease. Br Med Bull 2003;68:1–24.
113. Elten M, Benchimol EI, Fell DB, et al. Ambient air pollution and the risk of pediatric-onset inflammatory bowel disease: a population-based cohort study. Environ Int 2020;138:105676.
114. Ananthakrishnan AN, Bernstein CN, Iliopoulos D, et al. Environmental triggers in IBD: a review of progress and evidence. Nat Rev Gastroenterol Hepatol 2018;15(1):39–49.
115. Ananthakrishnan AN, McGinley EL, Binion DG, et al. Ambient air pollution correlates with hospitalizations for inflammatory bowel disease: an ecologic analysis. Inflamm Bowel Dis 2011;17(5):1138–1145.
116. Kaplan GG, Hubbard J, Korzenik J, et al. The inflammatory bowel diseases and ambient air pollution: a novel association. Am J Gastroenterol 2010;105(11):2412–2419.
117. Guo B, Guo Y, Nima Q, et al. Exposure to air pollution is associated with an increased risk of metabolic dysfunction-associated fatty liver disease. J Hepatol 2022;76(3):518–525.
118. Finlay SE, Moffat A, Gazzard R, et al. Health impacts of wildfires. PLoS Curr 2012;4:e4f959951cce2c.
119. Lowe SR, Garfin DR. Crisis in the air: the mental health implications of the 2023 Canadian wildfires. Lancet Planet Health 2023;7(9):e732–e733.
120. Tollefson J. Maui fires could taint the island's waters — scientists are investigating. Nature 2023;621:16–17.
121. Vaillant J. Fire weather. Canada: Alfred A. Knopf, 2023.
122. Wei J, Wang J, Li Z, et al. Long-term mortality burden trends attributed to black carbon and PM(2·5) from wildfire emissions across the continental USA from 2000 to 2020: a deep learning modelling study. Lancet Planet Health 2023;7(12):e963–e975.
123. Hiatt RA, Beyeler N. Cancer and climate change. Lancet Oncol 2020;21(11):e519–e527.
124. Fitzmaurice C, Abate D, Abbasi N, et al. Global, regional, and national cancer incidence, mortality, years of life lost, years lived with disability, and disability-adjusted life-years for 29 cancer groups, 1990 to 2017: a systematic analysis for the global burden of disease study. JAMA Oncol 2019;5(12):1749–1768.
125. Yin J, Wu X, Li S, et al. Impact of environmental factors on gastric cancer: a review of the scientific evidence, human prevention and adaptation. J Environ Sci (China) 2020;89:65–79.
126. Cong X. Air pollution from industrial waste gas emissions is associated with cancer incidences in Shanghai, China. Environ Sci Pollut Res Int 2018;25(13):13067–13078.
127. Gorham ED, Garland CF, Garland FC. Acid haze air pollution and breast and colon cancer mortality in 20 Canadian cities. Can J Public Health 1989;80(2):96–100.
128. Sun D, Liu C, Zhu Y, et al. Long-term exposure to fine particulate matter and incidence of esophageal cancer: a prospective study of 0.5 million Chinese adults. Gastroenterology 2023;165(1):61–70.e5.
129. Pritchett N, Spangler EC, Gray GM, et al. Exposure to outdoor particulate matter air pollution and risk of gastrointestinal cancers in adults: a systematic review and meta-analysis of epidemiologic evidence. Environ Health Perspect 2022;130(3):36001.
130. Smith AH, Hopenhayn-Rich C, Bates MN, et al. Cancer risks from arsenic in drinking water. Environ Health Perspect 1992;97:259–267.
131. Kensler TW, Roebuck BD, Wogan GN, et al. Aflatoxin: a 50-year odyssey of mechanistic and translational toxicology. Toxicol Sci 2010;120(suppl_1):S28–S48.
132. Council for Agricultural Science and Technology. Mycotoxins: risks in plant, animal, and human system, 2003. Available from: https://www.international-food-safety.com/pdf/Mycotoxins%20-%20Risks%20in%20Plant,%20Animals%20and%20Human%20Systems.pdf. Accessed January 2, 2024.
133. Battilani P, Toscano P, Van der Fels-Klerx HJ, et al. Aflatoxin B1 contamination in maize in Europe increases due to climate change. Sci Rep 2016;6(1):24328.
134. Nogueira LM, Yabroff KR, Bernstein A. Climate change and cancer. CA Cancer J Clin 2020;70(4):239–244.
135. Altizer S, Ostfeld RS, Johnson PT, et al. Climate change and infectious diseases: from evidence to a predictive framework. Science 2013;341(6145):514–519.
136. Blum A, Hotez P. Global "worming": climate change and its projected general impact on human helminth infections. PLoS Negl Trop Dis 2018;12:e0006370.
137. Baker-Austin C, Trinanes JA, Taylor NGH, et al. Emerging vibrio risk at high latitudes in response to ocean warming. Nat Clim Change 2013;3(1):73–77.
138. Tan TK, Saps M, Lin CL, et al. Is long-term ambient air pollutant exposure a risk factor for irritable bowel syndrome in children? A 12-year longitudinal cohort study. J Neurogastroenterol Motil 2019;25(2):241–249.
139. Kaplan GG, Szyszkowicz M, Fichna J, et al. Non-specific abdominal pain and air pollution: a novel association. PLoS One 2012;7(10):e47669.
140. Hickman C, Marks E, Pihkala P, et al. Climate anxiety in children and young people and their beliefs about government responses to climate change: a global survey. Lancet Planet Health 2021;5(12):e863–e873.
141. Lebano A, Hamed S, Bradby H, et al. Migrants' and refugees' health status and healthcare in Europe: a scoping literature review. BMC Public Health 2020;20(1):1039.
142. Burnett A, Ndovi T. The health of forced migrants. BMJ 2018;363:k4200.
143. El Saghir NS, Soto Pérez de Celis E, Fares JE, et al. Cancer care for refugees and displaced populations: Middle East conflicts and global natural disasters. Am Soc Clin Oncol Educ Book 2018;38:433–440.
144. Rigaud KKDS, Alexander M, Jones B, et al. Groundswell: preparing for internal climate migration, 2018. Available from: https://academiccommons.columbia.edu/doi/10.7916/D8Z33FNS. Accessed January 2, 2024.
145. Bowles DC, Butler CD, Morisetti N. Climate change, conflict and health. J R Soc Med 2015;108(10):390–395.
146. Whitmee S, Haines A, Beyrer C, et al. Safeguarding human health in the anthropocene epoch: report of the Rockefeller Foundation-Lancet Commission on planetary health. Lancet 2015;386(10007):1973–2028.
147. Vogel J, Hickel J. Is green growth happening? An empirical analysis of achieved versus Paris-compliant CO_2–GDP decoupling in high-income countries. Lancet Planet Health 2023;7(9):e759–e769.

148. Wang F, Harindintwali JD, Yuan Z, et al. Technologies and perspectives for achieving carbon neutrality. Innovation (Camb) 2021;2(4):100180.
149. Gillon R. Medical ethics: four principles plus attention to scope. BMJ 1994;309(6948):184.
150. Lenzen M, Malik A, Li M, et al. The environmental footprint of health care: a global assessment. Lancet Planet Health 2020;4(7):e271–e279.
151. Andrieu B, Marrauld L, Vidal O, et al. Health-care systems' resource footprints and their access and quality in 49 regions between 1995 and 2015: an input–output analysis. Lancet Planet Health 2023;7(9):e747–e758.
152. Dzau VJ, Levine R, Barrett G, et al. Decarbonizing the U. S. Health sector - a Call to action. N Engl J Med 2021; 385(23):2117–2119.
153. UNICEF. Climate change and intergenerational justice, 2012. Available from: https://www.unicef-irc.org/article/920-climate-change-and-intergenerational-justice.html. Accessed January 2, 2024.
154. Royal College of Physicians and Surgeons of Canada. CanMEDS: better standards, better physicians, better care. Available from: https://www.royalcollege.ca. Accessed March 20, 2024.
155. OECD. OECD Environmental Outlook to 2050: The Consequences of Inaction - Key Facts and Figures. Available from: https://www.oecd.org/env/indicators-modelling-outlooks/oecdenvironmentaloutlookto2050theconsequencesofinaction-keyfactsandfigures.htm. Accessed January 2, 2024.
156. Vaccari M, Tudor T, Perteghella A. Costs associated with the management of waste from healthcare facilities: an analysis at national and site level. Waste Manag Res 2018;36(1):39–47.
157. World Gastroenterology Organisation. WGO climate course for global Gastroenterology, 2023. Available from: https://www.worldgastroenterology.org/education-and-training/webinars/wgo-climate-course-for-global-gastroenterology. Accessed September 10, 2023.
158. Omary MB, Leddin D, Metz G, et al. World Gastroenterology Organisation - gut commentary series on digestive health and climate change. Gut 2023;72(12):2193–2196.
159. Williams JA, Kao JY, Omary MB. How can individuals and the GI community reduce climate change? Gastroenterology 2020;158(1):14–17.
160. My Green Doctor. Available from: https://mygreendoctor.org.
161. Lindemer A. The costs of climate activism for medical professionals: a case study of the USA, the UK, and Germany. Lancet Planet Health 2023;7(9):e770–e776.
162. Cunha Neves JA, Roseira J, Queirós P, et al. Targeted intervention to achieve waste reduction in gastrointestinal endoscopy. Gut 2023;72(2):306–313.
163. Gayam S. Environmental impact of endoscopy: "scope" of the problem. Am J Gastroenterol 2020;115(12):1931–1932.
164. Elli L, La Mura S, Rimondi A, et al. The carbon cost of inappropriate endoscopy. Gastrointest Endosc 2024; 99(2):137–145.
165. Pohl H, Baddeley R, Hayee B. Carbon footprint of gastroenterology practice. Gut 2023;72(12):2210–2213.
166. Henniger D, Windsheimer M, Beck H, et al. Assessment of the yearly carbon emission of a gastrointestinal endoscopy unit. Gut 2023;72(10):1816–1818.
167. Sebastian S, Dhar A, Baddeley R, et al. Green endoscopy: British Society of Gastroenterology (BSG), Joint Accreditation Group (JAG) and Centre for Sustainable Health (CSH) joint consensus on practical measures for environmental sustainability in endoscopy. Gut 2023; 72(1):12–26.
168. Rodríguez de Santiago E, Dinis-Ribeiro M, Pohl H, et al. Reducing the environmental footprint of gastrointestinal endoscopy: European Society of Gastrointestinal Endoscopy (ESGE) and European Society of Gastroenterology and Endoscopy Nurses and Associates (ESGENA) position statement. Endoscopy 2022;54(8):797–826.
169. Hernandez LV, Agrawal D, Skole KS, et al. Meeting the environmental challenges of endoscopy: a pathway from strategy to implementation. Gastrointest Endosc 2023; 98(6):881–888.e1.
170. Tennison I, Roschnik S, Ashby B, et al. Health care's response to climate change: a carbon footprint assessment of the NHS in England. Lancet Planet Health 2021; 5(2):e84–e92.
171. Thiel C, Pak E, Burkard R, et al. Green gastroenterology adaptation, resilience and an industry perspective. Gut 2023;72(12):2206–2209.
172. Baddeley R, Watts N, Donnelly L. NHS efforts in England to mitigate the climate crisis: uniting nurses and gastroenterologists. Gut 2023;72(12):2214–2215.
173. Haines A. Health co-benefits of climate action. Lancet Planet Health 2017;1(1):e4–e5.
174. Shaukat A, Shah B, Fritz CD, et al. Gastroenterology climate action opportunities via education, empowerment of trainees and research. Gut 2023;72(12):2219–2221.
175. Leddin D, Omary MB, Veitch A, et al. Uniting the global gastroenterology community to meet the challenge of climate change and non-recyclable waste. Gastroenterology 2021;161(5):1354–1360.
176. Leddin D, Omary MB, Metz G, et al. Climate change: a survey of global gastroenterology society leadership. Gut 2022;10:gutjnl -2022-327832.
177. Gifford R. 33 reasons why we cannot think clearly about climate change. London, United Kingdom: New Scientist, 2015.
178. Pohl H, de Latour R, Reuben A, et al. GI multisociety strategic plan on environmental sustainability. Gastroenterology 2022;163(6):1695–1701.e2.

Received October 17, 2023. Accepted January 26, 2024.

Correspondence:
Address correspondence to: Desmond Leddin, MB, MSc, Victoria General Hospital, 912 Victoria, Halifax, Nova Scotia, Canada B3H2Y9. e-mail: dleddin@dal.ca.

Acknowledgments:
The author wishes to acknowledge the contribution of Natalie Bruiners in preparing Figure 1 and Figure 3.

Conflicts of Interest:
Desmond Leddin is a member of the Board of Editors. Their paper was handled in accordance with our conflicts of interest policy. See https://www.ghadvances.org/content/authorinfo#conflict_of_interest_policy for full details.

Funding:
The authors report no funding.

Ethical Statement:
The study did not require the approval of an institutional review board.

Reporting Guidelines:
Not applicable for this article type.