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Sick Planet: The Link between Carbon, Climate Change, and Human Health

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Introduction

Our bodies are finely-calibrated, organic machines that are capable of dealing with the fluctuations of our internal systems in response to stimuli. We are able to regulate these changes through feedback loops in order to maintain the self in a prime 'operating condition' known as homeostasis. While deviations from homeostasis may occur, the body has processes in place to eventually return to normal. Long term or highly disruptive deviation, to the point where the body's natural feedback loops are insufficient at correcting the error, is an indicator of something abnormal at work—be it parasite, virus, or organ malfunction.

The Earth also displays similar mechanisms of homeostasis—complex feedback loops that allow it to regulate temperature, gas concentrations, and pH. Normally, small fluctuations are regulated within the system. Negative feedback loops maintain balance through chemical processes like the sink and release of carbon gases. However, as excessive fossil fuel combustion tips the scales, it is likely that we are moving further away from the point where these feedback loops are enough to return the carbon cycle to balance.

We can see symptoms of this deviation in alteration of the climate, increased warming, and the thawing of glaciers and permafrost. The study of these indicators allow us to monitor the disease and provide insight into the underlying cause. The feedback loops found in the carbon cycle are unable to rectify the anthropogenic carbon output post Industrial revolution, leading to some alarming trends. The greater the divergence from normal the greater the impact these indicators have on the system of the planet until, like the human body, there is irreparable harm to the system.

Is this warming a fever-- a planetary self-preservation system precipitated by the intemperate combustion of fossil fuels-- that aims to overcorrect the problem before returning to homeostasis in the geological timeline? How does a 'sick' planet impact our own health? This unit addresses the consequence of anthropogenic carbon sourced global warming on the planetary system and human physiology.

Rationale

I teach many classes of all levels including biology, chemistry, physical chemistry, and anatomy in an arts focused public high school. Our school, district, and state are making efforts to increase the inclusion of climate education in all schools as a way to educate our students about the facts and implications of climate change. Half of the courses I teach are biological science while the other half are physical science but I believe that this unit can be used as a bridge between both areas.

Students learn best when they can relate the topic at hand to something they are intimately familiar with. The human body is a good model to demonstrate some of the impacts of climate change on the individual. Furthermore, many physical science topics can be addressed by highlighting their link to human health and disease. In a physical science class, the climate change material being presented can bolster any chemistry or earth science curriculum, while impacts on the individual and the local populations can be used to emphasize their importance.

Curriculum Content

Pre-Anthropogenic Carbon Levels and the Carbon Cycle

Carbon and its movement through the different systems on Earth plays a role in the regulation of climate. Carbon can be locked in a few different forms. There are sources of organic carbon, found in molecules like sugar, cellulose, and other biological molecules. Many of these molecules can be found bound up in living plants and animals and act as energy storage or structural components.

Some of this carbon may move into a long term storage reservoir. One example is carbon that is converted over time and pressure into coal and fossil fuels. This carbon is often located underground in sub terrestrial deposits. Another example of long term carbon reservoirs include deep ocean waters. Organisms that are in upper pelagic or mesopelagic waters die and sink down into deeper ocean areas. It can take several hundreds of years for upwelling to return deep ocean deposits of carbon back to surface waters.

Much of this organic carbon is eventually decomposed and may be converted into inorganic carbon, like those found in carbon dioxide gases or other forms of dissolved inorganic carbon. Carbon dioxide and other greenhouse gases are essential components to the atmosphere. Without them, solar radiation would not be reflected back to earth, resulting in a much cooler planet unable to sustain the biodiversity we see today. Greenhouse gases play an important role in the earth system. They act as an insulation layer to reflect radiation back to earth, trapping radiation and helping to keep the planet warm. A healthy amount of CO_2 in the atmosphere is vital for keeping atmosphere, lithosphere and hydrosphere temperatures stable.

One of the major misconceptions that will need to be addressed while teaching this unit is the idea of weather versus climate. Weather is the day to day conditions in an area. This includes short-term precipitation events and temperature. Weather can change day by day or even hour by hour in certain areas. For example, in Connecticut, the weather for a single week during June can vary wildly. It may be in the 90s and sunny one day with the next day weather in the 60s and rainy.

Weather certainly can play a role in some of the cases that are presented in this study. For example, a sudden cold snap may kill tender ragweed plants that have started to come up. This may have a temporary impact on allergies as a major contributor of pollen is removed. However, this may be the exception and not the rule in this area, and pollen counts could return to normal the next season.

Climate, on the other hand, is the long term weather conditions that are typical for that particular region. Climate is long-term and gives the average conditions for the region including seasonal temperatures and precipitation. Climate is impacted by more than just carbon. The angle of the sun's radiant energy and the rotation of the earth's orbit have impacts on the air and water currents due to convection as areas of land and water heat up. The patterns of precipitation and temperature contribute to the average climate of a region.

A driving force behind this unit is understanding the changes in climate and how they can have an impact on human health. The planet is a complex system and there are multiple factors that can and do influence climate cycles. When changes in these cycles occur, there is a response by these systems to help return back to normal. We would consider this to be a negative feedback loop. In negative feedback loops, there is a stabilizing effect where the response essentially shuts off or stops the stimulus allowing for a return to normal levels. In a way, this system works similarly to the feedback loops in the human body, allowing for maintenance of homeostasis.

Sometimes, changes in a system can cause a disruption, which can result in abnormalities. In some cases these changes may even move a normal system into a positive or amplification feedback loop. In these cases, the stimuli continues to increase, causing a greater increase in the output. This cycle is perpetual, continuing to move the systems away from the average.

Another common misconception that will likely need to be addressed in class is the idea of periodic 'thawing' and 'freezing' that the earth seems to go through. There are times in the Earth's past where CO_2 levels have increased and decreased as part of these natural feedback loop cycles. This is true—studies of CO_2 from ice cores have given us a picture of the atmosphere saturation at points hundreds of years ago. However, the levels of CO_2 in this ancient ice demonstrate that, while CO_2 levels do naturally vary and are tied with the heating and cooling systems on Earth, it never rose above 300ppm.[1]

Historic carbon dioxide, back as far as 800,000 years, had concentrations averaging under 280ppm. In fact, over the last 800,000 years, the highest the concentration of CO_2 was 300ppm.[1] However, since the industrial revolution, the concentration of CO_2 has grown unchecked, increasing by over 100ppm in only a couple of centuries well past the previous high threshold to levels near 410ppm.

This extraordinarily fast increase in carbon dioxide is linked in part to an increase in combustion of fossil fuels which remove stored organic carbon and changes it into inorganic gas through combustion. In addition, logging, land clearing, and burning add additional carbon dioxide. In total, net carbon emissions increased by 51% between 1990 and 2015 due in part to the increasing demands for energy production and land use changes on a global scale.[2] All of these are considered anthropogenic contributors of carbon and other greenhouse gases, increasing levels at a rate previously unseen. These anthropogenic impacts tip the scales, dumping additional carbon gases into the atmosphere in a way that the negative feedback loops are unable to mitigate.

While much of the focus thus far has been on carbon, it is important to note that other greenhouse gases are also experiencing similar increases in emissions. Some of these greenhouse gases are even more potent than carbon dioxide. For example, methane is responsible for about 20% of the global warming seen to date and has a global warming potential of 30 times that of carbon.[3] Nitrous oxide, another greenhouse gas, is even more potent than methane. All of these factor into the global warming that has happened and is projected to continue into the future.

Warming Trends and the Impact on Zoonotic Vector Ranges

Indicators of Climate Change

Climate change can have long term impacts on large regions. In many areas, the average temperature has increased and is predicted to continue to increase as anthropogenic carbon continues to be emitted in the atmosphere. The United States has seen an average increase of 0.16° F per decade since 1901. This increase has almost doubled per decade since the late 1970s, falling between a 0.31 and a 0.54° F increase. Two of the hottest years on record have happened within the last 10 years.[4] Warmer averaged temperatures have been seen globally with 2011-2020 being noted as the warmest decade on record. However, warming is not equally distributed. There are areas in the United States, such as the northern and western most states, that have seen larger increases in their average temperature while the southeast seems to have more limited increases.[4]

This increase in average temperature has many long lasting effects for seasonal weather patterns. Winters in the United States have had average temperature increases of almost 3° F since the late 1890s.[4] Spring, summer and fall have also seen average temperature increases by between 1.4 to 2° F in this time period as well.

As climates change, the possibility for expanded ranges of vectors and the diseases they carry expand as well. Changes in climate can impact regions by opening up conditions that are suitable for novel arthropod vectors and reservoir species to colonize the area. This will, in turn, introduce new pathogens into these regions impacting the health of local populations. Many of the vectors of concern are arthropods and rely heavily on favorable climatic conditions to be able to sustain their populations. Climate changes to regions have opened up previously inaccessible regions by producing milder temperatures, increased humidity or rainfall, and conditions suitable for vertebrate hosts.

It is important to note that there is a lag between any changes to climate and the establishment of novel vector and host populations and that many of the cases presented here-in may have other mitigating factors such as global transport and accidental introduction to areas. However, climate change works in synergy with these incidents. While introductions to new zones are important for expanding range they would never be able to establish in these areas without suitable climates. There are several pathogens that are of particular medical concern in the United States that have seen expanded ranges due to changes in climate opening up habitable areas.

Example 1: Ixodes scapularis and Lyme Disease

Lyme disease is caused by a spirochete bacterium *Borrelia burgdorferi* and is transmitted by the deer tick *Ixodes scapularis*. These ticks often use deer and other common field and woodland organisms as hosts. However, the main host of interest is the white footed mouse which acts as a natural reservoir for *Borrelia*. Ticks that feed on these mice are able to pick up and transmit the bacteria through their bite.

Lyme disease itself is considered to be one of the most common vector borne diseases in the United States with approximately 30,000 confirmed cases reported to the CDC each year.[5] These numbers are considered to be severely underreported since additional survey methods by the CDC and other public health boards have models predicting over 400,000 annual cases.[5] Lyme disease often presents with *erythema migrans*, or a bull's eye rash that appears between 3 days up to a month post infection. The rash itself can grow up to 12 inches in diameter and may feel warm to the touch but is otherwise painless. Additional symptoms can appear later on post infection and include arthritis in joints, Lyme carditis, meningitis, and facial palsy. These symptoms range in severity by patient and can be short term when treated early or persist for years post infection.[6]

There is evidence that the range of the tick has expanded. One study looked at the appearance and establishment of the tick in ranges of Canada that were previously unable to sustain them due to the temperature.[7] Furthermore, shorter winters expand tick activity and can lead to an increase in breeding and active biting in areas where temperatures are milder. This is only exasperated in areas where human activity also increases due to milder temperatures. Milder winters, earlier springs, and prolonged warmth into fall can lead to increased outdoor activity, increasing exposure to ticks and increasing incidents of infection.

Since the mid-1990s, cases of infection have doubled per 100,000 people in the northeastern part of the United States with some of the largest increases happening in Maine, New Hampshire, and Vermont— states that had low reports of infection only 20 years prior.[7] It is no coincidence that much of the northeast has also experienced changes in their climate with regards to both temperature and humidity. Since the 1960s, there has been an average increase of temperature of 2° F with projections of up to an additional 10° F by 2080 of anthropogenic carbon emissions continue unmitigated.[8] This projected increase is followed by a projected rate of encounter and infection.

One effect of these seasonal increases is milder winters in some regions or lengthening the growing season by supporting earlier spring thaw and later hard frosts in winter. These changes can have large impacts on the suitability of regions to sustain arthropod vectors, causing shifts in their populations to expand into previously un-colonized areas.

Not only do warmer temperatures lead to a more sustainable zone of habitation for the tick, but the warmer temperatures can also lead to expanded ranges for reservoir vectors. White-footed mice populations have also moved into previously unestablished areas here previously long winters prevented populations from thriving.[9] Milder winters and earlier springs also provide an increased bounty of resources to sustain larger mouse populations and larger nests in areas where resources were historically limited.

Interestingly, while the population of Lyme carrying ticks has increased, infection rates appear to have declined in Connecticut from about 4000 diagnosed cases in 2008 to around 1900 cases in 2018.[10] This steadily decreasing trend is likely due to the robust public awareness and education programs maintained in the state of Connecticut to educate citizens on prevention of tick bites.[10]

While *I. scapularis* is primarily associated with Lyme disease, it is also a vector for several other diseases of concern including ehrlichiosis, anaplasmosis, babesia, and the Powassan virus. A breakdown of these diseases with their symptoms and treatments are located in a reference table at the end of this document.

Example 2: Amblyomma americanum and Southern Tick Associated Rash Illness (STARI)

The deer tick isn't the only tick species to see an expanded range. The lone star or turkey tick, *Amblyomma americanum*, is susceptible to cold temperatures and previously inhabited areas of the southeast United States but has recently moved along the coast up to and beyond upstate New York. Temperatures play a limiting factor in the expansion of the range as the tick requires a specific range to encourage egg development and activity.[11] While it may be able to survive in colder temperatures, reproduction is severely diminished preventing establishment in areas where temperatures dip below and sustain at freezing for extended lengths of time.[11] Just as in the case of the deer tick, *A. americanum* range has benefited from the warming trend seen in the Northeast region and is able to move into and colonize previously inaccessible regions.

The lone start tick is responsible for several medical conditions of interest including Southern tick associated rash illness which is similar in appearance to the *erythema migrans* rash seen in Lyme disease. Other pathogens transmitted by the lone star tick include the Bourbon virus, Heartland virus, and *Francisella tularensis* which causes tularemia. One of the most interesting outcomes of the lone star tick bite is a development of alpha-gal syndrome which is characterized by an allergic reaction to red meat and mammal products.

Example 3: Gulf Coast tick and Rickettsia

The Gulf Coast tick is another arthropod vector that has seen an expanded range. In a Connecticut Agricultural Experiment station newsletter, the movement of the tick is discussed. Normally endemic to areas of the Gulf Coast and Mexico, this tick has seen expanded ranges traveling up the eastern seaboard into the northeast.[12] This tick was first reported in Fairfield County in August 2020 and has likely established a population.

One of the medical conditions linked to this vector is rickettsia, a spotted fever, which is able to infect both humans and canines. Like the lone star tick, increasing temperatures in the northern latitudes have provided an expansion of suitable habitats for the tick to both live and reproduce in. As temperatures continue to rise it is highly likely that contact with these vectors will increase as will incidence rates of infection with the pathogens they carry.

Example 4: Mosquitoes

Ticks aren't the only vector to enjoy expanded ranges due to climate change. Mosquitoes, like other arthropods, rely heavily on external conditions like precipitation and temperature to support the development of areas that are suitable for habitation. Of the 3500 known species of mosquitoes over 2600 of them are native to the tropics and subtropics as they prefer humidity and increased temperatures.[13][14] There are mosquitoes that are also found in cooler regions—including one species that lives in the Arctic tundra and undergoes a large hatch in the summer as the heat melts the snow cover that is over the permafrost in this region.

Like the tick, mosquitoes are arthropods that feed on vertebrate blood. Female mosquitoes will seek out a blood meal in order to provide the protein essential for the healthy development of their eggs and larvae. Mosquitoes need a water source in order to lay their eggs, as their larvae are aquatic. This water source will provide a place for their larvae to develop into the flying adult. Their reliance on water means that mosquitoes tend to favor areas that are humid with adequate precipitation and relatively warm temperatures.

As climates change and areas further north experience increases in temperatures and humidity, they become more tolerable for mosquito populations. One study conducted found that only 5% of the Northeast is currently habitable by the Asian tiger mosquito (*Aedes albopictus*) which is known to carry several infectious diseases. However, projects estimate that this habitable area will increase to 16% in 2035.[13]

Mosquito ‘season’ is also changing. Mosquitoes are being encountered early in the year and persisting later. On average, mosquito seasons have increased by almost a month in most major US cities. Hartford has seen a gain of 37 days since the 1980s.[13] As with ticks, increases in season length can increase encounters and have an impact on the number of cases of mosquito carried diseases are present in a population.

Currently there are 49 species of mosquitoes in Connecticut, 28 of which are considered to be important disease vectors.[14] Of these mosquito species 10 of them have shown an increase in population size between 2000 and 2019.[10] There are several different viruses or parasites that can be transmitted by mosquito bites including Eastern equine encephalitis and West Nile virus.

Two of the mosquito species of concern in Connecticut are *Aedes aegypti,* a primarily subtropical species, and *Aedes albopictus* which was first identified in 2006 and is now showing increases in populations in New Haven and Fairfield counties.[10] This mosquito is a known worldwide carrier of several diseases including Cache Valley virus, West Nile virus, dengue, chikungunya, and Zika virus. Currently, the individuals caught in Connecticut have only carried Cache Valley and West Nile but there is always a concern of the introduction of new viruses now that the vector is currently in the area.[10] It is likely that *A. albopictus* is at its northernmost range currently but if temperatures continue to increase through climate change it is possible that the range can expand further into states like New Hampshire, Vermont, and the southern border of Maine.[15]

Expanded ranges of vector arthropods are not the only possible concern. As climates change, there are selective pressures applied to their natural predators as well. A recent study found that dragonflies, a predator of mosquito larvae, are experiencing an unexpected population shift due to climate change. Dragonflies that have reduced pigmentation in their wings and bodies are better able to deal with the increased temperatures associated with climate change. However, this change in coloration impacts the male dragonflies’ ability to attract mates, decreasing reproductive success.[16] A reduction in dragonfly populations can lead to a boom in mosquito populations and a corresponding increase in mosquito transmitted diseases.

Warming Impacts on Free-living Aquatic Pathogen Range

Indicators of Climate Change

There are additional consequences to increasing temperatures including warming of surface and shallow fresh and ocean waters. A study published in 2015 found that water temperatures of streams in the Chesapeake Bay area had an overall average increase in the surface temperature of the water of 1.2^{o} F in at least 79% of the sampled sites since the 1960s.[17][18] Surface temperatures of lakes have also increased between 1-2^{o} F since 1985, especially in Northern latitudes such as the Great Lakes. [19][20]

Oceans are experiencing similar trends to inland freshwaters. Surface sea temperatures (SST) have increased at a rate of 0.14^{o} F per decade since 1901 and have been higher during the past three decades than any point in past records.[21] This trend isn’t universal—the warmest areas tend to be near the equator and some areas, such as in the North Atlantic actually saw a temperature decrease although this is probably due in large to the melting of previously frozen polar ice cooling the waters.[22] Changes in the surface sea temperature can have a large impact on wind and weather patterns, influencing the frequency and intensity of storms.

Below surface waters, warming is also present. The epipelagic and upper-mesopelagic zones of the ocean (down to nearly 700 meters) act as heat sinks for the extra heat generated by global warming and have also increased in temperature. The ocean is able to absorb a great deal of heat energy without a correspondingly large change in temperature due to water's high heat capacity, helping to maintain atmospheric temperatures. However, steady increases in anthropogenic greenhouse gases continue to push the ocean heat content, showing an increase in nearly 18×10^{23} joules since the 1990s.[23]

Vector-borne diseases are not the only infectious agents that can benefit from a change in climate. Warmer ambient temperatures may also mean warmer waters—and the expansion of water-borne illnesses. While water itself is an excellent heat-sink for atmospheric heat, surface and shallow waters are impacted by increased temperatures and expanded warming seasons. As a result, certain water-borne pathogens or pathogens that are rarely seen outside of subtropical or tropical regions are moving into what is considered to be cooler waters. These outbreaks can be amplified by increases in extreme precipitation events.

Example 1: Ciguatera Fish Poisoning

One example of this is the increased range of ciguatera fish poisoning (CFP) from the Caribbean into areas of the Northern Gulf of Mexico.[24] Ciguatera often occurs in large reef fish like king mackerel, yellowfin grouper, barracuda, and several snapper species. There is a bioaccumulation of the ciguatera-toxin produced by the marine dinoflagellate *Gambierdiscus toxicus* which acts a food source for many of the prey species that these predatory fish feed upon. While this toxin is harmless to fish species, it is dangerous in humans and can cause symptoms from nauseas and vomiting to cardiovascular and nervous symptoms including abnormal heart rhythms (bradycardia or tachycardia), ataxia, and even cold allodynia neuropathic pain.[25]

A study completed in 2014 looked at the relationship between CFP cases in the United States, strength of tropical storm events, and surface sea temperatures. This relationship is due to the nature of *G. toxicus* to favor damaged or bleached reef formations and warmer waters. Intense tropical storms can cause widespread reef damage, especially in shallow water reefs like those found in the Caribbean.[24] Combined with increased surface sea temperatures (those remaining above 24^{o} C) these areas create the perfect breeding grounds for *G. toxicus* and abundant grazing for herbivorous fish species. Climate changes and global warming events have played a role in all aspects *G. toxicus* range as they can increase storm intensity and frequency, increase the temperature of surface waters, and cause coral bleaching providing the perfect habitat for increased habitation.[24]

An increase of even one storm per month lead to an 11% increase in CFP cases and there are predictions of increased storm frequencies and severity in the North Atlantic.[24] The model constructed by this study also noted that a surface sea temperature increase of 1^{o} C during high bloom months like August resulted in a 62% increase in CFP cases.[24] It is likely, according to their model that moderate increases in both surface sea temperature and storm frequency could increase cases could grow by as much as 200-400% yearly.[24]

While cases of CFP are rarely fatal, an increase in the number of cases is concerning especially since symptoms can persist from as few as two days up to long-haul cases where patients take more than a month to recover.

Example 2: Naegleria fowleri and PAM

There are also several freshwater examples of expanded pathogen range due to changes in climate. *Naegleria fowleri* is an ameboflagellate, known colloquially as the “brain eating amoeba”. It is a naturally occurring species that prefers freshwater hot springs and warm lakes and rivers and can be found on virtually every continent. It is thermophilic and will grow best in waters that reach 46^{o} C.[26] In cooler temperatures, it is often found in the sediment of rivers and lakes where it remains relatively not pathogenic.

Infections of *N. fowleri* are most commonly associated with the southern United States during summer months when water temperatures increase and encourage the amoeba to enter into the trophozoite phase.[27] This parasite enters through the nasal cavity of those swimming in warmer waters and penetrates through the cribriform plate into the brain causing fulminate (rapid) brain degeneration.[27]

Symptoms of primary amoebic meningoencephalitis (PAM) caused by an *N. fowleri* infection in early stages are very similar to those of bacterial meningitis. They can include nausea, vomiting, headaches, stiff neck, and photophobia. These symptoms usually occur between around five days after the amoeba has burrowed through the cribriform plate.[27]   The patient then begins to rapidly degenerate and may experience a loss of balance, seizures, and coma. Death typically occurs within a week to a week and a half after infection due to intracranial edema and destruction of brain tissues. Of the 143 known cases of PAM, only 4 people have survived.[26][27]

Cases of *N. fowleri* infection make the news because of the rareness of infection and the high mortality of those infected. Recently, some of those cases have been in northern areas where cases are not traditionally expected, including 1 case in Indiana, and two cases in Minnesota.[26] . In 2010, a case of infection was confirmed in Minnesota, making it the northernmost infection in the United States. Officials cite a hot summer and increased water temperatures for the case, activating dormant *N. fowleri* found in the sediments of those water bodies.[28]

As climates change and average temperatures rise, there may be a corresponding rise in the temperatures of surface waters. An article published by NASA in 2015 found that freshwater lakes are warming an average of 0.61 degrees each decade.[29]   Some of the largest increases were seen in northern latitudes, such as in Minnesota. Furthermore, milder winters and expanded warm seasons can increase exposure risk by encouraging extended periods of swimming and water sports. As populations aim to keep cool, participation in these outdoor events may increase incidents overall, not just in the north, as more people participate in risk behaviors that may expose them to the amoeba.

Allergies and the Expanded Growing Season

Indicators of Climate Change and Ragweed Seasons

Seasonal allergies due to pollen are also impacted by these changes both in their duration and their severity. Many people suffer from immune responses from the pollen that is released from plants in bloom, including ragweed and grasses. Pollen is released as part of the reproductive cycle of plants and is used as a dispersal mechanism. Since pollen is carried by the wind it can be distributed widely across a region.

As people breathe in the pollen or touch surfaces where it has stuck and rub their eyes or mucosa they take in these pollen grains. Pollen has proteins that coat the surface and act as antigens. Part of the immune response is to recognize foreign antigens, or non-self, and trigger a series of reactions aimed at defending the body against perceived threats. Often these threats are infectious pathogens, but there are cases where the body will also respond to non-pathogenic proteins.

Seasonal allergies such as those to grass pollen and ragweed are an overreaction of the body to these pollen granules. Symptoms of pollen allergies can be mild to moderate. One common symptom is allergic rhinitis, which is linked to congestion and sneezing or general irritation of the nasal tissues. Allergic rhinitis is relatively common, especially in areas that experience high pollen counts during the spring, summer, and fall. In addition to these mild respiratory symptoms, more concerning increases in asthma related respiratory distress also increase due to sensitivities to respiratory tract irritation.

In many states, growing seasons have increased on average by two weeks since the early 20th century with the steadiest increase happening since the 1980s.[30] This change in the growing season length can be linked to data showing that the last hard frost in spring is occurring on average six days earlier than the 1980s and the first killing frost of autumn occurring almost 7 days later than average.[30] In Connecticut specifically, frost days have decreased since the 1920s in a large portion of the state, altering the growing season by allowing for increased grow times and milder winters.[10] While this is amazing news for farmers and hobby gardeners, with longer growing seasons, early bloom date, and later frosts, this can expand the pollen bloom seasons linked to allergies.

In a 1995 ragweed pollen study conducted by the National Allergy Bureau across 11 locations in Canada and the United States, 10 of the cities had an increase in the allergy season—with some locations having an overall gain of over 20 days in length.[31] Warmer temperatures early in spring and increased available carbon dioxide concentrations allow for an increase in pollen production and higher overall pollen counts.[32] Furthermore, ragweed usually matures in late summer to early fall but will continue to be fruitful until the first hard frost. Expanded growing seasons allow for ragweed to bloom earlier and continue blooming longer, resulting in longer allergy seasons across these regions.[33]

Heat Related Illnesses and Deaths

Indicators of Climate Change

Heat waves, periods of at least three days where highs were sustained 90° F or more, are also occurring at a greater frequency, duration, and intensity. On average, there are around 6 heat waves per year, up from two in the 1960s, and those heat waves last at least a day longer.[34] One study found that 46 out of 50 cities not only saw an increase in the frequency of heat waves but also an increase in the intensity.[34]

Urban areas are susceptible to heat waves because of the infrastructure of the city itself. Increased amounts of asphalt and reflective surfaces like metal help to trap and re-emit heat which increases the ambient air temperature. In addition, heat is generated by running vehicles, buildings, and the large population in the area. This creates a ‘heat island effect’ increasing the overall temperature in these urban areas. In areas that are low-income and may have homes that lack insulation or air conditioning, this increased heat is compounded putting populations in this area at higher risk of experiencing heat-related complications.[10]

In Connecticut specifically, the average temperature has increased by about 3° F from 1895 to 2019 state wide even though the number of significant heat days has not increased significantly.[10] One of the most dangerous observations has been an increase in warmer nighttime temperatures which prevent cooling and have negative long term health consequences especially in high heat days, leading to the increase in medical emergency cases.

Heatstroke and Heat-Related Illnesses

As previously mentioned, the number of extreme heat days (those with temperatures above 90° F) have not statistically increased in Connecticut as of yet but as average temperatures increase it is expected that this trend will increase in the future. If changes are not made, it is possible that the number of days could increase from around 3 per year to around 44 per year by 2050.[10] In spite of this lack of visible increase, there has still been an impact on human health.

In Connecticut, hospital visits averaged around 422 visits and 45 hospitalizations per year between 2007 and 2016 due to heat related conditions although it is expected that these numbers are under reported because symptoms are often attributed to other conditions.[10]

Heat related deaths are those that are directly related to exposure as the underlying cause or as a contributing factor. Heat exhaustion and heat stroke occur due to prolonged exposure to high temperatures or due to physical exertion in high temperatures. Heatstroke is especially dangerous as the body temperature spikes and can rapidly impact the cardiovascular, respiratory and nervous systems of patients. Heatstroke can come on quickly and is aggravated due to high temperatures, high exertion, and dehydration. This is part of the reason behind the increase in football training camp deaths in August months—student athletes are in the perfect storm of conditions for heatstroke.[35]

Part of why extreme heat is so harmful is that it impacts the body's ability to maintain a safe temperature. The body has systems in place that are able to help regulate internal temperature, including sweating, however high heat days can lead to increased dehydration and other conditions that increase susceptibility to heat stroke. Warmer summer nights increase the inability of the body to cool itself leading to more cases.[10,34]

The extreme heat can also aggravate other heat-related complications, especially in the elderly or those with chronic-conditions since all body systems are impacted. Those patients with kidney, lung, or heart diseases are at risk because of the impact on those organs but it is also dangerous in populations that have diabetes. Groups that are at risk include the homeless, populations over 65, and individuals who are spending a significant amount of time outside doing physically demanding tasks. Inadequate temperature control measures or ventilation also puts indoor workers or individuals at risk as well.

Implications of further climate change on ice and glaciers

Indicators of Climate Change

Glaciers are losing mass as temperatures increase. Between 1956 and 2019, there has been a cumulative loss of nearly 30% of glacier mass globally.[36] Glaciers found in Alaska and Washington have seen corresponding losses in mass between 20 to 40% since the 1980s.[37] Another site, Glacier National Park located in Montana has 37 glaciers, which have all lost mass. An aerial survey of the park conducted to capture glacier recession during 1966 to 2015 by the US Geological Society estimates over 34% loss of the overall mass for the site.[38]

Permafrost, like glaciers, have also started to thaw due to warming temperatures. Permafrost is a layer of ground that is in a hard-frozen state found mostly in the northernmost latitudes near the Arctic. There are several areas that are extensively composed of permafrost layers—Alaska is about 85% permafrost.[39]   One of the ways that permafrost temperatures are measured is by drilling boreholes into the land and sampling at different depths. A data set published in 2020 by the University of Alaska Fairbanks found that 13 of the 14 borehole sites in Alaska have increased in temperature at both 49 and 85 foot depths.[39]   This warming allows for several things to occur—not only does it release frozen biomass in these areas which can have implications for human health, but it releases trapped greenhouse gases like methane and carbon dioxide into the atmosphere.[40]

Example 1. Unlocking the Viral Vault

Glaciers can act as time capsules for many things, including viruses and biological materials. Ice, especially ice that is deeper in the glacier, can be several hundreds of thousands of years old. Small pockets of ice may host bacterial, viral, and fungal pathogens from the environment or from frozen biological samples.

As climate change causes the recession of glacial ice, there is the potential for viruses to be released. Some cores of glacial ice from a Tibetan glacier had 28 novel virus genera that are calculated to be over 10,000 years old.[41]   There are concerns that some of these viruses may be influenza virus, the human calicivirus (HuCV), or other strains that might re-emerge.

Example 2. Thawing Permafrost and Anthrax

Illnesses thawing from the ice to infect humans is not just theory. In the Yamel Peninsula, there were cases of increasingly warm periods causing extensive melting of the active layer and some of the frozen soil underneath. In these deeper, more permanently frozen soils there may been organic material including bodies of animals or people who died due to different pathogenic outbreaks. In this particular area of Siberia, one case in 2016 involved the thawing of a reindeer carcass that was infected with and died from anthrax.[43][44]

Anthrax infections are caused by a soil bacteria called *Bacillus anthracis*. Anthrax is a soil bacterium that, as part of its life cycle, can release infectious spores. These spores can be inhaled, ingested, or introduced into the body through open cuts. When the spores enter human or animal tissues they become active and produce toxins that can be lethal. When a grazing animal eats grass that is infected with these spores they begin to multiply and spread.

The toxins produced by anthrax can impact the body in a variety of ways depending on the route of introduction. For example, cutaneous anthrax infections are the least dangerous and often result in cutaneous ulcers and blisters.[42]   Unaddressed cutaneous infections are dangerous and can result in loss of a limb due to extensive tissue damage or, if left unchecked, death. Inhalation or ingestion are more severe. With inhalation related anthrax cases, the anthrax can infest lymph nodes of the chest and alveoli, causing breathing problems and eventual organ failure. These cases are fatal in the untreated and have a 55% survival rate in those who receive prompt medical care.[42] Ingested anthrax is also survivable with treatment and exhibits symptoms similar to those of inhaled anthrax.

As the active layer and the layer of permafrost that covered the carcass thawed, the bacteria were able to thaw as well and the bacteria were able to make their way out into the soil. Grazing reindeer consumed the pathogen. As herders tended to these animals and came into contact with infected animals or spores themselves, they became infected. This outbreak ended up killing one person and hospitalizing multiple others. It also resulted in the death of over 2000 reindeer. [43][44]

If warming trends continue, it is likely that out breaks like this may occur more frequently in the future. An NPR article cites that across northern Russia there are around 7000 burial grounds that are covered by thin layers of permafrost similar to the one for the infected reindeer.[44] It isn't out of the realm of possibility that other viruses or bacteria may be frozen in the ice.

Teaching Strategies and Classroom Activities

Indicator Jigsaw Activity

There are many indicators that students can look at when first studying climate change—too many for each individual student to do alone. Instead, students can be broken up into small groups either randomly or by interest. Students should work together to understand and present these climate indicators. One way that this portion of the curriculum can be addressed is by completing a climate indicator jigsaw.

The EPA maintains a climate change indicators website that contains six major types of climate change indicators. Under each of these major indicator headers are sub-headers that link to raw data, graphs, and articles. Students should pick one sub-header or could be given a folder with two related sub-indicators of study. Individually, students will identify the trends in the data and how this connects with climate change.

Once students have individually looked at their indicator, they can join up with other peers in their climate change indicator group and share out. Amongst the group, students should come up with a poster or a short power-point presentation addressing the most important data that was presented in the group. Student groups can then share out to the whole class if time permits or student posters can be put up on a wall for a gallery walk where they gather additional data.

If this course is being completed in a physical science class or general biology where disease are not the focus but the teacher would like to show some of the direct implications for human health, the "Health and Society" section can be included as one of the sub-topics and shared out. Some additional time can be spent talking about human health connections and how they can be connected to the climate change indicators. In anatomy classes or other classes with a stronger biomedical focus, it may be best to remove that group from the survey and address those individual topics as a special focus or as a case study in the course.

Feedback Loop Practice

Feedback loops are an important concept for students who are in biology and anatomy to understand. Students who are studying climate change should also be familiar with feedback loops. One of the ways to give students additional practice is to give them some sample loops to work through.

First, students should be given a template of a positive and a negative feedback loop. Students need to understand that, in negative feedback loops, the conditions that stimulate the loop are inhibited by the outcome. In essence, this feedback loop will ‘return to normal’ and shut itself off until the next deviation. An example negative feedback loop may be like the following: I am thirsty. I put a quarter into the vending machine. The vending machine gives me a water bottle. I drink the water. I am no longer thirsty. In this example, the initial input of ‘thirst’ is cancelled by the ending output of drinking water and the loop stops.

A positive feedback loop is like a spiral staircase, moving someone away from the main floor either to a higher or lower level. In positive feedback loops the input is not resolved by the output. Instead, the output feeds into the input and continues the loop. An example positive feedback loop may be like the following: I am listening to my music while my roommate is talking to their friend. My roommate cannot hear over the music so they speak a little louder. I cannot hear my music so I turn my music up. In turn, my roommate and their friend speak a little louder. I turn my music up again since I can’t hear it. This set of events would continue, pushing the scenario further away from the normal volume. Usually in positive feedback loops there is a series of events that will ‘shut off’ the loop such as in the childbirth or lactation anatomy loops.

To begin studying feedback loops, begin by addressing the misconception that ‘positive’ and ‘negative’ are words that deal with the outcome of the feedback. Many students assume that the ‘negative’ feedback loop is called that because it causes a negative outcome. One useful tool can be to remind students that Negative feedback loops are a return to Normal in this system. Students can practice making their own scenarios like the ones above and analyzing real world scenarios to identify if they are positive or negative.

Once students are confident with identifying positive and negative feedback loops, students can be handed an envelope with arrows and phrases and use those to construct feedback loops related to climate change. A good stretch activity would be to introduce an anthropogenic change into the system and have students identify how that might impact their feedback loop.

Case Studies

Case files and case studies are excellent ways to engage students in biology or anatomy courses as a way to introduce the connections between climate change and human health. Physical science teachers can also consider incorporating a case file as a way to provide some diversity or re-energize a course. These allow students to practice their critical thinking skills and their ability to support a claim with evidence and solid reasoning. Casefiles should include important patient history in addition to their blood temperature, respiration rates, blood pressure, and other important intake information. For students who do not have familiarity with health ranges, a reference chart can be provided or the information can be discussed as a group.

Students should begin by reading through the patient file and text coding. A recommended method for reading through the casefile is as follows. Initially have students read the file and box any terms that they do not understand. Students can then take time to look up those words to create a class vocabulary list for the patient. This is an excellent opportunity to introduce medical terminology and help students learn prefixes and roots that are commonly used in medicine.

Once students have completed this initial read through, they should complete a second pass through where they underline any symptoms that the patient is experiencing. These symptoms can be listed on small white boards as a group assignment or on the class white board if the case file is being worked through as an entire class. Students begin the third and final reading where they identify any other important information about the patient that can be helpful in identifying what is wrong with their patient. It may also be important to include information about the time of year that the patient has started to demonstrate symptoms. For example, if the patient has Lyme disease, you may write in your case file that the patient has been out in their garden during the spring or summer when they started to notice the symptoms.

Students then brainstorm illnesses that could be causing the symptoms using reliable sources to identify the cause of the illness. Students should always complete a written analysis of the symptoms of their patient including how those symptoms are directly tied in with the suspected illness. Furthermore, since many illnesses may present with similar symptoms, it is crucial that students identify alternative diagnoses and justify their decision to dismiss them. This is especially true for many of the arthropod transmitted viruses which have similar presentations in patients. This would be an excellent time to introduce tools like a nucleotide BLAST where students can input a piece of a DNA or an amino acid sequence obtained from the virus and compare it to known samples. Provide students with a sequence for the viral pathogen of choice that they can upload to determine the specific virus. BLASTS can be completed for free using the NCIB Nucleotide Blast databank.

An alternative method is to create an initial casefile where the patient is admitted to the hospital with some of the initial symptoms. The patient's stats can change in 'real time' and crises can be included after certain periods of time. This format creates a sense of urgency as their patient becomes sicker and sicker. This particular set-up may be interesting to model *N. fowleri* where symptoms may start off mild and then rapidly progress.

A final suggestion is to create multiple interconnected case files with each diagnosing group receiving one or two. This sort of model is helpful for modeling an outbreak. Several patients with varying symptoms can be set up and teams must look for connections in symptoms, behaviors, and locations that may account for their illnesses. This sort of case file set-up is useful for a condition like CFP, where students need to trace the outbreak back to the source.

Predicted Ranges Activity

Modeling is an important skill for students to learn in high school science curriculum. This activity allows students to make predictions related to climate models and connections with possible changes on human health.

For this activity students should use local data if possible. Yale published a report providing local data based on different climate indicators specifically for Connecticut and the possible connections to human health.[10] Students can also use their data from the indicator website by the EPA. In this activity, students should use the data to make predictions on what might happen for temperature, precipitation, or any other factor of interest. If students are looking at one ecosystem they should use a few measures including seasonal temperatures, precipitation, humidity, in addition to ecosystem specific indicators such as the surface temperature of freshwater or streamflow for inland aquatic environments or drought for inland areas. Students need to make a prediction of what will happen with regards to the environment by 2050 and 2100 if no major changes are made and they should justify their reasoning based on the trend data.

Once students have made their predictions about the possible changes to the indicators for their system they should predict what medical or human health implications would follow. For example, if students predict that an area will become more humid and warmer with increased precipitation, they may mention that they believe that there could be increased cases of West Nile virus or Eastern Equine Encephalitis as a result of larger mosquito populations.

Heat Island Effect Lab

One simple lab that can be used to discuss the idea of the heat island effect is to have students experiment with how different substances can trap heat. This lab would require some pre-planning about the time of implementation—it should be done on a sunny day, preferably in August/September when students are just returning to school or in May/June to best replicate what may happen during the summer months.

In this experiment, students should identify different surfaces that are in their city such as black or darkly colored asphalt, brick buildings, metal structures, plastic or wooden benches, concrete sidewalks, grassy areas. Students can use a surface temperature probe to get the temperature of the item and compare that to the ambient air temperature. If there are multiple sections of this class, temperatures can be taken throughout the day to create a better overall picture.

Students can also set up well insulated vs. poorly insulated 'rooms' using containers to see how insulation can be used as a preventative measure for heat conditions. If possible, remote temperature probes are ideal since the box can be sealed off while still allowing for students to obtain readings. Students can attempt to develop the ideal insulation for their room through the experimental design.

Project Based Solutions

More districts are moving towards project based assessments where students tackle real world problems and present those solutions to an authentic audience. Depending on if this curriculum is to be taught in a physical science course or a biological science course there are a number of project based assessments that students could approach.

The teacher would need to pick a relevant essential question or task that complements the content that they wish students to cover in their course. These questions should be not be just researchable— they should require students to engage their engineering design skills or come up with a strategy to employ.

For example, a teacher may want to focus on how urban areas and suburban areas can reduce mosquito breeding grounds in order to lower disease incidence rates. Students may approach this problem in different, authentic ways. One group may come up with an educational campaign to encourage people to turn over buckets or not leave out containers that may contain standing water. Another group may design a screen system that could go over rain barrels that will prevent mosquitoes from laying their eggs in these areas.

An essential question that asks how their city can reduce the number of patients who are brought into the hospital each year may look at a number of different factors from educational campaigns, to letters requesting the opening of additional cooling centers for the populations who are most at risk.

Once a topic or a question has been posed, students should spend some time completing some research and brainstorming into the question. Students should generate a list of questions they need to know the answers to in order to be successful. While older students may be able to complete this step on their own, younger students may need to do this as a guided practice with modeling.

The teacher should be careful to only provide students with information as it becomes necessary to facilitate furthering student projects. For example, students may have a question about how different materials in a city absorb heat. Rather than giving students information about how different substances absorb radiation, the teacher should generate activities that allow students to draw their own conclusions using experiences. In this particular example, the teacher can pull in a lab activity similar to the heat island one discussed above so students can gather data.

Reference Table

Disease	**Vector**	**Pathogen Type**	**Key Symptoms**
Anaplasmosis	Ticks	Bacteria— *Anaplasma phagocytophilum*	Fevers, headaches, chills, and muscle aches. Late stage severe symptoms include respiratory issues, bleeding, organ failure
Babesiosis (Piroplasmosis)	Ticks	Protist— *Babesia microti*	Joint pains, fatigue, loss of appetite, chills, and headaches. Late stage can include hepatosplenomegaly and kidney damage
Bourbon Virus	Ticks	Virus	Nausea, vomiting, aches, rash, fever
Cache Valley	Mosquitoes	Virus	Nausea, vomiting, fatigue, and rash. In extreme cases can cause encephalitis, loss of coordination, aphasia, and seizure
Chikungunya	Mosquitoes	Virus	Fever, joint swelling and pain, fatigue, rash
Dengue	Mosquitoes	Virus	Eye pain, joint and bone pain, headaches, rash, nausea
Eastern Equine Encephalitis (EEE)	Mosquitoes	Virus	Fever, encephalitis symptoms, joint pain, chills, drowsiness, seizures. In some cases this virus can cause coma and death
Ehrlichiosis	Ticks	Bacteria—*Ehrlichia sp.*	Fever, chills, rash, muscle aches, confusion, nausea. In late stage cases it can cause organ failure and uncontrollable bleeding
Heartland virus	Ticks	Virus	Fever, fatigue, nausea, headache, joint pain, lowered white cell count
Powassan	Ticks	Virus	Fever, headache, vomiting, encephalitis, aphasia, seizures, memory loss
Rickettsia	Ticks	Bacteria—*Rickettsia sp.*	Fevers, chills, weight loss
Tularemia	Ticks	Bacteria—*Francisella tularensis*	Fever, ulceration of lymph glands, tissue damage, difficulty breathing
West Nile	Mosquitoes	Virus	Fever, headaches, vomiting, encephalitis, disorientation. In extreme cases it can include paralysis and vision loss
Zika	Mosquitoes	Virus	Microcephaly in infants, rash, conjunctivitis, muscle or joint pain, fevers, myelitis

Table 1. A Brief Summary of Some Arthropod Transmitted Diseases. This table includes some of the diseases mentioned in this paper and includes the vector and common symptoms as a quick reference. Other credible resources to reference to gather more information on the prevalence of this disease in your area, diagnostics, and treatment options.

Work Cited

Andreadis, T., M. Thomas, and J. Shepard. “Identification Guide to the Mosquitoes of Connecticut.” New Haven, CT: Connecticut Agricultural Experiment Station, 2005. Reference book to the mosquito species in Connecticut.

Bozzi, L., and R. Dubrow. "Climate Change and Health in Connecticut: 2020 Report." 2020. Accessed July 01, 2021. https://ysph.yale.edu/climate/YCCCH_CCHC2020Report_395366_5_v1.pdf. In depth, comprehensive study of the impact of climate change on human health in Connecticut.

Centers for Disease Control (CDC). "Data and Surveillance: Lyme Disease." April 29, 2021. Accessed July 07, 2021. https://www.cdc.gov/lyme/datasurveillance/index.html. Range and summary data of Lyme disease cases.

Centers for Disease Control (CDC). "Potential Range of *Aedesaegypti* and *Aedesalbopictus* in the United States, 2017." March 11, 2020. Accessed July 07, 2021. https://www.cdc.gov/mosquitoes/mosquito-control/professionals/range.html. Ranges and conditions for *Aedes* sp. and possible expansions due to climate change.

Centers for Disease Control (CDC). "Signs and Symptoms of Untreated Lyme Disease.” January 15, 2021. Accessed July 07, 2021. https://www.cdc.gov/lyme/signs_symptoms/index.html. Lyme disease symptomology.

Centers for Disease Control (CDC). "What Is Anthrax?" November 20, 2020. Accessed July 07, 2021. https://www.cdc.gov/anthrax/basics/index.html. A brief primer on anthrax.

Connecticut Agricultural Experiment Station (CAES). "Populations of Gulf Coast Tick, a New Species to the Northeast and a Vector of Spotted Fever to Humans, Discovered in Connecticut." August 24, 2020. Accessed June 28, 2021. https://portal.ct.gov/-/media/CAES/DOCUMENTS/Publications/Press_Releases/2020/CAES-Press-Release-Gulf-Coast-Tick-8-24-2020.pdf. Released document explaining expansion of novel tick in Connecticut.

Doucleff, M. "Anthrax Outbreak In Russia Thought To Be Result Of Thawing Permafrost." NPR. August 04, 2016. Accessed July 07, 2021. https://www.npr.org/sections/goatsandsoda/2016/08/03/488400947/anthrax-outbreak-in-russia-thought-to-be-result-of-thawing-permafrost. Summary of anthrax outbreak due to permafrost melt.

El-Sayed, A., and M. Kamel. "Future Threat from the past." Environmental Science and Pollution Research. October 17, 2020. Accessed July 07, 2021. https://link.springer.com/article/10.1007/s11356-020-11234-9.

Environmental Protection Agency (EPA). "Climate Change Indicators" EPA. July 16, 2021. https://www.epa.gov/climate-indicators EPA databank of climate change indicator research.

Environmental Protection Agency (EPA). "Climate Change Indicators: Ocean Heat." EPA. April 08, 2021. Accessed July 07, 2021. https://www.epa.gov/climate-indicators/climate-change-indicators-ocean-heat.

Environmental Protection Agency (EPA). "Climate Change Indicators: U.S. and Global Temperature." EPA. April 27, 2021. Accessed April 07, 2021.

https://www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-temperature.

Fagre, D.B., L.A. McKeon, K.A. Dick, and A.G. Fountain. 2017. “Glacier margin time series (1966, 1998, 2005, 2015) of the named glaciers of Glacier National Park, MT, USA.” U.S. Geological Survey data release. https://doi.org/10.5066/F7P26WB1.

Fann, N., T. Brennan, P. Dolwick, J.L. Gamble, V. Ilacqua, L. Kolb, C.G. Nolte, T.L. Spero, and L. Ziska, 2016. “Chapter 3: Air quality impacts.” The impacts of climate change on human health in the United States: A scientific assessment. U.S. Global Change Research Program. https://health2016.globalchange.gov.

Gingold, D. B., M. J. Strickland, and J. J. Hess. "Ciguatera Fish Poisoning and Climate Change: Analysis of National Poison Center Data in the United States, 2001-2011." Environmental Health Perspectives. June 2014. Accessed July 07, 2021. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4050511/.

Habeeb, D., J. Vargo, and B. Stone, Jr. 2015. “Rising heat wave trends in large U.S. cities.” Nat. Hazards 76(3):1651–1665. doi:10.1007/s11069-014-1563-z. Data set on increased heat wave in urban areas.

Horton, R., G. Yohe, W. Easterling, R. Kates, M. Ruth, E. Sussman, A. Whelchel, and D. Wolfe. "Climate Change Impacts in the Northeast." National Climate Assessment. May 2014. Accessed July 07, 2021. https://nca2014.globalchange.gov/report/regions/northeast. Impacts of climate change in the Northeastern states.

Intergovernmental Panel on Climate Change (IPCC). "AR5 Climate Change 2014: Mitigation of Climate Change." Accessed June 11, 2021. https://www.ipcc.ch/report/ar5/wg3/. IPCC report detailing impacts of climate change on human and natural interests.

Intergovernmental Panel on Climate Change (IPCC). 2019. “Summary for policymakers. In: IPCC special report on the ocean and cryosphere in a changing climate.” Portner, H.-O., *et al.* (eds.). https://report.ipcc.ch/srocc/pdf/SROCC_FinalDraft_FullReport.pdf. Changes in ocean and glacier health due to climate change.

Isreal, B. "Is Climate Change Making Temperatures Too Hot for High School Football?" Scientific American. August 13, 2012. Accessed July 07, 2021. https://www.scientificamerican.com/article/is-climate-change-making-termeratures-too-hot-for-high-school-football/. An article correlating climate change to the increase in football summer training camp deaths due to heat illness.

Jastram, J.D., and K.C. Rice. 2015. Air and stream-water-temperature trends in the Chesapeake Bay region, 1960–2014. U.S. Geological Survey Open-File Report 2015-1207. https://pubs.er.usgs.gov/publication/ofr20151207. A dataset looking at changes in the Chesapeake bay temperatures.

Kemble, S., *et al*. "Fatal Naegleria Fowleri Infection Acquired in Minnesota: Possible Expanded Range of a Deadly Thermophilic Organism." Clinical Infectious Diseases: An Official Publication of the Infectious Diseases Society of America. January 11, 2012. Accessed July 07, 2021. https://pubmed.ncbi.nlm.nih.gov/22238170/. Minnesota *N. fowleri* case and implications.

Lindsey, R. "Climate Change: Atmospheric Carbon Dioxide: NOAA Climate.gov." Climate Change: Atmospheric Carbon Dioxide | NOAA Climate.gov. August 14, 2020. Accessed June 10, 2021.

https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide. Connection between CO_2 levels and climate change.

Moore, M. P., *et al*. "Sex-specific Ornament Evolution Is a Consistent Feature of Climatic Adaptation across Space and Time in Dragonflies." PNAS. July 13, 2021. Accessed July 16, 2021. https://www.pnas.org/content/118/28/e2101458118. Study looking at loss of pigmentation due to increased temperatures of dragonflies and the impact on mating.

"Mosquito Season Getting Longer." Climate Central. July 29, 2015. Accessed July 07, 2021. https://www.climatecentral.org/gallery/graphics/mosquito-season-getting-longer. A brief synopsis of changes in mosquito-days for the United States.

NOAA (National Oceanic and Atmospheric Administration). 2021. "Extended reconstructed sea surface temperature." National Centers for Environmental Information. Accessed February 2021. www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst. Surface sea temperature changes over time.

NOAA (National Oceanic and Atmospheric Administration). 2021. "NOAA Merged Land Ocean Global Surface Temperature Analysis". Accessed March 2021. www.ncdc.noaa.gov/data-access/marineocean-data/noaa-global-surface-temperature-noaaglobaltemp.

NOAA (National Oceanic and Atmospheric Administration). 2021. "NOAA CoastWatch, Great Lakes node." Accessed February 2021. https://coastwatch.glerl.noaa.gov.

NORD (National Organization for Rare Disorders). "Ciguatera Fish Poisoning." Accessed July 07, 2021. https://rarediseases.org/rare-diseases/ciguatera-fish-poisoning. Clinical signs and symptoms of CFP in human populations.

Rice, K.C., and J.D. Jastram. 2015. "Rising air and stream-water temperatures in Chesapeake Bay region, USA." Climatic Change 128(1):127–138. Data set and study of surface water temperatures related to climate.

Roy-Dufresne, E., T. Logan, J. A. Simon, G. L. Chmura, and V. Millien. "Poleward Expansion of the White-Footed Mouse under Climate Change: Implications for the Spread of Lyme Disease." 2013. Accessed July 07, 2021. https://doi.org/10.1371/journal.pone.0080724. Range expansion of tick host and relation to warming climates.

Sagurova, I., *et al*. "Predicted Northward Expansion of the Geographic Range of the Tick Vector *Amblyomma americanum* in North America under Future Climate Conditions." National Institute of Environmental Health Sciences. October 31, 2019. Accessed July 07, 2021. https://ehp.niehs.nih.gov/doi/full/10.1289/EHP5668. A predictive model estimating possible tick range expansion with continued continental warming.

Sharma, S., *et al*. 2015. "A global database of lake surface temperatures collected by in situ and satellite methods from 1985–2009". Sci. Data 2:150008. doi:10.1038/sdata.2015.8. Dataset of lake surface temperatures over time.

Stella, E., L. Mari, J. Gabrieli, C. Barbante, and E. Bertuzzo. "Permafrost Dynamics and the Risk of Anthrax Transmission: A Modelling Study." Nature News. October 07, 2020. Accessed July 07, 2021. https://www.nature.com/articles/s41598-020-72440-6. Study looking at the release of anthrax spores and the introduction into human populations.

"Study: Climate Change Rapidly Warming World's Lakes – Climate Change: Vital Signs of the Planet." NASA. December 17, 2015. Accessed July 07, 2021. https://climate.nasa.gov/news/2378/study-climate-change-rapidly-warming-worlds-lakes/. A study of lake temperatures and the correlation to warmed climates.

University of Alaska Fairbanks. 2021. Sites map. Accessed February 2021. https://permafrost.gi.alaska.edu/sites_map. Alaskan permafrost site maps noting changes due to climate.

USGS (U.S. Geological Survey). 2020. Glacier-wide mass balance and compiled data inputs: USGS benchmark glaciers (ver. 4.0, November 2019). Accessed December 2020. https://alaska.usgs.gov/products/data.php?dataid=79. doi:10.5066/F7HD7SRF. Data set of glacier mass compiled by the U.S. Geological Survey.

WGMS (World Glacier Monitoring Service). 2020. Global glacier change bulletin no. 3 (2016–2017). Zemp, M., *et al.* (eds.). ICSU (WDS)/IUGG (IACS)/UNEP/UNESCO/WMO. Zurich, Switzerland: World Glacier Monitoring Service. Based on database version: doi:10.5904/wgms-fog-2019-12. Research of reduced glacier mass due to climate change.

Ziska, L., *et al*. 2011. Recent warming by latitude associated with increased length of ragweed pollen season in central North America. P Natl. Acad. Sci. USA 108:4248–4251. Summary study of ragweed season duration.

Appendix on Implementing District Curriculum Standards

Next Generation Science Standards

Selected are a list of Next Generation Science Standards that are aligned with this unit for high school, but this unit can also be adjusted to fit middle school environmental science and health curriculum. The core information in this unit is focused on climate change, which fits in well with the HS-ESS strand. Classroom activities and suggested labs are included at the end of this unit that are suitable for a general science, chemistry, or environmental science class.

The medical applications of this unit are suitable for any anatomy and physiology or human health course when prevented as a case study or a running thread to interweave throughout the body systems. Some sample activities are included for this unit for a medical or biology related course.

HS-LS2-7 Ecosystems: Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

HS-ESS2-2 Earth’s Systems: Analyze geoscience data to make the claim that one change to Earth’s surface can create feedbacks that cause changes to other Earth systems.

HS-ESS2-4 Earth’s Systems: Use a model to describe how variations in the flow of energy into and out of Earth’s systems result in changes in climate.

HS-ESS2-6 Earth’s Systems: Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

HS-ESS3-5 Earth and Human Activity: Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

Connecticut Common Core Standards for English

This curriculum can also be used to address Connecticut common core state standards for English. These common core standards may be different for teachers in other states, but the practices can easily be aligned and transferred.

CCSS.ELA-LITERACY.RST.9-10.1: Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

CCSS.ELA-LITERACY.RST.9-10.3: Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

CCSS.ELA-LITERACY.RST.11-12.7: Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

CCSS.ELA-LITERACY.RST.11-12.8: Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

CCSS.ELA-LITERACY.RST.11-12.9: Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Notes

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[1] Lindsey, “Climate Change: Atmospheric Carbon Dioxide”, 2020.

[2] IPCC, “Climate change 2014: Mitigation of climate change”, 2014.

[3] Class notes

[4] EPA, “Climate Change Indicators: US and Global Temperature”, 2021.

[5] CDC, “Lyme Disease: Data and Surveillance”, 2021.

[6] CDC, “Lyme Disease: Signs and Symptoms", 2021.

[7] EPA, “Climate Change Indicators: Lyme Disease”, 2021.

[8] Horton *et al.,* "Climate Change Impacts in the Northeast”, 2014.

[9] Roy-Dufresne *et al.,* “Poleward Expansion of White-footed Mouse” 2013.

[10] Bozzi *et al.,* “Climate Change and Health in Connecticut: 2020 Report”, 2020.

[11] Sagurova, *et al.,* “Predicted Northward Expansion of the Geographic Range of the Tick Vector *Amblyomma americanum* in North America under Future Climate Conditions”, 2019.

[12] CAES, “Gulf Coast Tick Press Release”, 2020.

[13] Climate Central, “Mosquito Season Getting Longer” 2015.

[14] Andreadis, “Identification Guide to the Mosquitoes of Connecticut”, 2005.

[15] CDC, “Potential Range of Aedes Mosquito”, 2020.

[16] Moore, *et al.,* “Sex-specific ornament evolution is a consistent feature of climatic adaptation across space and time in dragonflies”, 2021.

[17] Jastram, *et al.,* “Air and stream-water temperature trends in Chesapeake Bay region”, 2015.

[18] Rice, *et al.,* “Rising air and stream-water temperatures in Chesapeake Bay region”, 2015.

[19] Sharma, *et al.,* “A global database of lake surface temperatures collected by in situ and satellite methods from 1985–2009”, 2015.

[20] NOAA, “CoastWatch, Great Lakes node,” 2021.

[21] NOAA, “Extended reconstructed sea surface temperature”, 2021.

[22] NOAA, “NOAA Merged Land Ocean Global Surface Temperature Analysis”, 2021.

[23] EPA, “Climate Change Indicators: Ocean Heat”, 2021.

[24] Gingold, *et al.,* “Cigatera Fish Poisoning and Climate Change”, 2014.

[25] National Organization for Rare Disease, “Cigatera Poisoning”, 2009.

[26] Kemble, *et al.,* “Fatal Naegleria fowleri infection acquired in Minnesota”, 2012.

[27] CDC, “General Information: Naegleria”, 2016.

[28] Kemble, *et al.,* “Fatal Naegleria fowleri infection acquired in Minnesota”, 2012.

[29] NASA, “Study: Climate change rapidly warming world’s lakes”, 2015.

[30] EPA, “Climate Change Indicators: Length of Growing Season”, 2021.

[31] Ziska, *et al.,* “Update: Recent warming by latitude associated with increased length of ragweed pollen season in central North America”, 2016.

[32] Ziska, *et al., “*Recent warming by latitude associated with increased length of ragweed pollen season in central North America”, 2011.

[33] Fann, *et al.,* “Chapter 3: Air quality impacts”, 2016.

[34] Habeeb, *et al.,* “Rising heat wave trends in large U.S. cities”, 2015.

[35] Israel, “Is Climate Change Making Temperatures Too Hot for High School Football”, 2012.

[36] WGMS, “Global glacier change bulletin no. 3 (2016–2017)”, 2020.

[37] USGS, “Glacier-wide mass balance and compiled data inputs”, 2020.

[38] Fagre, *et al.*, “Glacier margin time series of the glaciers of Glacier National Park”, 2017.

[39] University of Alaska Fairbanks, “Permafrost sites map”, 2021.

[40] IPCC, “Summary report for policymakers”, 2019.

[41] El-Sayed *et al.,* “Future threat from the past”, 2020.

[42] CDC, “Anthrax Basics”, 2021.

[43] Stella *et al.*, "Permafrost Dynamics and the Risk of Anthrax Transmission”, 2020.

[44] Doucleff, "Anthrax Outbreak In Russia Thought To Be Result Of Thawing Permafrost”, 2016.