The impacts, vulnerabilities, and interventions associated with climate change for Grays Harbor County, Washington

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Introduction

The advent of climate change has brought about numerous concerns including: aeroallergens, drastic changes in temperature and precipitation, vector-borne and water-borne diseases, wildfires, etc. These climate effects have the potential to considerably impact human health. Certain vulnerable populations and areas may experience the effects of certain climate effects to a greater extent than others. The Centers for Disease Control and Prevention (CDC) has developed a five-step process in order to assist public health officials prepare for climate-related health effects through strategy development and program organization.[1] This process is known as the Building Resilience Against Climate Effects (BRACE) framework (*see Appendix, Figure 1*); the BRACE framework provided the basis for the development of this document; the objective was to describe the climate-related impacts, interventions, and vulnerabilities of Grays Harbor County, Washington.

Profile of Grays Harbor County

Grays Harbor County (GHC) borders the Pacific Ocean in the southwest corner of the Olympic Peninsula and is comprised of 1,902.03 square miles, 40% of which is rural.[2-4] Other than the ocean, the county also has many harbors, lakes, streams, channels, canals, and rivers, accounting for just over 300 square miles.[2,5] GHC is bordered by Jefferson, Mason, Thurston, Lewis, and Pacific counties (*see Appendix, Figure 2*)[6]. According to the United States (US) Census Bureau, there were an estimated 72,697 people living in the county in 2017 and had a population density of 38 individuals per square mile in 2010.[3] There are 16 census tracts in GHC and approximately 61% of the population lives in incorporated communities while the remaining 39% live in unincorporated communities.[7] The city of Aberdeen has the highest relative proportion of people in the county at 16,740; the county seat, Montesano, has 4,120 people.[7]

GHC's climate is characterized by mild summers and very wet winters. The hottest months, on average, are July and August; in Aberdeen these averages are 61°F and 61.3°F, respectively.[8] The average high temperature in Aberdeen for July and August is 72.5°F for both months.[8] Typically, the coolest and wettest months are December and January averaging 38.3°F/21.6 inches and 38.1°F/19.5 inches, respectively.[8] Graphs depicting historical average monthly, high, and low temperatures and average precipitation for Aberdeen compared to Seattle[9] can be seen in the *Appendix, Figures 3-5*. For the two years on record, the average annual relative humidity in Aberdeen was 85%; average monthly humidity ranged from 78% in May to 91% in January and December.[8]

Social & Health-Related Vulnerability:

There are three over-encompassing determinants of human health vulnerability as it pertains to climate change: exposure, sensitivity, and adaptive capacity.[10] Exposure refers to the contact between a person and a biological, chemical, physical, psychosocial stressor.[10] Sensitivity is the magnitude of either the adverse or beneficial effect of climate change on individuals or communities.[10] Sensitivity can differ by exposure and by group of people; those who are at higher risk of experiencing certain adverse climate effects are often referred to as vulnerable populations. Adaptive capacity pertains to an individual's or community's ability to adjust and/or respond to potential hazards and its consequences.[10] Due to a variety of reasons, vulnerable populations often need more assistance in extreme climate events, like extended heat waves, which are increasing in frequency as a result of climate change.

A social vulnerability index (SVI), created by the Agency for Toxic Substances & Disease Registry's (ATSDR) Geospatial Research, Analysis & Services Program, used US Census data to rank census tracts, counties, and states on 15 social factors (*see Appendix, Figure 6*).[11,12] The SVI includes variables related to socioeconomic status, household composition and disability, minority status and language, and housing and transportation.[11,12] GHC ranked in the highest category for overall social vulnerability, the only county in western Washington to do so (*See Appendix, Figure 7*).[13] The county also ranked in the highest category for socioeconomic vulnerability, which encompasses variables related to poverty, unemployment, income, and high school diploma status (*See Appendix, Figure 8*).[13]

Approximately 12.5% of GHC's population identified as a race other than white; 10.1% of all races identified as Hispanic (*See Appendix, Table 1*).[13] Additionally, 3.9% of the population aged ≥5 years of age spoke English less than 'very well' in 2015[13] and 9.0% of the same population lived in a home that spoke a language other than English.[14] Minority populations and those who have limited English proficiency are at increased risk for adverse climate exposure because they are more likely to live in risk-prone areas.[10] Historically, they also demonstrate higher incidence of chronic medical conditions, which are often aggravated by climate-related health impacts.[10] Similarly, older adults are also more vulnerable to extreme weather events and are more likely to have chronic conditions exacerbated by climate-related health impacts.[10] Of the estimated 14,000 adults aged 65 years and older living in GHC (*See Appendix, Table 1*), 13.4% live alone in a non-family household.[13]

People living in poverty are more likely to be exposed to extreme heat and air pollution; poverty affects an individual's ability to relocate to less risk-prone areas and their perception of associated exposure risks.[10] In 2013, almost 20% of GHC's population was living in poverty[13] and 31% of children under the age of 5 years lived in a household with an income below the federal poverty line.[15] GHC's median income in 2015 was $43,902, which was approximately $20,000 less than the state's median[16]; 49% of the population also reported that rent accounted for greater than 30% of their income.[15] Additionally, 14% of the population reported being unemployed in 2015.[13] Regarding educational attainment, the population of GHC had a lower proportion of individuals who had at least a high school degree (*See Appendix, Table 2)*.[17]

As of 2012, there are 2.75 hospitals per 100,000 people in GHC.[13] The consensus in the public health community indicates that individuals without health insurance tend to have poorer overall health. Uninsured individuals are more likely to be exposed to adverse climate effects, be affected at greater degree, and have decreased ability to adapt to said effects. Approximately 22% of GHC's population did not have health insurance in 2013.[13] Similarly, individuals with disabilities and chronic diseases are also more sensitive to climate change and have limited ability to properly adapt to changing risks or limit exposure.[18] In 2015, 20.7% of individuals over the age of 5 years reported having a disability in GHC.[13]

Living in a rural community can also increase vulnerability; these populations are more likely to be physically isolated, live in poverty, and be older than the general population.[4] The nature of these communities also make access to necessary services (e.g., medical services, fresh food, etc.) more difficult.[4] Governments in rural communities also often have limited capacity to respond, plan for, and anticipate impacts associated with climate change.[4]

Climate Impacts

When compared to historical data, it is clear that climate change is influencing current climatic trends. The state of Washington has already begun to experience warmer temperatures, melting snow and ice, more drought, extreme rainfall, and rising sea levels.[19] Future projections largely depend on factors that affect greenhouse gas emissions such as population growth, economic development, and future technology.[19] While there are numerous possible scenarios, the following projections will summarize information from sources that used the A1B, A2, and B1 scenarios and the RCP 4.5, and 8.5 pathways (described below).[13,19, 20] Currently, greenhouse gas emissions are rising faster than what is projected in the A1B and B1 scenarios, suggesting that climate impacts will likely be worse than what is currently projected in either scenario.

The A1B, A2, and B1 storylines/scenarios belong to the ‘Special Report on Emissions Scenarios’ (SRES), which helped form the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report.[21] The Representative Concentration Pathways (RCPs) were developed for the IPCC Fifth Assessment Report.[21] The primary difference is that the SRES scenarios do not explicitly account for carbon emission controls; the RCPs take climate change mitigation policies, implemented to limit emissions, into consideration.[21] Overall, the A1 scenarios describe a future with very rapid economic growth, a global population peaking at mid-century and subsequently declining, and a rapid introduction of more efficient, novel technologies.[22] The subtypes of the A1 scenario describe divergences in technological growth; the A1B scenario predicts a balance between fossil-intensive and non-fossil energy sources driving technological advancement.[22] The A2 scenario predicts that economic development will be regionally-oriented, technological and per capita economic growth will be slower than other scenarios, and a gradual increase in the global population.[22] The B1 scenario mirrors the A1 scenarios in regards to population growth but emphasizes improved equity and global solutions towards economic, social, and environmental sustainability, excluding further climate initiatives.[22] The RCP scenarios are named after the estimated radiative forcing relative to pre-industrial levels achieved in 2100 or at stabilization following 2100.[21] The RCP 4.5 pathway is comparable to the SRES B1 scenario while the RCP 8.5 matches that of the SRES A2 by 2100.[21]

Temperature:

Between 1920 and 2003, average annual temperatures rose by 1.5°F in the Pacific Northwest (PNW).[19] There is little difference in the warming rates seen at rural and urban weather monitoring stations, indicating fairly uniform warming.[19] Despite the expectation of an overall increase in average annual temperatures in the coming years, the Pacific Decadal Oscillation, El Niño, and La Niña will continue to influence average temperatures, resulting in colder or warmer than average years.[19]

GHC-specific temperature trends were discussed previously (*also see Appendix, Figures 3 & 4)*. In 2013, GHC experienced 15 extreme heat days between May and September, using a 90th percentile relative threshold.[13] Using the same threshold, GHC experienced two extreme heat events, defined as a minimum duration of three consecutive days of extreme heat, between May and September of 2013.[13] In 2016, GHC experienced four months of mild drought or worse, as determined by Standardized Precipitation Evapotranspiration Index data.[13]

Projections: Using historical data from 1971-2000 and a relative threshold of the 98th percentile, GHC is projected to have an increase in the number of extreme heat days in both the B1 and A2 scenarios (*See Appendix, Figure 9 & 10*).[13] Projections using the RCP 4.5 and 8.5 scenarios yielded similar results regarding the average number of days with daily minimums and maximums above the 99th percentile; a general trend of increasing frequency is seen in both (*See Appendix, Figure 11*).[20] The differences between current, mid-century, and end-of-century projections are noticeably less pronounced in low emissions scenarios when compared to those in high emissions scenarios.[20] In either case, projections are markedly above what is seen in historical data.[20] Likewise, projections of daily minimum and maximum temperatures demonstrate a steady increase; end-of-century projections show that median daily minimum temperatures will be in the mid-60° range, while median daily maximum temperatures will be in the low-90° range (*See Appendix, Figure 12*).[20]

According to projections using CMIP5-MACA simulations, the number of extreme days per heatwave, total number of heatwave days, and the average duration of heatwaves are expected to increase throughout the end of the century in high emissions scenarios (*See Appendix, Figure 13*).[20] Overall, the annual frequency of heatwaves is also expected to increase through the end of the century in both low and high emissions scenarios.[20] Using an index which accounts for both humidity and temperature, known as a humidex, heat event statistics for GHC were also produced (*See Appendix, Figure 14*). Trends for the number of extreme days and average duration per heat event using the humidex match the trends of the aforementioned heat index.[20] The median frequency of annual heat events using the humidex notably changes from the low to high emissions scenarios in projections at the end-of century, increasing from approximately 4.5 to 8.5 events.[20] The total number of heat event days is also projected to be higher than historical data but remains stable throughout the end-of-century in the low scenario.[20] Contrarily, the trend in the high emissions scenario show a small increase in mid-century projections and a drastic increase in end-of-century projections.[20] Figure 15 in the Appendix compares the aforementioned projections for daily maximum temperatures (99th percentile), heat index temperatures, and humidex temperatures.[20]

Wildfires:

Extreme weather events (e.g., droughts and heatwaves) are expected to increase due to climate change.[19] Higher temperatures and reduced precipitation in the summer could increase wildfire risk.[23] While the risk of wildfires within GHC is low, the air quality can be impacted by smoke blown in by offshore winds from large fires on the eastern slopes of the Cascades.[23] Due to copious amounts of relatively damp, large, evergreen forests in this region, the risk of high levels of smoke exposure is very high.[23] When burned, this type of fuel is known to emit large quantities of particulate matter.[23] Despite the low wildfire risk, the potential for serious health impacts is high.[23] Beyond air quality and more apparent consequences (i.e., property damage, loss of forested habitats, injury, death, etc.), water quality may also be affected due to erosion and sedimentation of water bodies.[19]

Projections: Relative to historical data (1916-2006), wildfires are projected to burn twice as many acres annually by the 2040s and three times as much forest area by the 2080s in the PNW.[19] The area burned in forested ecosystems (e.g., the eastern and western Cascades) are projected to increase by a factor of 3.8 by the 2040s, relative to 1980-2006.[19] Given that GHC does not have a recent history of large fires, there are no county-specific projections regarding wildfires.[23] Additionally, due to the county's cool and humid climate and long fire return interval (500+ years), it is plausible to assume that the potential for wildfires is low.[23]

Precipitation:

Overall trends of annual precipitation in the PNW have increased; between 1920-2000, there was a 13% increase in annual precipitation.[19] These increases were most notable in the spring (37%) and lowest in the autumn (6%).[19] The frequency of the top 1% of rainfall events, known as heavy downpours, has also grown by 12% in the PNW.[19] For precipitation trends specific to GHC, see the 'Profile of Grays Harbor County' and Figure 5 in the Appendix.

Projections: Due to rising winter temperatures, Washington is predicted to receive more rain and less snow, on average, in the future.[19] Under the moderate emissions scenario (A1B), the majority of models project an average increase of 8% in precipitation by the 2080s.[19] As noted above, these fluctuations will not be uniform across seasons. Most models predict an average decline of 14% in summer precipitation by the 2080s, while others project reductions of as much as 20-40%.[19] Storm intensity is also expected to increase in the future; the magnitude of a 24-hour storm is projected to increase 14-28% in the next 50 years in the Seattle-Tacoma area.[19]

Under the low emissions (B1) scenario, GHC is projected to have slight increases in the rate of annual precipitation intensity through the end-of-century (*See Appendix, Figure 16*).[13] Projections for the high emissions (A1) scenario similarly match that of the low emissions projections, with slightly higher rates of annual precipitation intensity at the end of the century (*See Appendix, Figure 17*).[13] The number of future extreme precipitation days is also projected to increase in GHC. In the low emissions scenario, it is expected to increase to 6.99 days near the end-of-century from current numbers (5.66 days in 2020) using a 98th percentile relative threshold (*See Appendix, Figure 18*).[13] This number rises to 8.27 near the end-of-century in the high emissions scenario (*See Appendix, Figure 19*).[13]

Flooding:

Flood risk is highest in western Washington during the fall and winter seasons, when precipitation is the highest.[19] Rising sea levels compound on predicted increases in precipitation and upsurges in storm intensity, further increasing the frequency and intensity of coastal flooding.[19,24] In 2011, just over 8% of the area in GHC was within a Federal Emergency Management Agency (FEMA) designated flood hazard area; translating to approximately 133.5 square miles.[13] This area accounted for 8,406 housing units and 17,738 people in 2011.[13]

Projections: County-level projections for GHC regarding flooding were not available but state-region projections are described. Due to the movement of the tectonic plates, the sea levels in Washington are not changing homogenously.[19] South Puget Sound is subsiding at a rate of 2 millimeters per year while the Olympic Peninsula is rising at a similar rate, meaning that relative sea level rise will be greatest in south Puget Sound and the least in the northwestern tip of the Olympic Peninsula.[19] Depending on the rates of ice melt from Greenland and Antarctica, sea level increases as much as a 3.5 feet for the central and southern coasts, 3 feet for the northwest Olympic Peninsula, and 4 feet for Puget Sound are possible by 2100.[19] Rises of 2 feet can turn extreme flood events that only occur once every 100 years to annual occurrences.[19]

The frequency of flooding in Washington is projected to increase from January to March and decrease in April and May.[19] The largest increases in flood frequency are predicted to be in Puget Sound, the west slopes of the Cascades in southwest Washington, and at lower elevations on the east side of the Cascades while rain-dominated basins are projected to have little change.[19]

Water temperature and acidity:

With predicted increases in overall temperature, increases in water temperatures and decreases in summer water inputs are expected to follow.[19] Freshwater bodies, marine waters, and nearshore systems, will be affected by temperature increases.[19] Marine waters are also becoming more acidic due to human influence; global oceans have absorbed roughly 30% of carbon emissions generated by humans since the Industrial Revolution.[19] The production of carbonic acid is the result of mixing dissolved carbon dioxide (CO_2) and seawater, which is subsequently causing a reduction in ocean pH.[19] In addition to other factors, both rises in water temperature and acidity increase the likelihood of harmful algal blooms (HABs) occurring.[25]

From 1964 to 1998, the annual average water temperature Lake Washington in King County increased by approximately 1.6°F.[19] Average sea surface temperatures have increased by slightly less than that since 1950, rising roughly 1.1°F.[19] Regarding acidity, the Hood Canal area of Puget Sound has substantially lower pH than global levels (~8.1 units) ranging from 7.39-7.56 units.[19]

Projections: Projections for water temperature and acidity were not available but state-level projections for water temperature and global projections for acidity are described below. Washington's average summer stream temperatures are projected to increase by 1.8°F by the 2020s and between 3.6°F and 9.0°F by the 2080s.[19] Rising temperatures can cause lakes to experience longer stratification periods during the summer, leading to increased eutrophication and oxygen depletion in deep zones.[19] Sea surface temperatures along the coast of Washington are also expected to rise; projections estimate an approximate 2.2°F increase by the 2040s.[19] Warming ocean temperatures will subsequently contribute to sea level rise, greater stratification of the water column, and increases in storm intensity.[19] Additionally, assuming that the current trend of carbon emissions remains stable, global ocean pH is projected to decrease to roughly 7.8 by 2100.[19]

Aeroallergens:

Climate change is also expected to affect aeroallergen production; pollen production will increase with rises in temperature and CO_2 levels.[26] Higher concentrations of pollen increase the chance of sensitization and exacerbation of illness, such as more severe allergic response.[26] Figure 20 in the Appendix depicts a pathway describing the relationship between climate change, changes in CO_2 levels, changes in aeroallergen production, and subsequent health impacts.[26] GHC has a variety of allergens that vary slightly by season (*See Appendix, Table 3.*)[27] Some of these allergens (i.e., Common Timothy and other grasses) elicit an allergic response in 20% of the general population.[27,28]

<u>Projections:</u> Projections regarding aeroallergens were not available at the region, state, or county level. An experiment simulating elevated CO_2 levels and the effects on grass pollen and allergen exposure and a review of aeroallergens and climate change are summarized.[26,28] Studies have shown that doubling current levels of CO_2 to projected levels would result in a 30-90% increase in the production of ragweed pollen.[26] Similarly, another study found that elevated CO_2 levels will increase pollen production by 55-90% in allergenic plants, including ragweed.[28] Atmospheric pollen loads are also expected to increase due to rising temperatures, related to CO_2, lengthening the flowering season.[28]

Ozone (O_3) is a known repressor of pollen and allergen production[28]; assuming global compliance with the Montreal Protocol, substantial recovery of the ozone layer is expected around mid-century.[29] An experimental study found that elevated levels of CO_2 increased grass pollen production by approximately 50% per flower, regardless of O_3 levels.[28] Using quantitative estimates of the number of flowering plants and increased pollen production, the authors reported up to an estimated 200% increase in airborne grass pollen concentrations in the future.[28]

Health Impacts

As indicated previously, climate change is projected to drive drastic fluctuations in temperature, precipitation, flooding, etc. by the end-of-century. Climate change has bearing on environmental and social determinants of health, such as safe drinking water, clean air, and sufficient food.[30] While these determinants are less likely to be of huge concern in the US, the aforementioned climate impacts also have obvious implications on human health, including probable increases in the number of heat-related illnesses, vector-borne diseases, and other illnesses. Quality of life is adversely impacted when increases in climate-attributed illnesses and diseases compound on other factors such as inability to work (i.e., increased sick days and leaves of absence), cost of healthcare, and insurance claims.[19]

Heat-related Illness:

Apparent temperature is sometimes considered to be a better measurement than air temperature when describing heat-related vulnerability. Apparent temperature uses regression equations to attempt to quantify how an individual feels when accounting for factors such as air temperature, vapor pressure, solar radiation, wind speed, and whether said person is standing in the shade.[31] Not all equations quantifying apparent temperature will adjust for all variables;

more often than not, the equation only includes air temperature, vapor pressure, and wind speed.[31] While GHC typically has mild temperatures, it also has fairly high humidity, ranging from 78-91% throughout the year.[8] This high humidity contributes to higher apparent temperature. Additionally, due to the low frequency of extreme heat days in the Puget Sound region and along the Washington coast, most homes do not have cooling systems.[19] The combination of a lack in cooling systems, the projected increases in temperature, and the already high humidity will greatly affect the community's adaptive capacity related to heat.[19] Furthermore, as of 2011, GHC had very little high-intensity land development and had a high proportion of forest-coverage.[13] In addition to being located on the coast, both aspects will likely mitigate some of the expected temperature increases attributed to climate change.

People with chronic diseases (e.g., cardiovascular and respiratory diseases) are at increased risk of medical complications related to climate change exposures, especially heat.[9] Medications used in the treatment of chronic diseases have been associated with increases in hospitalization, emergency room admission, and death due to extreme heat.[9] Among those aged 35 years and older in GHC, there was an age-adjusted rate of 213.1 per 100,000 individuals for ischemic heart disease and 34.3 per 100,000 individuals for hospitalizations for a heart attack in 2015 and 2014, respectively.[13] Individuals with other chronic disease, like diabetes, may also exhibit adverse effects due to increase in temperature. In 2008, GHC had an age-adjusted rate of 10.2 per 100,000 individuals among those aged 20 years and older.[13] Additionally, results from the Behavioral Risk Factor Surveillance System (BRFSS) from 2013-2015 indicated that 38% of adults aged 18 years and older were obese in GHC.[15]

Rising temperatures are also correlated with increases in smog levels and other air pollutants.[19] As mentioned, these increases will have implications for individuals with respiratory illnesses. The BRFSS also indicated that 23% of GHC aged 18 years and older smoked cigarettes in 2013-2015.[15] Additionally, in 2015, the age-adjusted rate for chronic obstructive pulmonary disease (COPD) in individuals aged 25 years and older was 73.4 per 100,000 individuals in GHC.[13] Furthermore, the age-adjusted rate of hospitalizations attributed to asthma was 4.2 per 100,000 individuals in GHC in 2014.[13]

Vector-borne Disease:

With significant temperature increases predicted throughout the end-of-century, concerns have arisen regarding the possibility of vector-borne diseases expanding to previously unaffected areas.[32] A vector-borne disease is defined as a human illness caused by a living organism that transmits infectious diseases between humans and animals or between humans, known as a vector.[32] Vectors include a variety of organisms such as: ticks, mites, mosquitoes, flies, lice and snails; they induce illness by transmitting bacteria, viruses, or parasites.[32] In combination with rising temperatures, changes in agricultural practices, inadequate solid waste management, unreliable pipe water, and growth of urban slums is expected to expand the current range of specific vectors (i.e., mosquitoes) and subsequent vector-borne disease.[32]

Information on vector-borne diseases specific to GHC were unavailable; state-level data is described below. The projected increases in frequency and intensity in flooding and precipitation in Washington will create breeding grounds for disease-carrying insects (e.g., mosquitoes).[13,19,30] While there have been numerous vector-borne diseases seen in Washington, trends in past years have shown low numbers of cases and rates, most of which were connected to out-of-state exposures.[32] The primary vectors within the state are mosquitoes and ticks.[32]

Arboviral Disease: These diseases (i.e., chikungunya, yellow fever, Zika, dengue, etc.) are usually the result of the bite of arthropods (e.g., mosquitoes, ticks, etc.).[32] Prior to 2013, Washington reported a small number of travel-related chikungunya cases and approximately 10-20 travel-related dengue cases annually.[32] Excluding West Nile virus, a case of western equine encephalitis in 1988 was the last human arboviral infection due to an exposure within the state.[32] Two sizable outbreaks of West Nile virus occurred in Washington in 2009 and 2015 with 38 cases and 24 cases, respectively.[32] The outbreak in 2009 had 36 cases confirmed to be exposed within the state.[32] A table summarizing the number of cases and incidences of select arboviral diseases in Washington in 2016 is depicted in the Appendix (*Table 4*).[32]

Mosquitoes: There are 40 species of mosquitoes in Washington, many of which are potential vectors for severe diseases (*See Appendix, Figure 21*).[33] Similar to the aforementioned arboviral diseases, Washington annually reports between 20-40 cases of malaria, all of which are attributed to travel outside the state.[32] In 2016, there were 0.6 cases per 100,000 individuals of travel-associated malaria.[32] Twenty-nine of the forty-six cases in 2016 were linked to the follow mosquito species: *Plasmodium falciparum, P. vivax, P. ovale, P. malariae,* and other unknown *Plasmodium* species.[32]

Ticks: There are 5 species of disease-carrying ticks in Washington: *Dermacentor andersoni* (Rocky Mountain Wood tick), *Dermacentor variabilis* (American Dog tick), *Ixodes pacificus* (Western-Blacklegged tick), *Rhipicephalus sanguineus* (Brown Dog tick), and *Ornithodoros hermsi* (a species of soft tick).[32,35] These ticks are responsible for a variety of disease including: Lyme disease, Anaplasmosis, Ehrlichiosis, Q fever, relapsing fever, Rocky Mountain Spotted Fever, and Tularemia.[32] Washington annually reports 7-33 cases of Lyme disease, no more than 5 cases of Q fever, 1-10 cases of tick-borne relapsing fever, and 0-3 cases of Rocky Mountain Spotted Fever, and 1-10 cases of Tularemia.[32] Table 5 in the Appendix depicts the number of cases, incidence, and related notes of select tick-borne diseases in Washington for 2016.[32]

Other Vectors: Fleas, deerflies, mammals, and birds have also been implicated as vectors for a number of diseases in Washington.[32] The latter three have been associated with some cases of Q fever and Tularemia.[32] Fleas that carry the bacterium *Yersinia pestis* can transmit plague.[32] No cases were reported in Washington in 2016; the last known case was in Yakima in 1984 and was attributed to an animal trapper exposed to the disease while skinning a bobcat.[32] In conducting wildlife testing, the state has only identified 2.6% of specimens to be seropositive for the disease between 1975 and 2014.[32]

All states have a list of notifiable conditions that healthcare providers/facilities, veterinarians, laboratories, food service establishments, and child day care facilities are required to report to local health jurisdictions and/or the state.[34] Table 6 in the Appendix lists the notifiable vector-borne diseases in Washington by reporter.[36]

Harmful Algal Bloom-related Illnesses:

Projected increases in water temperature and acidity are contributing to rises in the occurrence of HABs. Algal blooms are the result of the uncontrollable growth of algae, photosynthetic organisms.[37] Not all blooms are directly harmful but a subgroup of these organisms can produce severe illness in humans.[37] Besides the detrimental effects to human health, HABs can also cause illness in pets and have lasting damaging effects to marine and freshwater ecosystems.[37]

Human illness due to HABs have been attributed to a variety of methods of exposure: direct exposure to toxic algae, byproducts of water treatment, and exposure through nutritional supplements.[37] Depending on the dose, direct exposure (i.e., accidental swallowing, drinking, swimming, or inhalation) can produce symptoms such as respiratory problems, rashes, stomach and liver illness, and/or neurological effects.[37] Though very uncommon, a few documented cases of individuals becoming ill following consuming nutritional supplements contaminated with toxin-producing cyanobacteria have been noted.[37] Algae and algal toxins can also contaminate the water supply.[37] Water treatment facilities typically use a variety methods to filter algae from raw water, but as the algae die, they can release toxins that may not be removed during normal processes.[37] Toxins can be removed through activated carbon filtration and oxidation but certain disinfectants used in the treatment of drinking water can react with toxin-producing algae, creating dioxins, a carcinogenic chemical.[37] There are no current federal regulations in the US pertaining acceptable levels of cyanobacteria and cyanotoxins in public drinking water.[37] However, the Environmental Protection Agency (EPA) and World Health Organization (WHO) have recommended guidelines for certain algal toxins in drinking water.[37]

There was no available information regarding phytoplankton species specific to GHC; organisms common to the PNW are reported. Additionally, rates of HAB-associated illnesses were also not available at the county-level; information at the state-level is described instead. In the PNW, the diatom *Pseudo-nitzchia* and the marine dinoflagellate *Alexandrium* are the principal concerns pertaining to HABs.[37] *Alexandrium* produces saxitoxin which can cause Paralytic Shellfish Poisoning (PSP) while *Pseudo*-nitzchia produces a toxin called domoic acid, causing Domoic Acid Shellfish Poisoning (a.k.a. Amnesiac Shellfish Poisoning; DASP).[37] Until recent events implicating the marine dinoflagellate, *Dinophysis*, in cases of Diarrhetic Shellfish Poisoning (DSP) in the PNW, it was only seen along the Gulf of Texas.[37] All three diseases can result in severe cases.[37] As the names imply, individuals often become ill following consumption of certain shellfish and other marine animals (e.g., clams, mussels, oysters, crabs, small fish, etc.).[38] There are 0-7 reported cases of PSP in Washington every year.[38] Contrarily, there have been no confirmed cases of DASP since 1991; this may be attributed to monitoring for unsafe levels of domoic acid razor clams, Dungeness crab, mussels, clams, and oysters.[38] In 2011, there were three cases of DSP in a family who ate cooked mussels from Sequim Bay.[38]

Other Infectious Diseases:

While not described in detail, other infectious diseases can also be expected to rise with climate change. Increases in flooding and heavy precipitation will likely be followed by rises in waterborne disease outbreaks.[19] Additionally, though it varies by illness, for every degree increase (°C) in temperature, the risk of foodborne illness increases by 2.5-6.0%.[19] Projected increases in the frequency and severity of wildfires will also result in habit alteration and impact the distribution of rodent populations, which could result in rises in illnesses to disease-carrying rodents.[19]

Allergic Disease:

Allergic diseases can be exacerbated by air pollutants and aeroallergens, both independently and in combination with one another.[26] The primary allergic illnesses associated with aeroallergen exposure are allergic rhinitis (i.e., hay fever), atopic dermatitis (i.e., eczema), and asthma.[26] Changes in the timing and length of the pollen and flowering season, as attributed to climate change, can affect sensitization and exacerbate allergic illneses.[26] Shifts in temperature may also expand the range that plants species can inhabit; such introductions of novel pollens into a region can increase the prevalence of allergic illnesses in a population.[26] Extreme weather events (e.g., thunderstorms, heavy precipitation, etc.) also provide ideal conditions for pollen grains to burst and release small allergenic particles that can enter the lower airways.[26] Aeroallergens can also aggravate symptoms attributed to respiratory illnesses such as, COPD and asthma. The prevalence of asthma and COPD specific to GHC is mentioned in the 'Heat-related Illness' section above.

Interventions

With the advent of climate change and the subsequent impacts on human health, it is unsurprising that a variety of methods and systems have been developed to attempt to prevent, mitigate, and/or control its effects. The conduction and implementation of these interventions can range from system-level changes to individual changes.[39] It is also important to note that the efficacy and feasibility of specific interventions will vary by location and population of interest. A summary of global interventions related to select climate health impacts is described below; much of which will be abstracted from the CDC's Climate and Health Intervention Assessment.[39]

Heat-related Illness:

The CDC describes interventions pertaining to heat-related illnesses as being part of seven distinct categories: real-time data surveillance and warnings, education and information, built environment, heat alert system, access to cooling, zoning/building regulations, and hydration.[39] These interventions can be classified as preemptive, primary, and secondary in nature; some also aim to reduce atmospheric carbon dioxide levels and more suitable environments for physical activity.[39] Figure 23 in the Appendix describes each heat-related intervention's effectiveness based on criteria regarding the amount, type, and quality of existing evidence pertaining to the intervention (*See Appendix, Figure 22*).[39]

<u>Real-time Data Surveillance and Warnings:</u> Monitoring of temporal heat-related illness trends can assist health departments in identifying outbreaks, allowing health officials to send out warning notifications to healthcare providers and the public to take preventative measures.[39] With advancements in technology, hospitals and 9-1-1 call centers can frequently submit data to local and state health departments, by means of cloud-based public health surveillance systems.[39] There is a lack of consensus regarding how best to structure heat surveillance and warnings; however, the literature points to data-driven approaches being the most effective.[39]

<u>Education and Information:</u> Public education regarding the prevention, identification, and treatment of heat-related illnesses has also been proposed as an intervention.[39] This information is distributed by means of brochures at clinics, nursing homes, pharmacies, etc.,

through call-centers, and training programs for healthcare workers.[39] Additionally, these sessions/brochures can be used to provide practical advice, answer specific questions, and target especially vulnerable populations.[39]

Built Environment: There are a number of mechanisms to reduce indoor and outdoor temperatures through the built environment (i.e., the physical environment created and constructed by humans).[39] Landscape design, energy systems, and transportations are usually the primary targets in attempting to reduce temperatures; the purpose in changing the built environment is to prevent heat-related illnesses from occurring in the first place.[39] This intervention has shown to be especially useful in reducing the urban heat island effect, a phenomena where the built landscape (i.e., more concrete and less green space) contributes to elevated temperatures in metropolitan areas.[39]

Heat Alert System: The utilization of a response plan that activates when temperatures or a heat index (i.e., a humidex) exceed predetermined thresholds act as system to alert the public and necessary officials about potentially dangerous health conditions.[39] Beyond alerting essential officials and populations, the system can include community education and engagement, community outreach plans, and the development of an efficient communication plan.[39] These components include facilitating systematic approaches to reaching vulnerable populations, identifying community-specific needs, and raising awareness and educating the public about the impacts of heat-related illness.[39]

Access to Cooling: As the name implies, the intervention aims to reduce heat-related illness and death with access to air-conditioned or cooled spaces.[39] While there is strong evidence that access to air-conditioned spaces can prevent heat-related illnesses, the intervention has been met with some criticism.[39] This is largely due to the fact that air-conditioning is very energy-intensive, therefore increases carbon dioxide emissions, and fairly costly.[39] The feasibility further depends on geographical setting, vulnerable populations, and safety and security (e.g., high crime communities).[39] Access and transportation can be barriers in the implementation of the intervention in both rural and urban areas.[39] This is further complicated when considering vulnerable populations, like the elderly, who may not have the desire or ability to leave their homes to travel to community cooling centers (i.e., public libraries, local health departments, community centers, religious centers, etc.).[39]

Zoning/Building Regulations: Similar to that of the built environment intervention, the focus of the intervention lies on policies and ordinances requiring developers to include infrastructure designed to reduce heat in residential and commercial development plans.[39] Like the aforementioned interventions, this method works at the city/municipal-level.[39]

Hydration: One of the few interventions that acts at the individual-level, hydration has proven to be very effective in mitigating and preventing heat-related illness and death.[39]

Wildfire Smoke:

Wildfires pose a number of dangers to human health including smoke-related illness, physical injury, and death. With the projected increases in frequency and severity of wildfires due to climate change, there are concerns regarding increases in particulate matter and ozone emissions.[39] Wildfire smoke has a number of adverse impacts on human health (i.e., exacerbating existing cardiovascular and respiratory illnesses) and contains fine and coarse particulates, carbon monoxide, polycyclic aromatic hydrocarbons (PAHs), and volatile organic compounds.[39] The CDC groups interventions related to wildfire smoke into five categories: evacuation, air filtration and cleaning units, personal air filter masks or respirators, warning systems, and public service announcements, all of which are discussed in detail below.[39] According to the CDC, existing literature indicates that the utilization of air filtration and cleaning units in home and health facilities are most effective in reducing indoor smoke concentrations while air filtration masks are best for the reduction of outdoor smoke exposure.[39] Figure 24 in the Appendix describes the effectiveness for the discussed wildfire smoke interventions.

Evacuation: When a wildfire approaches a populated area, evacuation, which can voluntary or mandatory, is common.[39] Factors that contribute to evacuation warnings and mandates include: population exposure to severe smoke hazards lasting days, unusually toxic smoke (e.g., contaminated with hazardous chemicals), detection of smoke-related health impacts through surveillance, or identification of a population with known sensitivity to smoke-related health effects.[39]

Air Filtration and Cleaners: Both air filtration and cleaning systems use similar mechanisms to remove harmful contaminants from the air.[39] Filtration removes particulate matter (PM) from the air using an air-handling system a filter but cannot remove gases and vapors (e.g., carbon monoxide).[39] These systems can be portable or in-duct systems that are part of a building's heating, ventilation, and air conditioning system.[39] Types of filters also differ in their efficiency, higher efficiency filters can be used to capture very fine particles associated with wildfire smoke.[39] A stipulation to using these filters is that it requires an air-handling system equipped to handle airflow resistance and an increased power load.[39] Air cleaning uses an air-handing system and sorbent filters (i.e., granular activated carbon, impregnated carbon, and potassium permanganate impregnated alumina) to remove gaseous contaminants from the air.[39]

Personal Air Filter Masks: To properly protect against contaminants in wildfire smoke, air filter masks must be able to filter very small particles (0.3 to 0.1 microns).[39] Respirator masks (a.k.a. particulate respirators) are capable of filtering out 95% of particulates 0.3 microns, the average size of smoke particulates, or larger.[39] Dust masks (a.k.a. comfort masks) are designed to trap larger particles (e.g., sawdust) and therefore should not be used for smoke protection.[39] In order to properly provide protection from wildfire smoke, the EPA recommends buying masks labeled with "R95", "p95", or "N95".[39] Masks labeled "R,N", or "P99 and R,N", or "P1000" have higher ratings and therefore filter out additional particles.[39] It is important to note that proper fitting (i.e., providing an airtight seal over the wearer's mouth and nose) is essential to full protection.[39] This is often a problem for young children and individuals with beards.[39]

Forecast/Warning Systems: Similar to the heat alert system, air quality forecasting uses an Air Quality Index (AQI) to report and forecast daily air quality.[39] The EPA and National Oceanic and Atmospheric Administration (NOAA) calculate the AQI using five primary pollutants: particulate matter, ground-level ozone, sulfur dioxide, carbon monoxide, and nitrogen dioxide.[39] EPA's AirNow website displays national forecasts and current local air quality conditions as well as current fires and projected hazardous smoke plumes.[39] The information is freely available and allows any user to look at specific areas.[39]

Public Service Announcements (PSAs): The intervention uses publicly disseminated messages to inform and educate the public via the media; PSAs can be found online, on radio or television stations, and through print .[39] In relation to wildfires, the message generally emphasizes wildfire prevention and/or immediate fire safety (e.g., evacuation planning).[39] They are also sometimes used to inform the public about wildfire smoke-related health risks and preventative measures.[39]

Vector-borne Disease:

Factors such as seasonality, distribution, and prevalence of vector-borne disease are greatly influenced by climate.[39] While there a number of other vectors and related diseases, this section will focus on interventions for mosquito- and tick-borne diseases; the CDC's determination of the effectiveness of these interventions is displayed in the Appendix (*Figures 25 & 26*).

Given the vast differences in environmental conditions and other factors, no single intervention is appropriate for every area.[39] Determining which interventions are best fit for a particular area requires knowledge about environmental conditions, pathogens of concern in the area, and mosquito species.[39] Using a combination of source reduction and biological and chemical control usually produce the most effective pest control programs.[39]

<u>Source Reduction:</u> The intervention involves the destruction or removal of mosquito breeding sites or the modification of said sites to ensure that they cannot be used for breeding.[39] A number of habitats can be the target of source reduction, including: flowerpots, pet bowls, tires, freshwater lakes, ponds, freshwater swamps, freshwater and salt marshes, and temporarily flooded areas.[39] Artificial containers in urban areas are often the target for laying eggs in a number of species (e.g., *Ae. albopictus*).[39]

<u>Pesticide/Insecticide Application:</u> Pesticide and insecticide use includes: larvicides, adulticides, autocidal gravid ovitraps, insecticide-treated clothing, the environmental application of pesticides, and wildlife treatment.[39]

Larvicides kill mosquitoes in the larval and pupae stages while adulticides target adult mosquitoes.[39] Both involve the ground or aerial application of chemical agents (e.g., biorational pesticides, broad-spectrum pesticides, other insecticides, etc.) to control mosquito reproductions.[39] To effectively use larvicides, knowledge of the biology of the targeted species, the timing of the application, and the amount of larvicide applied are all crucial.[39] Certain larvicides may be more appropriate for certain species and habitats.[39] Adulticides disrupt neural activity in mosquitoes and eventually leads to mortality.[39] The two main methods of application for adulticiding include residual spraying (a.k.a. barrier/surface treatments) and space spraying (e.g., cold/thermal fogging).[39] Residual spraying applies insecticides to foliage, the ground, and other surfaces that adult mosquitoes may land.[39] This type of treatment is usually done when people are not present and in limited areas (e.g., nighttime outdoor events, yards, parks, etc.).[39] Depending on the insecticide and appropriate dosing, it is efficient in providing long-term control.[39] Space spraying releases aerosols into a targeted zone that persist in the air column until coming into contact with flying mosquitoes.[39] Given that the method is only effective so long as the droplets remain airborne, it is not as efficient as residual spraying in long-term management.[39] However, it is efficient in controlling a large area in a short amount of time; this makes it especially effective for severe nuisance mosquito outbreaks and vector-borne disease epidemics.[39] Meteorological conditions (e.g., humidity, wind, temperature, and lunar illumination) will affect mosquito activity and therefore should be considered when timing the application of the insecticide/pesticide.[39]

Autocidal gravid ovitraps target mosquito species that lay eggs in artificial containers (i.e., *Aedes spp.* and *Culex spp.*); ovitraps are small glass, plastic, or metal containers that hold water or substrate where female mosquitoes can lay their eggs.[39] They prevent the females from escaping using funnels or sticky boards and prevent the hatching of larvae through either chemical or mechanical means.[39] Ovitraps are often inexpensive and efficient in eliminating specific container-breeding mosquitoes and their offspring.[39]

Insecticide-treated clothing has been used for recreational activities and by military personnel for personal protection against mosquito bites; clothing can be treated at home or in the factory.[39] The only insect repellant used for factory treated clothing in the US is permethrin, a broad-spectrum, synthetic pyrethroid insecticide that targets larvae and adult invertebrates.[39] The EPA has indicated that the amount of permethrin allowed in clothing is very low, but typical human exposure from wearing treated clothing is also low given that permethrin is poorly absorbed through the skin.[39] There is similarly-treated clothing to repel ticks; the clothing is commercially soaked with a repellant substance (e.g., acaricides) that allows it to retain its effectiveness after multiple washings.[39] While self-applied repellants such as personal pesticide sprays (e.g., DEET) are also used to repel ticks and mosquitoes, factory and commercially-treated clothing have been found to be more effective.[39]

The environmental application of pesticides has proven to be a reliable method in reducing tick populations.[39] However, the use of this method is not widely accepted due to concerns related to adverse environmental and health impacts.[39] Public and scientific acceptance may differ by the use of synthetic versus natural, plant derived acaricides.[39] Environmental application of pesticides seems to be most effective in reducing tick populations when applied using a high-pressure sprayer.[39] Another strategy includes treating common hosts for ticks (e.g., deer) with acaricides.[39] Its effectiveness is varied because it involves constant maintenance, is costly, and is time-consuming.[39] The intervention is also not easily scalable has numerous potential concerns including human exposure to acaricides, attraction of disease-carrying animals, etc.[39]

Surveillance and Response Plans: Mosquito-borne disease surveillance can assist in assessing human health risks and provide information on endemic levels of disease.[39] Surveillance can also include monitoring of mosquito populations, trapping and landing counts, and environmental conditions (e.g., temperature changes, tidal events, precipitation events, changes in land use, etc.) that could influence mosquito species ranges and abundance.[39] Tracking environmental conditions can expand beyond areas currently at risk for mosquito-borne disease; said areas could have increased susceptibility due to future environmental and vector-transmission changes.[39] Establishing appropriate surveillance measures can help inform and develop response plans and determine action thresholds.[39] It is important that these plans are flexible in order to adapt to new challenges that arise.[39]

Public Education: Informing and educating the public on how vector-borne diseases are transmitted and what protective actions should be done to reduce the likelihood of being bitten has also been supported in some literature. Protective actions related to tick-borne diseases include: self-checking for ticks, avoiding areas of high tick density, tick removal techniques, using insect repellent, and wearing protective clothing.[39] Some of these actions can also be applied to mosquito-borne diseases. The effectiveness of this intervention appears to be very dependent on how well the educational program is designed; if the public perceives the risk to be real, that preventive actions reduce this risk, and that they have the ability to perform these actions, then education can be very effective.[39]

Harmful Algal Blooms:

The majority of HAB interventions have indirect effects on human health; they aim to reduce, eliminate, or prevent the occurrence of blooms.[37] HAB interventions can be divided into three broad categories: prevention, mitigation, and control.[37] The success of an intervention and its implementation largely depends on the severity of the bloom, the targeted organisms, and the location of the bloom (i.e., freshwater or seawater).[37] Surveillance and policy implementation are also considered to be HAB-related interventions and encompass aspects of at least two of the aforementioned categories.[37] The large majority of this information will be abstracted and summarized from a semi-systematic review detailing global public health interventions of HABs; the methods are reported elsewhere.[37]

<u>Surveillance:</u> Numerous organizations have employed surveillance measures for HABs; the CDC, partnered with the National Centers for Coastal Ocean Science, set up the Phytoplankton Monitoring Network (PMN) to monitor HABs and marine phytoplankton.[37] The PMN has reported over 250 algal blooms and 15 toxic events.[37] Individual states and regional areas also have HAB surveillance programs; oceanographers and marine algae experts from the University of Washington, state and tribal fishery managers, human health experts, and Seattle-based NOAA HAB researchers have collaborated to form the Olympic Region Harmful Algal Bloom project (ORHAB).[37] Washington's coastal fisheries have managed to save approximately 3 million dollars through selective beach openings during bloom events in 2001 and 2003-2005 while partnering with ORHAB.[37] Operating specifically in Puget Sound region, the SoundToxins program monitors and documents bloom events and new species, determines the environmental conditions that promote the initiation and propagation of HABs, and devises monitoring method to provide early response warnings.[37] Washington's Department of Health (DOH) is able to utilize this information through the SoundToxins' online database to view HAB risk maps in near-real time.[37]

<u>Prevention:</u> NOAA reports that increases in nutrient loading, mainly nitrogen and phosphorus, and pollution due to climate change are potential drivers of the recent increase in frequency and geographical expansion of HABs.[37] Habitat alteration, changes in hydrology, decreasing nutrient loading, and the establishment/enhancement of local shellfish communities have been used in HAB prevention efforts. While all the aforementioned methods have been discussed in literature, prevention efforts seem to largely focus on the reduction of nutrient loading.[37] There is a lack of consensus whether reductions in nutrient loading should emphasize decreasing phosphorus or nitrogen loading.[37] A field study conducted in a lake in China found that the addition of both nitrogen and phosphorus was the strongest indicator of high algal productivity, which is largely consistent with previous studies.[37] Similarly, a review of five global nutrient experiments determined that targeting both nutrients for HAB control was necessary.[37] However, a 37 year-long study conducted in the Precambrian Shield within the US indicated that controlling phosphorus loading should be the focus of future prevention efforts.[37] The authors found that reductions in nitrogen loading resulted in nitrogen-fixing cyanobacteria being favored in the study environment.[37]

<u>Mitigation:</u> This intervention refers to the attenuation of impacts on human and animal health, living resources, and coastal economies; it includes policy, forecasting, monitoring/rapid detection of HABs, sediment dredging, fishery closures, and controlling of ballast water.[37] The latter three will not be discussed due to limited literature discussing their effects.

Policy: Given the absence of federal regulations pertaining to acceptable levels of cyanotoxins and cyanobacteria in public drinking water, many states have developed their own policies.[37] The Oregon Health Authority developed cyanotoxin guidelines for recreational use and drinking for both humans and dogs, specific to the toxins found in Oregon.[37] These guidelines are based on tolerable daily intake levels, which were determined using observable adverse effect levels and benchmark doses.[37] In combination with cell counts, the guidelines resulted in 14 advisories were averted where using cell counts alone would have indicated a necessary advisory.[37] Using the WHO's tolerable daily intake levels and the EPA's reference dose, the DOH developed similar regulatory guidelines for freshwater and marine toxins endemic to the state, including; microcystin, saxitoxin, anatoxin-a, domoic acid, cylindrospermopsin, and diarrhetic shellfish toxins.[37] The state uses a three-tiered approach to manage and respond to potentially toxic cyanobacterial blooms.[37] 'CAUTION' signs indicate the presence of a visible bloom which has been sent for toxicity testing and potentially unsafe lake conditions, 'WARNING' signs indicate that bloom toxin levels have exceeded recreational guidelines and definitive unsafe lake conditions, and 'DANGER' signs indicate that bloom toxin levels are uncharacteristically high and lake closure.[37]

Monitoring/Rapid Detection: HABs can cover expansive areas, especially along the coast or in large lakes.[37] Monitoring and rapid detection can be used to aid in responding to the occurrence of new HABs in a timely manner. Remote sensing, satellite ocean color imagery, and in situ data can be used to detect and characterize HABs.[37] A study in Florida found that this technique could be used to identify chlorophyll α, which is a suitable surrogate for certain species of blooms.[37] It is of note that a fair amount of expertise in phytoplankton ecology and the region of interest are needed to appropriately interpret the images.[37] Another study conducted in the United Kingdom found that a cyanobacterial biomarker pigment, C-PC, was also efficient at characterizing algal bloom abundance.[37] Though fairly costly and limited by meteorological conditions, using small, unmanned aircraft systems and cameras modified to take images of near infrared and blue light wavelengths to identify algal blooms has also been done.[37] A study found that this method was best suited for tracking the distribution and surface density of HABs.[37] Additionally, all remote sensing and similar methods are limited in that they are unable to offer any information on toxin concentrations of HABs.[37]

Forecasting: Satellite imagery has also been used to predict the movement and conditions in which HABs potentially occur.[37] The aforementioned study conducted in Florida determined that satellite imagery is efficient in predicting the direction and speed of existing blooms by analyzing wind patterns.[37] For example, this information was used to forecast the when a bloom in Florida would reach land; it allowed for public health agencies and shellfish management to respond in a timely manner.[37] Statistical and process-based models have also been used to predict the likelihood of toxin-producing cyanobacteria blooms occurring in specific bodies of water.[37] It has proven to be effectual for targeted monitoring and management for lakes a high risk for developing toxins.[37]

<u>Control:</u> These interventions include methods that would directly contain or reduce a bloom.[37] Blooms can be controlled by physical/chemical means, biological means, and/or mechanical means.[37] Each category can be further broken down into a variety of different methods, further discussed below.

Physical: Clay treatment is a popular method of controlling HABs.[37] The purpose of clay treatment is to remove algal cells and minerals through flocculation, which aggregate and quickly settle and trap other cells in their descent.[37] Removal efficiency is largely dependent on particle size and clay composition.[37] A Spanish study found that bentonite and kaolinite, both of which are small particles, demonstrated to be the most efficient at cell removal, with removal rates of greater than 80% in 15 minutes.[37] Contrarily, a Finnish study found that the aforementioned clays were insufficient at properly removing cells alone, but with the addition of 5 ppm of polyaluminum chloride (PAC), an inorganic flocculant, cells removal was slightly improved.[37] The cell removal rate was further improved in nutrient replete conditions.[37] The authors proposed that poor removal efficiency was due to a phenomenon called 'hydrodynamic retardation', which refers to the concept that contacts between particles are decreased because of the smaller particles' (i.e., algal cells) inability to transcend hydrodynamic forces of flowing water and approach the larger particles (i.e., clay flocs).[37] The results from a US study found similar results, demonstrating that survival and recovery of algal cells depended on duration of contact between clays and cells, frequency of resuspension, and clay amout.[37]

Magnesium (Mg) and Calcium (Ca) aminoclays have also been proposed to selectively inhibit HABs.[37] In a South Korean study, they found that both the Mg and Ca aminoclays had much higher algicidal selectivity than yellow loess in mixed-cell culture. A limitation to this method is the relatively unknown nature of the biodegradability of the organic components in aminoclays.[37] Another study found that adding sophorolipid, a glycolipid biosurfactant, to loess drastically increased its removal efficiency.[37] Unlike aminoclays, sophorolipid is reported to have low toxicity, be ecologically acceptable, and is biodegradable.[37] Furthermore, using a combination of both sophorolipid and loess costs approximately 29% of the cost of using loess and 40% of the cost of using sophorolipid alone. Similarly, a study conducted in China found that local beach sands treated with chitosan and PAC were relatively efficient at removing algal cells.[37] Using local sands reduces cost and avoids the introduction of foreign clay into the environment.[37] A limitation of using chitosan is that its netting and bridging properties are negatively affected by high alkalinity and ionic strength, limiting its use in seawater.[37]

Chemical: Tannic acid, a natural substance synthesized from plants with safety approval from the US Federal Drug Administration, has shown to suppress the abundance of phytoplankton in high concentrations.[37] Unlike, chitosan, waters high in salinity and alkalinity promote tannic acid toxicity, improving its effectiveness further.[37]

Biological: Algicidal agents, isolated from bacteria, have also been proposed to control HABs.[37] Three compounds (i.e., palmitoleic acid, tryptoline, and tryptamine) isolated from two different bacteria, all demonstrated to reduce algal cell density, though the result may be species-dependent.[37] The latter two compounds displayed equivalent algicidal activity when compared to copper sulfate in a study, the primary chemical means of controlling HABs.[37-] There are concerns that the use of algicides could increase the production and release of cyanotoxins through lysis of the cell wall.[37] Furthermore, given their short decomposition time, regular reapplication may be required to sustain effective algicidal concentrations.[37] Secondary contamination from the harmful chemical residues is also a possibility.[37]

A few studies have evaluated the use of biomanipulation to control cyanobacteria.[37] One such study found that the grazing of large-bodied *Daphnia*, a planktonic crustacean, suppressed the net growth rate of phytoplankton in both laboratory and field experiments.[37] The authors also noted that success was contingent on low levels of fish predation and that some species may posses some invulnerability to the *Daphnia*, indicating that it is insufficient in controlling blooms with significant cyanobacterial diversity.[37]

Mechanical: In theory, pumps can mix the water column in lakes and reservoirs, reducing net light exposure to phytoplankton, and subsequently light-limiting their growth.[37] A study conducted in Australia found that the use of a surface-mounted solar-powered water mixer was unable to adequately mix lakes or reservoirs.[37] It was only able to reduce surface temperatures by approximately 2°C and deepen the surface mixed layer by one meter.[37]

Due to direct exposure to wet weather runoff and the atmosphere, surface water systems are more easily contaminated.[37] Although water treatment is already standard of practice in controlling HABs, coagulation does not eliminate certain algal toxins (e.g., microcystins) in water.[37] Additionally, under the influence of coagulants, cyanobacteria are more sensitive to chemicals which could result in the release of their toxins into the water.[37] Using micro-sieves to pre-filter water could reduce the amount of chemicals needed to treat the presence of phytoplankton.[37] A Polish study found that micro-sieves were successful at reducing the amount of phytoplankton in water by 23-91%, depending on the water's phytoplankton density.[37] Assuming proper usage, micro-sieves should ideally reduce phytoplankton levels in water by 40-90% as well as reduce total suspended solids, color intensity, and water turbidity.[37]

Ultrasound techniques can also be used to reduce algal growth by structural/functional destruction of cells.[37] The reported mechanism behind this method is that ultrasound radiation in water results in the collapse of generated cavitation bubbles and the production of localized temperatures of 5000°C and 500 atmospheres of pressure.[37] While high ultrasonic frequencies were found to be more effective in controlling algal blooms in a number of studies, it also resulted in a higher likelihood of toxin release.[37] It was found that using ultrasonic radiation in durations of less than 5 minute intervals was effective in inhibiting algal growth without resulting in toxin release.[37] There is a significant upfront cost associated with ultrasound devices, approximately $160,000 for four devices.[37] But, when compared to using copper sulfate for the same length of time, the payback period was estimated to be 1.8 years.[37] Another limitation is that the consequences of this type of ultrasound usage on human health is unknown, and therefore areas may need to be restricted during sonication.[37]

Conclusions

As has been demonstrated in previous literature and in this document, climate change raises a host of concerns related to aeroallergens, changes in temperature and precipitation, vector-borne and water-borne diseases, wildfires, etc. These climate effects and their subsequent impacts to human health can have drastic implications for future policy. The use of the BRACE framework in this document to evaluate the climate-related impacts, interventions, vulnerabilities specific to Grays Harbor County will ideally provide the basis for informing a climate-adaptation plan in the future.

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