One Health and Climate Change:
Linking Environmental and Animal Health to Human Health

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The One Health Initiative was formed in 2007 by the American Medical Association and the American Veterinary Medical Association "to promote, improve, and defend the health and well-being of all species by enhancing cooperation and collaboration between physicians, veterinarians, and other scientific health professionals" [1]. Many public health professionals also view environmental health as essential to the purpose of One Health. The basic idea is that human health cannot be protected unless animal health and environmental health are also addressed. This concept is not new; Sir William Osler, recognized as the founder of modern medicine, coined the term "one medicine" in the late 1800s [2]. Recent incidents involving emerging zoonotic diseases and public health consequences of environmental degradation have led to urgent calls for veterinary medicine, human medicine, and environmental health approaches to be combined and prioritized. One means to explore the One Health perspective is to assess global climate change (GCC), since GCC affects the environment in which humans and animals, as well the disease vectors and pathogens affecting both groups, exist.

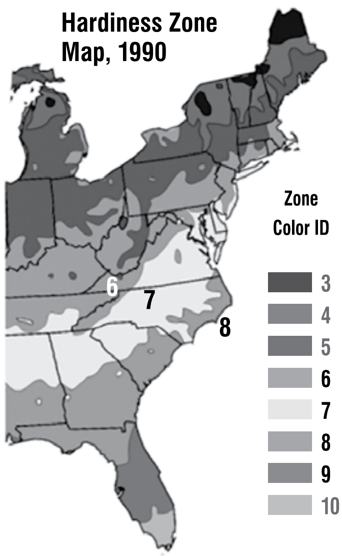
Fundamentals

The theory and physics of greenhouse gases and climate were described during the late 1700s and the mid-1800s [3]. GCC is supported by compelling scientific evidence from multiple independent sources (eg, weather records, glacier dynamics, geochemistry, satellite imaging, and tree-ring investigations). Although controversy has dogged GCC for decades—and has flared recently—there is strong scientific evidence for a direct relationship between current climate changes and increasing anthropogenic greenhouse gases, primarily carbon dioxide (CO_2) and methane (CH_4) [4].

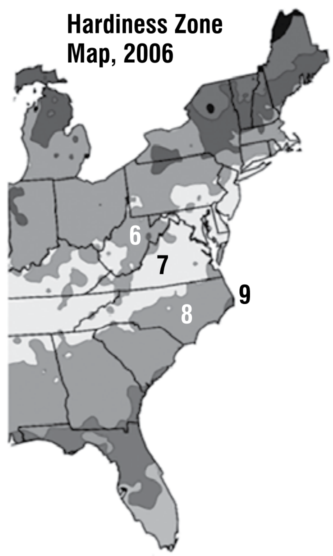
Comparison of plant hardiness zone maps for 1990 and 2006 offers evidence that GCC is occurring (Figure 1). As demonstrated in the maps, the zones have generally moved north, indicating broad warming trend in the United States. For North Carolina, the dominant zone in 1990 (ie, zone 7) was, by 2006, superseded by the next warmest zone (ie, zone 8). Concurrently, the colder zone 6 contracted, and the warmer zone 9 made its first appearance on the state's eastern shores. In 16 years, then, the state became warmer from the beaches, through the Piedmont, and across the mountains.

GCC does not, however, simply involve increasing average temperatures. A variety of events arise, including changes in ocean chemistry, changes in the frequency and intensity of extreme weather episodes, and shifts in seasons and geographic ecosystems [6]. These large-scale dynamics influence local-scale ecosystem health by altering growing seasons and decoupling relationships between plants, animals, and vectors. Unfortunately, because of inherent uncer-

Figure 1.
Comparison of US Department of Agriculture Plant Hardiness Zones for the Eastern United States, 1990 and 2006



Zone Color ID	Avg Low Range (ºF)	North Carolina Pct of Area 1990	2006
3	-40 to -50	0%	0%
4	-30 to -40	0%	0%
5	-20 to -30	0%	0%
6	**-10 to 0**	**11%**	**3%**
7	**0 to 10**	**66%**	**32%**
8	**10 to 20**	**23%**	**63%**
9	**20 to 30**	**0%**	**1%**
10	30 to 40	0%	0%



Note. Data are adapted from [5] and used by permission of the Arbor Day Foundation. Hardiness zones in North Carolina during 1990 and/or 2006 are in boldface.

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tainties about the degree and rapidity of local changes, the health consequences of GCC cannot be predicted exactly.

Practitioners must recognize the difference between *climate* and *weather*. Weather happens at a given locality over a short period; climate is the combination of local effects into large-scale long-term trends. Thus, oscillations in weather (such as North America's cold winter of 2009-2010) are expected within a generally warming climate. Global records from the National Oceanic and Atmospheric Administration show that the period from December 2009 through February 2010 was the fifth warmest on record [7]. The main point is that climate (ie, long-term trends) determines ecosystem health over time but can hide weather (ie, short-term local trends) that drives immediate disasters and resulting health impacts.

Ecosystem Health

GCC will affect ecosystem health, and the negative impacts of changed climate parameters will likely outweigh benefits for most animals and humans [8]. A nonexhaustive list of GCC outcomes, by ecosystem effectors and entities affected, is specified in Table 1. Of note, although Table 1 breaks a system of systems into discrete categories, the categories, by definition, specify interactive factors and are not separable.

Discussion of specific items in Table 1 conveys some of the complexity of the systems involved. For instance, permafrost thawing is part of a potentially rapid, nonlinear feedback system that influences GCC both as an outcome of an effector and an effector itself. Permafrost covers approximately one-fourth of the earth's landmass and contains nearly double the atmospheric mass of carbon. Many permafrost areas are receding. As they melt, they release CO_2 and CH_4. These greenhouse gases induce further atmospheric warming, which could accelerate permafrost melting and release more greenhouse gases. Increased temperatures would result, potentially yielding a runaway feedback process [9].

Marine and aquatic acidification has potentially devastating consequences for coral reefs, on which 25%-33% of marine life depends. Atmospheric CO_2 dissolves in water, lowering its pH and destabilizing coral substrates. Research suggests that if atmospheric CO_2 stabilized at a concentration of 450 ppm, the resulting change in ocean pH could endanger 92% of coral reefs [10]. Frighteningly, 450 ppm of CO_2 approximates a *near best-case* scenario for future concentrations [11].

A final example illustrates system interrelationships. Decoupled ecologic interdependencies are outcomes that involve interconnected species and ecosystems. For instance, research has identified increasing mistiming

Table 1.
Dynamics of Global Climate Change, by Ecosystem Effectors and Entities Affected

Variable	Outcome(s)
Contributing effector	
Temperature change	Extreme weather events
	Glacier melting
	Permafrost thaws
	Sea level rise
	Weather variability
Chemical events	Atmosphere-component concentration changes
	Marine and aquatic acidification
	Soil-component concentration changes
Hydrologic events	Drought and floods
	Extreme weather events
	Glacier melting
	Sea level rise
	Weather variability
Entity affected	
Ecosystem	Biodiversity loss
	Decoupled ecologic interdependencies
	Ecologic niche changes
	Food and feed insecurity
	Habitat destruction
	Productivity loss
	Water insecurity
Human/animal populations	Environmental-refugee emergence
	Incident foodborne disease (humans only)
	Incident infectious diseases
	Incident vectorborne disease
	Incident waterborne disease
	Invasive-species emergence
	Malnutrition
	Population growth, contraction, and movement
	Social conflict (humans only)
	Trauma

Note. Outcomes are ordered alphabetically. Outcomes appearing in more than one category might have different causal mechanisms.

between migratory bird nesting and peak food abundance, owing to earlier plant germination and flowering (which are driven by temperature) relative to photoperiod cycles (which drive bird migrations) [12]. The resulting decrease in food supplies predisposes bird populations to malnutrition and disease. Concomitant habitat destruction compels birds of several species to crowd into shrinking ecological niches and increases the frequency of cross-species pathogen transmission, which has likely been occurring with the H5N1 avian influenza strain since 2003.

Direct Human and Animal Health Effects

Although the rising sea level due to temperature changes clearly damages coastal areas and low-lying islands, it also allows salt water intrusions into inland water tables (Table 1). A Fall 2008 report suggests that over half of the North Carolina coast is at "very high risk" for adverse events associated with a rising sea level [8]. Part of this risk is from erosion and subsidence, but part is from damaged ground water resources, on which 98% of North Carolina water systems depend [8]. Human, animal, and ecosystem damage associated with a lack of water quality and availability is, therefore, a major concern.

Additionally, the expected increase in extreme heat events will have health consequences. Thirty years of research in North Carolina found that each 1°F increase in average summer temperature raised the rate of heat-related deaths by 59% [13]. This is sobering, because 4°F-9°F increases in southeastern average temperatures are expected over the next 70 years [14].

Emerging and Re-emerging Diseases

Despite uncertainties surrounding GCC and ecosystem health, there are well-recognized disease-associated consequences of weather events. For instance, temperature-driven and hydrology-driven increases in extreme weather events will play out in several ways (Table 1). Obvious health-related effects from droughts or floods are immediate trauma, crop failures, food and water insecurities, and other population stressors. Not so obvious, however, is the potential for increased human waterborne diseases (eg, giardiasis and shigellosis) outside of disasters. For instance, public health data demonstrate that two-thirds of waterborne disease outbreaks occur after rain events that are among the top 20% in terms of intensity, most of which do not qualify as disasters [15]. As extreme weather events increase in frequency, so too will outbreaks of waterborne diseases among humans. There is no reason to assume a similar dynamic does not occur among wildlife.

Although vectorborne diseases and GCC are a major concern, the story is not simple. North Carolina has a long history with tickborne and mosquito-borne diseases, and pathogens currently not endemic to the United States (eg, the viruses that cause dengue fever and Rift Valley fever) have competent vectors in North Carolina and therefore threaten the state. There is little argument that as regions warm, impediments against vector survival diminish at higher latitudes and higher altitudes. However, climate is not the sole driver for the spread of vectorborne disease. As a simple example, West Nile virus arrived in North America during 1999 through human travel and rapid transportation, not because of ecosystem changes. Furthermore, climate change–associated improvements in habitat do not ensure a new vector's success. For instance, incursions of *Aedes albopictus* organisms (ie, Asian tiger mosquitoes) into the southeastern United States have been limited because the larval stages of the species are smaller than those of the indigenous species *Aedes triseriatus* (ie, treehole mosquitoes), and they are taken by predators at higher rates [16]. Higher predation has so far blunted the ability of *A. albopictus* organisms to become endemic. The point is that sole dependence on climate models to predict such events is of doubtful usefulness [17].

There are, however, current examples of climate-related agent and/or vector incursions to territories or regions where they are newly endemic. Bluetongue virus, a disease agent among livestock, was unknown north of the Mediterranean until recently. Warmer winters allowed its traditional African/Asian vector, *Culicoides imicola*, to become endemic in southern Europe during the 1990s. The virus then began using indigenous European *Culicoides* species as vectors [18]. Another example is seen among oysters, which play a major economic role in coastal North Carolina. Dermo, a devastating protozoal disease caused by *Perkinsus marinus,* became established among Chesapeake Bay oysters during the 1980s and 1990s, when drought yielded increased salinity, when there were long periods of warmth during the spring and fall, as well as warm winters—conditions GCC will exacerbate. As a result, area oyster beds are now 5% of their previous size [19]. As a third current example of climate-related disease effects, the incidence of human disease due to tickborne pathogens has increased as the burden of tick vectors increased in the wake of GCC. Workers from Sweden have shown that a 20-year increase in the incidence of tick-borne encephalitis among humans is significantly related to changes in the tick-vector burden during milder winters and earlier arrivals of spring [20]. It is therefore important for decision makers to realize that climate is one factor—sometimes a determining factor—in whether a disease agent or vector expands or contracts its territory of endemicity.

Preparation and Mitigation

Many issues discussed here are poorly understood by scientists, let alone by political and commercial decision makers. A major effort in preparing for the health impacts of GCC, then, should be to promote research that provides information about effectors and outcomes, including the interdependencies that are uncovered as initial subjects are explored.

Figure 1 implies an important way to mitigate GCC effects on human, animal, and ecosystem health: we must adapt to generally warmer, yet more variable, weather patterns.

Oscillations between drought and extreme amounts of precipitation suggest soil protection will be central to maintaining food and water supplies and to limiting downstream contamination. All of these factors are important for human and animal health.

Parts of society are at special risk during extreme weather events: people who are homeless, are very old or very young, are poor, and/or work outdoors. Establishing mitigation tools and plans for these groups should happen now. Hospital emergency departments should establish triage protocols and supplies as warm seasons increase in duration and become more severe. Likewise, public safety and public health professionals must increase public education programs about the risks and harm heat waves can produce.

Planning for changes in the array of infectious diseases faced under GCC is a challenge, yet some activities should start now. Bolstering mosquito abatement activities and public education to minimize mosquito and tick exposures would be constructive. First-line medical professionals should augment their training in awareness, diagnostic tests, and therapy for what are now considered "foreign" vectorborne, waterborne, and foodborne diseases. Importantly, academia must find time to expose students to interactions between environmental health, animal health, and human health.

Last, society must increase its resources and support for public and environmental health activities. Unfortunately, 33 states, including North Carolina, have *decreased* public health budgets in the past year, resulting in staffing cuts at more than half of local public health agencies [21]. A continued partnership between first-line practitioners—veterinary and medical—and public health professionals, biologists, and epidemiologists offers the best chance to make early determinations of emerging health threats. It is essential that we take these larger, more encompassing views of what constitutes health and what our roles need to be. And *that* is what One Health is all about. NCMJ

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