A New Food System for the Chesapeake Bay Region and a Changing Climate

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Rising seas drown the islands and shores of the Chesapeake Bay, 
the warming climate taking a building toll each day.

 Burning the fossils of life long past, 
is changing the Bay terribly fast.

Add to that the lust for meat, 
with its emissions that increase the heat.

For the sake of the future we can and must do better, 
seeking a food system that won’t make our feet any wetter.

Food systems have the potential to nurture human health and support environmental sustainability; however, they are currently threatening both . . . Increasing evidence shows that food production is the largest cause of global environmental change, and a transition to sustainable food production is necessary for global sustainable development (Willett et al. 2019).

Abstract

Climate change is reshaping the Chesapeake Bay ecosystem and its linked food system. Sea level rise and increased precipitation drive regular flooding events and the erosion of islands and coastal features. This results in the loss of habitat for various species of birds and fishes. Increased temperatures extend the growing season and reduce the incidence of frosts. Rising water temperatures accommodate the immigration of warm-adapted species and endanger populations of cold ones. Increased temperature interacts with cultural eutrophication to extend the duration and extent of seasonal hypoxia. Higher regional temperatures threaten human health, particularly populations of poorer residents that lack refuge from heatwaves and flooding events. Acidification of the Bay, which is linked to climate change agents, endangers species that rely upon calcium carbonate for shell and skeleton. Emission of greenhouse gases (GHGs, primarily CO2, NO2, CH4) from human economic activity drives climate change. The food system accounts for 25–30% of human GHGs emissions. Half of these comes from livestock, which contribute 14.5% of the global anthropogenic GHG load. Eliminating animal-based foods, particularly ruminants (cattle) would facilitate building a sustainable food system with improved health outcomes for the residents of the Chesapeake Bay Region.

Keywords

Ruminants · Animal-based-foods · Plant-based-foods · Ocean acidification · Sea level rise · Habitat loss

The climate of the Chesapeake Bay region is changing, as is true for the entire world. Three centuries of burning fossil fuels, deforestation, population growth, and an expanding
animal-based food system have combined to increase the concentration of greenhouse gases (CO₂, CH₄, N₂O and others) in the atmosphere. The concentration of CO₂ in the atmosphere went from 310 ppm in 1950 to 415 ppm in June of 2019. Since 1950, earth’s global temperature increased 1 °C, and is on track to increase another 0.5° by 2050 (IPCC 2018). The rate of increase in air temperature for the Chesapeake Bay Region is 0.036 °C/year, 30% higher than the global rate of 0.025 °C/year (Irby et al. 2018). About 31% of the CO₂ produced from burning fossil fuels is dissolving in the ocean, having caused a drop in pH from 8.2 to 8.1; a 30% increase in acidity (Gruber et al. 2019; NOAA 2019a). The Chesapeake Bay’s ecosystem and food system are responding to climate change in numerous ways. The current food system contributes to the problem by adding to the load of greenhouse gases. This chapter explores how climate change has already altered the Chesapeake Bay ecosystem and considers a new food system to meet the challenge of curtailing the upward trajectory of warming and acidification.

The Changing Climate of the Chesapeake Bay: Rising waters  Extreme high tides and storms regularly bring the waters of the Chesapeake Bay into the streets and front yards of Tangier Island (Fig. 1). It wasn’t always that way. Previously such flooding occurred every few years in association with hurricanes and other severe storms. Now it’s expected several times a year (Sweet et al. 2018).

Tangier Island, VA (37° 49’27.48” N, 75° 59’33.64 W°) is about halfway between Cape Henry and Annapolis, MD. It lies just 20 km southwest of Crisfield, MD on the coast of the Delmarva Peninsula. To the northwest and 22 km across the Bay is Smith Point, marking the southern side of the mouth of the Potomac River. Sitting just 1.2 m above mean sea level, Tangier is one of just two remaining inhabited islands in the Chesapeake Bay. The other is Smith Island, which lies 15 km to the north of Tangier. In the sixteenth Century, English cartographers named about 400 islands in the Bay. Most no longer exist, succumbing to rising sea level and sinking land.

The Bay is a dynamic system and islands have always come and gone. But the system is far from equilibrium, no longer do new islands emerge to take the place of those washed away. The process of island loss accelerated starting about 1850. That year marked the end of the little ice age and coincided with intensification of the mostly coal-fired Industrial Revolution. The natural warming cycle, joined by human-produced greenhouse gases and deforestation, accelerated post-glacial Sea Level Rise (SLR). Melting glaciers and thermal expansion of the sea started to drown the Bay’s islands. Add to that the land subsidence from natural settling following the last glacial cycle and withdrawal of water from the aquifer to supply the food system (Kenney and Brainard 2019). The fate facing Tangier is stark evidence of how a changing climate is reshaping the Chesapeake Bay ecosystem (Beringer 2018).

Fig. 1  Tangier and Port Isabel Islands as they appeared in 1850, 1984 and 2015. The extensive loss of land is apparent. The once inhabitable “Uppards” illustrated in the 1850 map has been converted to marsh by the rising sea level. Images from historic map and Google Earth
A map from 1850 shows Tangier Island with two contiguous main sections, the more northerly “uppards,” and the southerly town of Tangier. The uppards is now all but gone, converted to low marsh and shoals. Presently, about 300 ha (740 acres) comprise the island, but only 34 ha (83 acres) are high enough to support habitation. Tangier Island is a third of the size of what it was in 1850, and projections suggest it will become uninhabitable if not completely washed away by the end of the twenty-first Century (Tangiers Plight 2019).

As their ancestors for generations before them, the less than 800 current residents of Tangier Island make their living primarily from the food system. Most work the surrounding waters to catch crab and fish, raise soft shelled crab, or provide seafood dinners to tourists. Native Americans used Tangier as a fishing camp prior to it being taken by English Colonists in the seventeenth Century (Worrall 2018).

Despite being just an hour’s boat ride away from Maryland’s Eastern Shore, Tangier Island retains a distinctive culture and unique speech, tracing to Cornwall, England, the ancestral home of most of the current residents. The Island also figured large in the Nation’s history. During the War of 1812, it harbored 1000 people who escaped enslavement and sought the protection of the British. It was the primary British base for Royal Navy operations in the Bay, and from its shores, vice-admiral, George Cockburn launched the attack on Baltimore in September of 1814. The successful resistance of Fort McHenry to that invasion is the subject of a poem by Francis Scott Key that became the US National Anthem (NPS 2019). Climate change and the rising waters of the Chesapeake stand poised to wash away what remains of this fishing village and physical evidence of its storied past. And it’s not just Tangier and the few other remaining islands of the Bay threatened by rising sea level. Nearby Crisfield, MD is one of a dozen coastal communities facing regular and extensive flooding that will restrict future habitation (Kleinosky et al. 2006).

The long term rate of SLR (Sea Level Rise) for the Chesapeake Bay ranges from 3.17 mm/year in Baltimore over the past century, twice that of the global average of 1.6–2.1 mm/year over the past century, to 4.7 mm/year in Norfolk, VA over the course of a century (VIMS 2019; CSSR 2017; Fig. 2). The region is slowly subsiding from relaxation of the glacial forebulge, tracing back to the Pleistocene (DeJong et al. 2015). But sea level rise has been accelerating. By the year 2100, sea level in the Bay will rise 0.4–1.3 m, depending on the world’s ability to reduce the release of greenhouse gases (GHGs) (Boesch et al. 2013). The rising waters won’t affect all communities equally. Those in low-lying coastal areas where land forms focus tidal surge will see the greatest damage. Such places are often home to large populations of African Americans. Crisfield is located in Somerset County, which has the lowest income and some of the lowest lying lands in Maryland. Its population is 40% African American, and many residents have suffered from flooding during recent storms (Kobell 2015).

Chesapeake Bay communities face different kinds of flooding, all linked to climate change. Sunny day (nuisance, or high-tide) flooding occurs during high-tide events, often tied to surge from winds and atmospheric pressure differentials. High-tide flooding of the sort that regularly inundates Tangier Island and other coastal communities is on the rise in the Chesapeake, occurring about eight times per

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**Fig. 2** Rising sea level at Sewells Point, Norfolk, VA as indicted monthly mean sea level data from 1927 to 2018. This is equivalent to a change of 0.47 m in 100 years. This station is located in Hampton Roads, at the southern end of the Chesapeake Bay (NOAA 2019b)
year in 2015, compared to once per year in 1955. Importantly, the rate of increase is exponential, predicting 40 events per year by 2055 (Fig. 3).

Storm surge associated with tropical storms and nor’easters pushes water from the Atlantic Ocean into the Bay, where it breaches natural shores and seawalls. Intensified rains associated with storms drain from the watershed to cause tributaries to overflow into natural and developed lands along their banks. At times the different drivers of flooding may co-occur, making the flooding more severe.

Flooding is part of natural hydrography and has long informed the food system. For eons before the evolution of humans, periodic storms and seasonal melting caused rivers to escape their banks and deposit rich sediments in floodplains. Indeed, civilization and agriculture evolved on these nutrient-rich soils that provided bountiful harvests (Crawford et al. 1998). Of course floodplains do flood, at times inundating and destroying crops. However, climate change, deforestation and increased urbanization combine to make flooding more common and intense. A warming Earth means faster evaporation, hotter air able to temporarily store more moisture, and more intense storms coming more frequently (Nicholls et al. 2012).

Coastal Flooding Destroys Habitat Flooding of developed lands catches people’s attention. Impassable roadways, flooded buildings, and undermined structures reduce human habitability. But excessive flooding also destroys habitability of natural areas for non-human populations in the Chesapeake Region. Rising water levels in the Bay drown the shore-side nests of laughing gulls (*Leucophaeus atricilla*). In 1993 counts found 45,387 nesting pairs in the Bay. That’s down to 16,653 in 2019 (Dietrich 2019). To reduce erosion and flooding landowners often harden the shore line with rip-rap (large rocks) or bulkheads. These structures eliminate the natural ecotones (transitions) between aquatic and terrestrial systems. About 63 different species of water birds require those transitions for feeding, mating and nesting along the shores of the Bay’s tributaries. As little as 5% shoreline hardening significantly reduces water bird habitat and counts (Prosser et al. 2017). As of 2016, 18% of the shoreline of the Bay and its major tributaries had been hardened, substantially reducing habitat (Mitchell 2016).

Tidal marshes of the Chesapeake Bay come in three basic varieties; *extensive* (large areas adjacent to the shore or independent islands), *embayed* (comprising the sides of creeks), and *fringing* (narrow expanses along the shoreline). All provide habitat for wildlife and important ecosystem services. Marshes slow runoff and filter particulate matter from the water. They also sequester carbon, nitrogen and other nutrients, reducing the effects of water pollution. Marshes dampen wave activity, protecting shores from erosion (Mitchell et al. 2017). SLR is combining with subsidence and land development to cause a net loss in marsh area for the Bay. The York River lost 9% of its marsh area between 1973 and 2009 (Mitchell 2016). Marshes in this area may accrete at a rate of 5 mm/year in the Bay, which roughly matches the combined effects of SLR and subsidence. Consequently, eroded and drowned fringing and extensive marshes aren’t being replaced much by shoreward migration. Most of the new marsh comes from flooding of adjacent, low-lying forest in the upper reaches of the tributaries. Stands of dead Loblolly pines (*Pinus taeda*) that succumbed to drowning of their roots, stand as silent witnesses to the encroaching waters of the Bay. The 11% expansion of up-tributary marshes by the process of forest drowning can’t make up for the 32% loss of down-tributary fringing and extensive marshes, observed for the interval between 1973 and 2009 (Mitchell et al. 2017).

Rising and More Extreme Temperatures The average temperatures of the air and water are rising. The mean annual air temperature in Baltimore, the largest city on the Bay, went from about 13 °C in the 1890s to 15.5 °C by 2016. The mean
The annual surface water temperature of the Patuxent River rose from 14.5°C in the 1940s to 17.0°C in 2010 (Fig. 4). If these trends continue, we could expect to see mean annual air temperatures of 16.4°C by 2060 and 17.5°C for surface waters.

It’s not just the average temperature that’s rising. The region is experiencing about ten fewer days of frost (temperatures ≤0°C) and ten more tropical (nighttime temperatures ≥21°C) nights per year than it did in at the end of the nineteenth Century (Figs. 5 and 6). This difference is exacerbated in the hottest regions within urban areas which can be as much as 6°F warmer than the cooler urban regions in Baltimore. These hotspots are correlated with high rates of poverty, and low levels of green space (NPR 2019). Fewer cold days means a growing season length (GSL) about 15 days longer than in 1900 (Fig. 7). GSL is, “...the number of days between the first span of at least 6 days with daily mean temperature warmer than 5°C and the first span of 6 days after July first with daily mean temperature below 5°C (Mueller et al. 2015).” Output of crops should be increasing with expansion of the GSL in the Chesapeake Region, as is generally true for mid-latitude farms (Gornall et al. 2010). However, climate change also brings more days of extremely warm temperatures, longer periods of drought and springtime
flooding of fields, which may sporadically reduce crop yields. "While change in long-term mean climate will have significance for global food production and may require ongoing adaptation, greater risks to food security may be posed by changes in year-to-year variability and extreme weather events. Historically, many of the largest falls in crop productivity have been attributed to anomalously low precipitation events (Gornall et al. 2010)."

**Climate Change Increases the Frequency and Intensity of Rain Events**

Higher temperatures mean more evapotranspiration and the capacity for the atmosphere to hold more moisture. The total amount, frequency, and intensity of precipitation has increased since 1900 in the Chesapeake Bay Region. The rate of increase in annual precipitation is 1 cm per decade. This trend is expected to continue and intensify in coming decades. More extreme rain-events will bring increased flooding. The future appears to hold wetter springs followed by summer droughts (Kunkel et al. 2013).

Increased precipitation means more nutrients (N & P) washed from the watershed into the Bay. Wetter years and higher nutrients yield higher concentrations of phytoplankton. Diatoms, the dominant taxonomic groups of phytoplankton show the biggest response to wet years. Although most species of diatoms serve as excellent food for oysters, menhaden, and zooplankton, their numbers in wet years overwhelm these consumer’s ability to eat them (Harding et al. 2015). This results in massive oxygen loss due to bacterial respiration of the decaying algae in the deeper waters of the Bay (see chapter “The Journey from Peruvian Guano to Artificial Fertilizer Ends with too Much Nitrogen in the Chesapeake Bay” on Eutrophication).

**SLR, Temperature and Precipitation Interact to Cause a Net Reduction of Oxygen in the Bay**

Climate change involves a suite of factors that are altering the availability of free oxygen in the Bay. SLR will enhance estuarine circulation, bringing more oxygen rich water from the Atlantic Ocean in to the Bay. However, that effect is being overwhelmed by other factors that lead to reduced oxygen.

As noted above, increased precipitation brings more nutrients to the Bay, promoting excessive algal growth. When those algae die, they sink to the deeper waters where bacteria digest them and in doing so deplete the reserves of free oxygen. While intense storm events produce strong winds that can ventilate the Bay and temporarily increase oxygen concentrations, this is offset by runoff laden with nutrients and oxygen-demanding organic material (Najjar et al. 2010).

Higher temperatures increase the rate of microbial metabolism. This speeds both the rate of algal growth and its subsequent decomposition by oxygen demanding bacteria. In addition, the solubility of oxygen (and all gases) is inversely proportional to temperature, thus reducing the capacity of the warmer waters to supply oxygen to meet the demands of increased bacterial respiration. The warming
climate is also extending the duration of the Bay’s stratification, moving the onset of hypoxic waters a week earlier in the spring. Of the three factors, modeling suggests that increasing temperature appear to be the most important in determining oxygen availability (Irby et al. 2018).

Efforts to reduce eutrophication in the Bay by curtailing nutrient loading (which comes mostly from the food system) are confounded by climate change. Increased temperature and river flows are projected to reduce the effectiveness of nutrient-reduction by 5–45%, with the most detriment for waters at mid-depths that flank the deep main channel of the Bay. This will reduce habitat for fish, crabs, and other demersal species in mid and lower reaches of the Bay (Irby et al. 2018). Climate change is making the job of restoring the Bay harder.

**Projecting Climate Change Impacts on the Bay’s Ecosystem** Najjar et al. (2010) developed a comprehensive narrative for the changes predicted to be wrought by climate change on the Chesapeake Bay by the end of the twenty-first Century. Let’s consider some of these that haven’t been addressed above. Increased precipitation in winter and spring will drive more intense blooms of diatoms in the spring followed by aperiodic blooms of dinoflagellates in the summer. The nutrient laden runoff will increase productivity of the phytoplankton over the course of the year. Increasing concentrations of CO2 in the water will couple with higher temperatures to alter the composition of the algal community. This will likely result in the increased frequency of harmful algal blooms (HABs). The toxins produced by HABs will discourage zooplankton grazing, resulting in net increases of dissolved organic carbon (DOC), that will help fuel an increasingly heterotrophic food chain.

Increasing temperatures will shift the composition of the fin and shell fish in the Bay, with those adapted for colder waters being replaced by warm-water species expanding their distributions into the estuary. Brown shrimp (*Farfantepenaeus azte cus*) historically supported a strong commercial fishery off the shores of North Carolina, and significant populations now appear in the southern reaches of the Chesapeake Bay. Warm water species already occurring in the Bay are expected to increase. These include southern flounder (*Paralichthys lethostigma*), cobia (*Rachycentron canadum*), spadefish (*Chaetodipterus faber*), Spanish mackerel (*Scomberomorus maculatus*), mullet (*Mugil curema*), tarpon (*Megalops atlanticus*), pinfish (*Lagodon rhomboids*), black drum (*Pogonias cromis*), red drum (*Sciaenops ocellatus*), weakfish (*Cynoscion regalis*), spotted sea trout (*C. nebulosus*), spot (*Leiostomus xanthurus*), northern kingfish (*Menticirrhus saxatilis*) and southern kingfish (*M. americanus*). Most of these species are part of the Bay’s food system and stand to benefit from longer growing seasons and milder winters.

Cold-adapted species in the Chesapeake Bay that occupy the southern portion of their range may fare poorly as temperatures rise and oxygen concentrations drop. This includes; soft clam (*Mya arenaria*), yellow perch (*Perca flavescens*), white perch (*Morone americana*), striped bass (*Morone saxatilis*), black sea bass (*Centropisstriat a*), tautog (*Tautoga onitis*), summer (*Paralichthys dentatus*) and winter flounders (*Pleuronectes americanus*), silver hake (*Merluccius bilinearis*), and scup (*Stenotomus chrysops*). The inclusion of striped bass in this list seems counter-intuitive, since their range extends to the Gulf of Mexico. Yet, stratification of the Bay often leads to pockets of surface water temperatures >30 °C, sufficient to cause stress (Cook et al. 2006).

Increasing temperatures and changes in salinity may increase the abundance and efficacy of pathogens attacking the Bay’s fisheries. Oysters already suffer from *Perkinsus marinus* (Dermo) and *Haplosporidium nelson* (MSK). Effects of these pathogens stand to increase in warmer temperatures (Cook et al. 1998).

As noted above, SLR is reducing marsh habitat in the lower reaches of the Bay’s tributaries. This may reduce success of juvenile fish and crabs that depend on those habitats as refugia and feeding grounds. Eel grass (*Zostera marina*) is the most important SAV (Submerged Aquatic Vegetation) in the lower (mesohaline) portion of the Bay, its extensive beds serve as important habitat for fin and shell fish. Eel grass is near the southern extent of its range in the Chesapeake. Periods of elevated temperature have already caused massive diebacks (Moore and Jarvis 2008).

The projections outlined above are those with definitive direction. However, the complexity of the ecosystem makes other predictions about the effects of climate change less certain in both direction and magnitude. For example, comb jellies (*Mnemiopsis leidyi*) are important predators of zooplankton in the Bay, including the larvae of fin and shell fish. A warming Bay may increase their population and effective rate of predation. Yet this ctenophore does poorly at temperatures >30 °C, now a common occurrence in the Bay (Haraldsson et al. 2012). The effect of climate change on the trophic interactions surrounding this key planktonic predator are uncertain, as is true for most of the complex ecology in the Bay ecosystem. So, we can add uncertainty to the list of projected changes (Najjar et al. 2010).

**Changing Climate Challenges Human Health** The warming climate threatens public health, particularly for vulnerable populations. People of color, the poor, elderly, young children, pregnant women, and those with various illnesses stand to suffer the most from the overheating of the Chesapeake Bay region (USEPA 2017). High temperatures have direct impacts on health. People exposed to high temperatures for extended periods may suffer dehydration
and heatstroke, as well as exacerbation of cardiovascular, cerebrovascular, and respiratory disease. This falls hardest on people with outdoor jobs, such as in agricultural, transportation and construction; and those dwelling in buildings without air-conditioning. People living in urban areas, such as Baltimore, Richmond, and the District of Columbia will suffer from the heat island effect. The abundance of concrete and dearth of trees renders such cities several degrees warmer during heat waves (Imhoff et al. 2010; NPR 2019).

Indirect effects of warming are manifold. Higher temperatures promote the production of ground-level ozone. The secondary air pollutant reduces lung function and exacerbates asthma (Sheffield et al. 2011). In addition to creating GHGs, fossil fuel combustion produces particulate matter, such as black carbon, that stresses pulmonary function. More frequent forest fires associated with climate change will also add such particles to the air (Flannigan et al. 2000).

The extended growing season brought by warmer temperatures isn’t just for crops. The spring pollen season is getting longer, posing problems for those with allergies. The higher temperatures extend the infective seasons for many vector-borne disease. A longer season for mosquitoes and ticks means increased chances of infection from West Nile virus and Lyme disease (Khatchikian et al. 2015).

More frequent and more intense storms increases the washing of pathogens from the watershed into the Bay and its tributaries. This exposes swimmers and beachgoers to sewage and animal wastes (Najjar et al. 2010). The Bay staying warmer for a longer period of time each year also increases the chances of encountering these pathogens.

Poultry dominates the animal food industry of the Chesapeake Bay. Most commercial flocks in Concentrated Animal Feeding Operations (CAFOs) and the meat they produce are contaminated with Salmonella, and Campylobacter. These cause food poisoning (see chapter “Livestock and Poultry: The Other Colonists Who Changed the Food System of the Chesapeake Bay”), and grow faster at higher temperatures (USEPA 2017).

The mental health of people subjected to the arduous climate change also suffers. Some psychotherapeutic medications interfere with body temperature regulation, endangering those taking the drugs during heatwaves. People with pre-existing mental illness suffer a tripling of the risk of death during high temperature events (GlobalChange.gov 2016).

**Acidification as Part of Climate Change** Ocean acidification is a consequence of elevated atmospheric CO₂ concentrations that dissolve into the water. The Chesapeake Bay experiences a second source of acidification, the seasonal production of H₂S in the anaerobic sediments during the warmer months of the year. The combination of CO₂ and H₂S acidification produces pH levels near 7.4 (Cai et al. 2017) in sections of the Bay. This has profound implications for species, such as oysters that use calcium carbonate to build their shells. The eastern oyster (Crassostrea virginica) was once the basis for the most economically important fishery in the Chesapeake Bay. It is also a foundational species that provides essential habitat and the ecosystem service of filtering the water (see chapter “The Chesapeake Bay Oyster: Cobblestone to Keystone”). In addition to the devastation wrought by decades of overharvesting and invasive pathogens, oysters now face the new challenge of acidification of the Bay’s waters. Levels of pH of 7.5 or less reduce the ability of the oyster to produce its shell and to reproduce (Beniash et al. 2010; Boulais et al. 2017).

**Climate Change Challenges the Food System** Rising temperatures will influence the food system of the Chesapeake Bay in numerous ways, including some that may not be predicted. The list includes; extended length of growing season, more evapotranspiration increasing sensitivity to drought, expansion of the ranges of plant pests and weeds, stress on pollinators, and changes in migratory patterns of birds and fish.

**Higher CO₂ Alters Crop Production and Nutrition** Higher concentrations of atmospheric CO₂ will favor some plants over others. About 97% of plant species use C-3 metabolism for collecting CO₂ to be used in photosynthesis. These species suffer in dry conditions when they must keep their stomata closed to reduce loss of water from their leaves. Under such conditions C-3 plants waste much of their energy in the process of photorespiration fueled by high concentrations of oxygen. C-4 plants evolved in dry tropical areas. They use an intermediary molecule with higher affinity for CO₂ combined with special anatomy. This allows them to photosynthesize efficiently with reduced stomatal opening and less loss of water. Despite comprising less than 2% of all plant species, C-4 plants account for 25% of global terrestrial primary production (Ehleringer 2002).

In order, the three dominant crops in the US food system are corn (Zea mays), soy (Glycine max) and wheat (Triticum aestivum). Corn is a C-4 plant, soy and wheat use C-3 metabolism. Both C-3 and C-4 plants increase their yields and growth rates at higher levels of CO₂. But, C-3 plants benefit the most experiencing increases of 20–40%, about two to four times that for C-4 plants. This means that with increasing CO₂ concentrations, corn will suffer more competition from C-3 weeds, such as lambsquarters (Chenopodium album).
album). On the other hand, soy will better compete with the C-4 pigweeds (Amaranthus spp.) (Miri et al. 2012).

Increasing CO₂ concentrations changes the macronutrient ratio available to plants. This has two consequences. First, it increases the likelihood of nitrogen (N) limitation for the plant, meaning that more reactive N will be required for the crop to realize its full yield potential. This may encourage farmers to use more N-rich fertilizer on non-leguminous crops, such as wheat. Soy and other legumes use their root nodules that contain mutualistic N-fixing cyanobacteria to fulfill their requirement for that nutrient, so they are expected to increase yields with elevated CO₂. Indeed, a meta-analysis of 111 studies finds a 24% increase in seed yield for soy under elevated CO₂ (Ainsworth et al. 2002).

Second, under elevated CO₂ the relative lack of N will reduce the relative amount of N-rich molecules (protein) in the plant (Ehleringer 2002). One study using CO₂ levels 150 ppm above ambient (expected levels by 2050) found a 10.4% increase in yield of wheat. But, the grain suffered decreased nutritional value; protein dropped 7.4% and iron declined 5.0%. The grain also increased in sugar and lipid content (Högy et al. 2009).

Increasing Temperature Lengthens Growing Season But May Reduce Yields

Between 1900 and 2018, Growing Season Length (GSL) in the Chesapeake Bay region increased by about 25 days (Fig. 7). This should be a boon to agriculture. However, the extension of the GSL may be countered by crop damage associated with higher temperatures. The yield for corn increases with rising temperatures up to 29 °C (84.2 °F), and that for soy up to 30 °C (86 °F), but declines with continued warming. Based upon projected temperature increases, yields for these two key crops in the US are expected to decline 30–82% by 2100, with less reduction in yield if the world curtails GHG emissions (Schlenker and Roberts 2009). Temperatures in the region already regularly exceed those damaging to corn and soy. Baltimore recorded an average of 47.5 days with temperatures >32.2 °C between 2010 and 2018 (NOAA-NCEI 2019).

The Animal-Based, Chemical-Based Food System Challenges the Climate, Ecosystem Sustainability and Human Health

As addressed above, climate change is altering the food system of the Chesapeake Bay Region. Yet the more important issue is how that food system is responsible for much of the climate change that challenges the sustainability of the local and global ecosystem as well as the degradation of human health (Horrigan et al. 2002; Willett et al. 2019). The current US food system requires 7–10 kcal of energy subsidy from fossil fuel to produce just one kcal of food. That energy subsidy is apportioned as follows; production (14.4%), transportation (3.5%), processing (18.7%), packaging (6.5%), marketing (15.1%), food service (12.9%), household storage and preparation (28.8%). Production of fertilizers and pesticides accounts for 40% of production energy use (Heller and Keoleian 2000). If a 113 g (290 kcal) hamburger seems oily, it should, as it required 3190 kcal of fossil fuel to produce it. That’s like drinking 300 ml of diesel fuel!

The food system begins with people’s dietary habits. Farmers, fishers and food processors match their products to market demand, as there is no profit in unsold products. Of course, corporate marketing seeks to shape that demand, influencing consumer’s decisions. The USDA last published data on food marketing by category in 1997. The food industry spent $7.074 billion in marketing that year. Convenience food, confections, alcoholic beverages, and non-alcoholic beverages accounted for 71.6% of expenditures. Meat of all kinds and dairy combined for 10.1%, while vegetables, fruits, nuts, and beans summed to just 2.2% of the advertising dollar (Gallo 1999). The marketing expenditures seem to work, as...
they roughly reflect how people in the US are getting their calories (Fig. 8). The USDA collects information on the nation’s diet, but doesn’t parse that out to specific regions or states. So we operate under the assumption that people in the Chesapeake Bay Region eat diets similar to that of most of the nation. What constitutes the Standard American Diet (SAD)?

From the standpoint of mass (weight) of macronutrients, on average people in the US split their diet between carbohydrates (58%), fat (24%), protein (15%) and fiber (3%). This results in a daily average of about 3100 kcal consumed per capita from food that provides an energy density of 5 kcal per gram (Gerrior et al. 2004; Hiza and Bente 2011). The SAD supplies the plurality (30%) of its calories from animal products, with grains, added plant-oils, and added sugar combining for another 59%. That leaves just 8% from vegetables, fruit and nuts (Fig. 8). Note that about 90% of the grains in the diet are highly processed with the elimination of most fiber and the additions of oils, sugars, and sodium (USDA 2019). This diet is unhealthy for both the people eating it and the agroecosystem producing it (see chapter “Eutrophication: Obesity of the Bay and Its People”). It is also unsustainable in terms of GHG production and required subsidies of energy, water, artificial fertilizers and pesticides (see chapters “The Journey from Peruvian Guano to Artificial Fertilizer Ends with too Much Nitrogen in the Chesapeake Bay” and “Pesticides Bring the War on Nature to the Chesapeake Bay”).

The food system accounts for 25–30% of all anthropogenic GHG production. Livestock production dominates the food system designed to support the SAD and is responsible for half or more of food system emission. This includes the potent GHGs of methane (CH₄) and nitrous oxide (N₂O) (Barioni et al. 2019, Fig. 9). While CO₂ does promote crop growth, the other carboniferous GHG, methane, causes indirect damage to plants. Photooxidation of methane produces ground level ozone, a potent oxidizing agent that damages crops and that already accounts for about a 5% reduction in agricultural yield (Shindell 2016).

Poore and Nemecek (2018) summarize the environmental problems posed by animal-based diets, “In particular, the impacts of animal products can markedly exceed those of vegetable substitutes . . . , to such a degree that meat, aquaculture, eggs, and dairy use ~83% of the world’s farmland and contribute 56–58% of food’s different emissions, despite providing only 37% of our protein and 18% of our calories.” “We find that the impacts of the lowest-impact animal products exceed average impacts of substitute vegetable proteins across GHG emissions, eutrophication, acidification (excluding nuts), and frequently land use . . . .” “Most strikingly, impacts of the lowest-impact animal products typically exceed those of vegetable substitutes, providing new evidence for the importance of dietary change.”

Environmental Footprints of Foods Examining the environmental impacts of specific food-groups reveals the outsized role that animal products play in stressing the environment. Consider the environmental footprint formed by a serving of various foods (Fig. 10). The environmental footprint of a serving of animal product of any kind well exceeds that for almost any plant-based food. The primary reason is a basic ecological principle. Energy is lost with each
step up the food chain. In nature, typically only 10% of the energy in primary producers is transferred into the biomass of consumers. That’s because the consumers usually can’t digest and absorb all of the plant tissue they consume, and what they do absorb is used for various metabolic processes in addition to growth. What consumers burn-up in metabolism won’t add to their biomass. Much of the energy absorbed by homeothermic (warm blooded) animals is used to produce heat. All of the major sources of terrestrial animal food comes from homeotherms (cattle, poultry and pigs), meaning much of what they eat is turned into heat rather than flesh. In the US food system, the vast majority of cattle, poultry and pigs are produced in Concentrated Animal Feeding Operations (CAFOs). Rather than grazing from field or forest, these industrially produced animals eat mostly soy and corn. Indeed, 59.5% of US corn goes to animal feed, 30% to ethanol production (engine feed), and 10% for direct human consumption (mostly refined grains and high fructose corn syrup) (NCGA 2018). For soy, 70% goes to animal feed, 15% for human consumption after processing, and 5% for biofuel (USDA 2018; USDAERSA 2019). Feeding the soy and corn to an animal, and then eating that animal means that most of the nutrition from those plants is lost before it gets into one’s mouth. Consider pork and soy. It takes 1 m² of land area to produce one serving of pork, while it takes 0.02 m² of land to produce a serving of soy (Fig. 10).

Traditionally, livestock farmers use a Feed Conversion Ratio (FCR) to determine how much animal product results from a given amount of food. This is typically done as a ratio of weight of the feed to live weight of the animal. FCR is variable, depending on the feed composition and the conditions faced by the livestock. FCR for the most common livestock are; 8–12:1 for beef cows, 5–6.5:1 for pigs, and 2–2.5:1 for chickens (Smil 2000). FCR is deceptive when considering nutrition available to humans, since even the most enthusiastic meat-eaters generally don’t consume the entire body of an animal. Processing, butchering, and dining utensils removes uneatable parts from servings of meat. A better way to understand the lack of efficiency associated with livestock is to calculate the transfer of energy from the feed to the edible portions of the animal (Table 1).

For ruminant animals (cows and sheep) only about 1% of the energy in their feed makes it into the edible meat they produce. Protein conservation is only slightly better, transferring 13% of the energy and 20% of the protein from its feed into meat. Considering that modern intensive animal agriculture is mostly based on very edible (for humans) grain and soy, the practice is clearly wasteful, losing 87–99% of the energy and 75–97% of the protein in the feed.

Globally, livestock produces 14.5% (7.1 gigatons CO2-eq year−1) of all human induced GHG emissions. To put this in
perspective consider the magnitude of GHG production by the other main sectors of the global economy; electricity and heat production (35%), industry (21%), transportation (14%), non-animal agriculture (9.5%), buildings (6%) (USEPA 2020). This means that the portion of the food system devoted to eating animals produces more GHG than comes from autos, trucks, aircraft, trains and ships combined. All aspects of the food system that produces livestock contribute to GHG production as follow; enteric emissions (39%), feed production (36%), manure (10%), land use change to support animal husbandry (9%), processing and transportation (6%) (Edenhofer et al.2015). Most of the emissions come from ruminant animals, 41% from beef cattle, and 20% from dairy. Monogastric (simple stomach) animals contribute less; 9% from pigs, 8% from chicken eggs (Gerber et al.2013).

Meat and dairy from ruminants account for 13 g of protein person$^{-1}$ day$^{-1}$, about a third of the world’s animal protein supply. CAFOs supply 87% of ruminant meat and 6% of dairy production. The balance comes from animals grazed on grasslands. CAFO raised animals receive a grain based diet, generally produced off-site. Some farmers raise animals in a mixed system, combining some grazing with supplemental feed. Proponents of grazing animals on rangeland suggest that it results in increased carbon storage in soil and a smaller GHG hoofprint. Yet, even cattle raised on rangeland are net producers of GHGs, and there is insufficient land available to meet current demand for meat and dairy (Garnett et al. 2017).

Per serving, ruminant meat (mostly beef) exerts an impact on the environment well in excess of any other type of food. Compare a serving of beef to a serving of legumes, another protein rich food. The beef uses 24 times the amount of land, produces 80 times the GHG, yields 14 times the phosphorus water pollution, requires 80 times the amount of energy subsidy, makes 2.8 times the amount of acid-forming pollution, and uses 4 times the amount of water (Fig. 10). The outsized environmental footprints of ruminants traces to the combination of low FCR and the way they digest their food. The low FCR means that ruminants require large swaths of land for the production of feed. This explains much of the environmental footprint of ruminants. The phosphorous pollution comes from runoff of fertilizer used on feed crops. This leads to eutrophication of waterbodies. The energy subsidy is from production of reactive nitrogen fertilizers, transportation, farm equipment, processing, and refrigeration. The acid-forming pollution comes from emissions of CO2, SO4, and N2O. All of these gasses produce acids in the atmosphere, and hence acid precipitation. The water use is from irrigation, CAFO maintenance, and food processing.

The low FCR of ruminants also explains a portion of their GHG footprint. The extensive use of fertilizers on feed crops results in NO2 emissions. The main fraction of GHG comes from the animals themselves in the form of CH4. Ruminants evolved to eat grasses and other high-fiber plants. Since most of what they ate was cellulose, they evolved a mutualism with microbes that produce the enzyme cellulase, which breaks down the cellulose. Digestion takes place in a specialized four-chamber stomach. One chamber called the rumen is where the mass of digesting fibrous food is fermented, producing copious quantities of methane which is burped out the atmosphere (Garnett et al. 2017). The production of methane by ruminants accounts for 39% of all GHG emissions associated with livestock (Fig. 11).

The extraordinary environmental footprints of beef, dairy and other foods from ruminants surely limits or eliminates

| Animal          | Caloric efficiency % | Protein efficiency % |
|-----------------|----------------------|----------------------|
| Sheep           | 1                    | 3                    |
| Beef Cow        | 1                    | 4                    |
| Farmed shrimp   | 7                    | 15                   |
| Dairy Cow       | 7                    | 16                   |
| Pig             | 10                   | 15                   |
| Poultry         | 11                   | 20                   |
| Farmed finfish  | 12                   | 18                   |
| Chicken egg     | 13                   | 25                   |

The input includes both human-edible (grains, beans, oils) and human-inedible feeds (grasses, crop residues). Note the inefficiency of beef. Data from Searchinger et al. (2019)

Fig. 11 Greenhouse gas emissions (GHG) from the main sectors associated with the production of livestock. Note that the enteric emissions come from cattle and other ruminants. Land-use change refers to the loss of natural carbon sinks in the natural vegetation and soil of land that is converted to crop production. Data from Garnett et al. (2017)
their role in a sustainable diet for the Chesapeake Bay ecosystem. What about non-ruminant animal food? Although carrying half or less the environmental footprint of ruminants, these animals still require more of the environment than almost all plant-based foods (Fig. 10).

**Seafood** Seafood produced from the Chesapeake Bay spares the land from the production of crops used to feed terrestrial animals. It is instead fed by the Bay’s natural food chain, which is highly productive. However, harvesting seafood comes with environmental consequences. The more fish, oysters, crabs, clams and mussels that people catch, the less of these are available for their non-human predators. Some fishing methods destroy important habitats, such as the case with oyster reefs (see chapter “The Chesapeake Bay Oyster: Cobblestone to Keystone”). Destructive overfishing devastated the Bay’s oyster population and contributed to the decline of other species. Ecosystem based management of fisheries takes into account the role of these species beyond food for humans, and is discussed in chapter “A Fishing Trip: Exploiting and Managing the Commons of the Chesapeake Bay”. In addition to the potential for damaging natural food webs, fishing requires energy subsidies to power; fishing vessels, processing plants, and refrigerated transportation. In general, seafood generates about ten times the GHG of protein rich legumes (Fig. 10). A study of GHG emissions from Chesapeake Bay seafood is needed to quantify the footprint of the industry. It’s reasonable to assume that the relatively short distances required by vessels on the Bay to get to fishing grounds means much less fuel consumption compared to coastal and open-sea operations.

Aquaculture is the world’s fastest growing food sector. In 1970 it accounted for only 4% of the world’s seafood. In 2016 aquaculture produced 80 million metric tons of seafood, nearly as much as the 91 million tons obtained by the world’s capture fishery (FAO 2019b). There are essentially three types of aquaculture for human food; (1) farming of seaweeds, (2) un-fed animal systems where nutrition is provided by the environment, and (3) fed animal systems that rely on industrially produced feeds, typically made from wild-caught species of lower economic value fish and sometimes soybeans or other crops. Seaweed farming is fairly benign but not practiced on the Chesapeake Bay. Fed-aquaculture carries a large environmental footprint that includes water pollution, habitat destruction and wasteful harvesting of seafood for the production of feed. The Bay’s largest fishery is that for menhaden (*Brevoortia tyrannus*), which is shipped to feed farm raised salmonids and other species in facilities far from the shores of the Chesapeake (see chapter “Menhaden, the Inedible Fish that Most Everyone Eats”). Fortunately, fed-aquaculture farms aren’t a significant part of the Bay’s current food system. This may change as state authorities sponsor research to promote fed-aquaculture in the region (VATech 2019). Bay area residents intersect with fed-aquaculture when they purchase farm-raised salmon and shrimp. Indeed, a meal of farm-raised seafood may contain mostly protein and oils that originated in the Chesapeake Bay in bodies of menhaden.

Un-fed aquaculture is a growing industry on the Bay. Farmers raise native oysters (*Crassostera virginica*) and clams (hard clam, *Mercenaria mercenaria*). In Virginia these two produced $53.4 million of sales in 2017, 70% going to the more lucrative hard clams (Hudson 2018). Oysters are raised in cages or containers that exclude predators. The cages may be placed on the bottom or suspended in the water column. Hard clams are grown in the sediments and typically protected from predators by a mesh laid down after planting the young bivalves into the bottom. Both species feed on natural populations of plankton, providing the ecosystem service of removing excess algae from the water. Farmers depend on specialized hatcheries to produce the juvenile oysters and clams. Bivalve aquaculture is highly sustainable, providing food and cleaner water with little discernible impact on the environment. However, these suspension feeders may collect pathogens and toxic contaminants, presenting a potential health risk to consumers (see chapter “Instead of Eating Fish: The Health Consequences of Eating Seafood from the Chesapeake Bay Compared to Other Choices”). Certainly, farm-raised oysters and clams present the most sustainable source of animal food for people insistent upon having such in their diet.

The processed food industry offers an alternative for those wanting to abandon consumption of animal products but retain the experience of dining on seafood. Tyson Foods now owns a stake in New Wave, a company that uses seaweed and soy to make a plant-based facsimile of shrimp (Shanker 2019a). The fake shrimp eliminates the environmental damage of fishing for or culturing the real thing. It’s also healthier, providing fiber and eliminating the cholesterol found in this crustacean.

**Eating Food from Plants and Not Animals Is the Most Sustainable Choice** Barioni et al. (2019) summarized numerous studies to determine which diet improvements offer the greatest potential for mitigating GHG production (Fig. 12). Generally, the higher the amount of animal-based food in the diet, the lower the mitigation potential. The vegan diet, which excludes all animal products, proved the best. For example, the “Climate Carnivore” diet that replaces 75% of ruminant meat and dairy with other non-ruminant meat, achieves only 44% of the GHG mitigation created by the vegan diet. Eating only plants also means producing the smallest footprints for land use, energy subsidy, acidification, eutrophication, and water consumption. “Moving from current diets to a diet that excludes animal products has transformative potential, reducing food’s land use by 3.1 (2.8–3.3)
billion ha (a 76% reduction), including a 19% reduction in arable land; food’s GHG emissions by 6.6 (5.5–7.4) billion metric tons of CO$_2$eq (a 49% reduction); acidification by 50% (45–54%); eutrophication by 49% (37–56%); and scarcity-weighted freshwater withdrawals by 19% (−5–32%) for a 2010 reference year. For the United States, where per capita meat consumption is three times the global average, dietary change has the potential for a far greater effect on food’s different emissions, reducing them by 61–73% (Poore and Nemecek 2018).

The USDA doesn’t presently include the role of sustainability in figuring their dietary recommendations. Indeed, universal adoption of their ideal diet would result in a 12% increase in GHG emissions in the US. This is due to the high content of meat and dairy (Heller and Keoleian 2014). As discussed in chapter “Ethics and Economics of Building a Food System to Recover the Health of the Chesapeake Bay and Its People”, the USDA is conflicted by its mandate to promote agricultural products even when they negatively impact human and environmental health.

Widescale adoption of a plant-based diet means reducing the amount of land under cultivation in the Chesapeake Bay Watershed (CBW), and the attendant environmental foot prints. Pennsylvania, Virginia and Maryland account for most of the crop production in the CBW. For these three states respectively, 75.3%, 56.7% and 68.6% of their agricultural land is devoted to producing animal feed (see Table 4 in chapter “The Journey from Peruvian Guano to Artificial Fertilizer Ends with too Much Nitrogen in the Chesapeake Bay”). Reorienting agriculture in the CBW for a vegan diet will eliminate most, but not all of the cultivation on lands presently devoted to animal-feed. A small portion of these lands (about 10%) will need to stay active to produce more plant-based foods to replace the nutrition from animal products. For the region this means that over half of currently cultivated land will be allowed to revert to forest. The new forests would provide a growing carbon sink and other ecosystem services such as clean water, reduction of air pollution, and wildlife habitat. Agriculture is responsible for 92% of the global human water footprint, and nearly a third of this traces to the production of animal foods (Gerbens-Leens et al. 2013).
**Plant-Based Diets Improve Human Health** Human health is part of a sustainable ecosystem, as humans are keystone species in this epoch of the Anthropocene. The vegan diet wins the competition for the best human health outcomes (Sabaté and Soret 2014). A 5-year-long study with 96,000 participants found that plant-based diets were associated with: lower body mass index, lower rates of type-2 diabetes, lower prevalence of metabolic syndrome, lower all-cause mortality, and lower cancer rates (Orlich and Fraser 2014). Consumption of animal products is associated with numerous preventable maladies including: coronary artery disease (number one source of mortality in the US and the world), type-2 diabetes, various cancers, obesity, Alzheimer’s dementia, hypertension, and ischemic stroke (Godfray et al. 2016). Consequently, vegans live several years longer than omnivores (Fraser and Shavlik 2001). Yet, some authors still allow for animal-based foods in reduced amounts as part of proposed healthy and sustainable diets (Tilman and Clark 2014; Barioni et al. 2019; Willett et al. 2019).

According to Willett et al. (2019); “Healthy diets have an appropriate caloric intake and consist of a diversity of plant-based foods, low amounts of animal source foods, unsaturated rather than saturated fats, and small amounts of refined grains, highly processed foods, and added sugars. Transformation to healthy diets by 2050 will require substantial dietary shifts, including a greater than 50% reduction in global consumption of unhealthy foods, such as red meat and sugar, and a greater than 100% increase in consumption of healthy foods, such as nuts, fruits, vegetables, and legumes. However, the changes needed differ greatly by region. Dietary changes from current diets to healthy diets are likely to substantially benefit human health, averting about 10.8–11.6 million deaths per year, a reduction of 19.0–23.6%.” Why not propose complete elimination of animal products from the ideal diet? Most authorities probably view such a change as too radical to be accepted by the population. And in some cases the authors work in the context of funding agencies such as the USDA or FAO that have arms which actively promote the production and consumption of meat and dairy. As this book goes to press in June of 2020 the world is gripped by the Covid-19 pandemic. As with all other human epidemics, the disease jumped from an animal host (Ahmad et al. 2020). Such zoonotic diseases trace to domesticated animals or those gotten as bush meat or in the live animal trade (Greger 2006). The comorbidities associated with the consumption of meat (cardiovascular disease, hypertension, diabetes) increase the risk of Covid-19 (Wang et al. 2020). Avoiding and surviving future pandemics require eliminating or drastically reducing the role of animals in the food system.

**Rationalizing the Consumption of Animal Products** People of the Chesapeake Bay Region steeped in the SAD may question the efficacy of a plant-based diet in delivering complete nutrition, primarily with concern to protein. Consumers in the US typically eat twice the recommended amount of protein, and this is also true for vegans. Chapter “Instead of Eating Fish: The Health Consequences of Eating Seafood from the Chesapeake Bay Compared to Other Choices” addresses the mythology of protein in detail. In addition, plant-based protein comes at about 2% of the energy costs associated with that from animals (González et al. 2011).

Individuals generally quit eating animal products primarily for one or more of three reasons: damage to the environment, poor health outcomes, and concern for animal welfare (see chapter “Ethics and Economics of Building a Food System to Recover the Health of the Chesapeake Bay and Its People”) (Vongkiatkajorn 2019). That consumption of animals remains so widespread in the US and most developed nations begs the question of how omnivores decide to continue this practice in the face of evidence speaking against it? Joy (2010) introduced the three N’s to explain why people continue to eat meat. Since most people are raised in families that eat meat, it appears Normal. Society teaches that humans are superior animals and it is Natural for them to eat lesser ones. The mythology of protein also convinces many consumers that eating meat is Necessary for their health, despite abundant evidence otherwise. Omnivores use the three N’s to defend consumption of animal products to their own conscious and to their social network. Piazza et al. (2015) added a fourth N for Niceness to capture the enjoyment derived from consuming meat, and tested the efficacy of the four N’s in a series of studies. They found the four N’s encompassed 83–91% or reasons given for eating meat. The four N’s differed in frequency of response; Necessary 36–42%, Natural 17–23%, Nice 16–18%, Normal 10–12%. Omnivores endorsed the four N’s, while they were mostly rejected by vegetarians and vegans. Those embracing the four N’s tended to objectify the animals they ate, attributed little mental capacity to cows, were suppurative of social inequality, unmotivated by ethics in making food choices, and frequently ate animal products. “...it would seem that the 4Ns are a powerful, pervasive tool employed by individuals to diffuse the guilt one might otherwise experience when consuming animal products (Piazza et al. 2015).”

**Reducing Consumption of Animal Products** Attempts to reduce the consumption of animal products in the Chesapeake Bay Region may benefit from adopting a dual-process model of decision making. Food labeling, education,
and taxes on animal products would appeal to the consumer’s reflective decisional system. These would arm citizens with rational reasons to reduce or eliminate consumption of animal products. However, rational thought doesn’t motivate everyone to the same degree. Many people might be swayed to reduce meat consumption by appeals to their automatic decisional system which is driven by immediate perceptions and short-term impulses. Examples include; restructuring restaurant menus to include vegan items first, increased marketing of non-meat alternatives, and decreasing the portion size of meat in restaurants (Godfray et al. 2018).

Eliminating or reducing consumption of animal products requires that consumers reshape the way they eat. Advocates of whole food plant based (WFPB) diets suggest eating a variety of; fruits, vegetables, legumes, whole grains, nuts, spices and herbs. This diet eschews highly processed foods and draws upon traditional ethnic recipes (ex. Asian, Mexican and African cuisines) as well as novel efforts to produce appealing dishes (Greger 2017). However, people transitioning from the SAD to a healthier and more sustainable diet may find it difficult to leave behind familiar forms of food. For many this means replacing animal foods with plant-based facsimiles. For example, lightly processed veggie burgers made from beans, ground flaxseed, onions and peppers may not satisfy those used to eating hamburgers made from beef. Food corporations, including some heavily vested in the meat industry, now produce plant-based burgers designed to provide the taste and feel of eating ground beef. These alternative products pose two problems. First, their ingredients may be unhealthy, including levels of saturated fats above that for beef (Table 2). One brand (Impossible Burger™) uses genetically modified yeast to produce heme-iron to simulate the taste of eating muscle. Heme-iron is pro-inflammatory, carcinogenic, linked to coronary artery disease and other maladies (Ward et al. 2012; Fang et al. 2015). That brand uses highly processed GMO soy, coconut oil, and a host of other ingredients to make an earnest imitation of ground beef. This product eliminates most the environmental footprint of beef, but isn’t as healthy as a simple traditional veggie burger (Table 2). Second, by so closely imitating meat, this burger is unlikely to help a consumer to transition their palate away from animal-based products. Indeed, most committed vegans, particularly those embracing animal welfare, aren’t looking to pretend they are eating meat. Vandana Shiva decries the rise of fake foods as contributing to the industrialization of the world food system, resulting in proliferation of chemical agriculture, loss of biodiversity, the commodification of life and extending corporate control (Shiva 2019).

Despite presenting a nutritional profile not much healthier than traditional meat-based burgers, demand for the Impossible Burger™, overwhelmed the supply during the first half of 2019, shortly after its introduction to the market. Increased manufacturing capacity has placed the burger in over 9000 restaurants across the US, including major fast-food chains (Shanker 2019b). Regardless of the down-sides of fake meat, the quick acceptance of such products indicates that the public is ready to experiment with significant changes to their diet. Will embracing fake meat be a gateway to increasing the level of processed food in the diet? Or will it enable more people to make the transition to a whole food plant based way of eating?

### Table 2  Nutritional value, GHG CO2-eq, and liters of gasoline equivalents of three non-meat burgers as compares to one typical fast-food meat brand

|                       | Earth Grown™ soy protein burger | Beyond Burger™ | Impossible Burger™ | Burger King™ Burger |
|-----------------------|-------------------------------|---------------|------------------|-------------------|
| Kcal                  | 129.0                         | 270           | 240              | 261.0             |
| Protein g             | 20.6                          | 20            | 19               | 14.1              |
| Total fat             | 1.3                           | 20            | 14               | 10.4              |
| Saturated fat         | 0                             | 5             | 8                | 3.8               |
| Fiber                 | 5.2                           | 3             | 3                | 1.0               |
| Kg GHG Eq-CO2/100 g   | 0.07                          | 0.07          | 0.07             | 2.9               |
| Liter gasoline-Eq     | 0.02                          | 0.02          | 0.02             | 1.2               |

Values are per 100 g. Data from the nutrition facts labels of the products and Clune et al. (2017) for GHG emissions. The estimates of GHG is based upon values for legumes (assigned to the non-meat burgers) and beef. Gasoline contains 2.35 kg CO2 per liter (USEPA 2019b). Absent the energy cost of food processing, these values may be conservative. The two imitation meat burgers present nutritional profiles similar to a traditional hamburger, including high caloric and saturated fat content. The soy burger also provides the highest content of health-promoting fibers.

**Breastfeeding Improves the Health of People and the Environment**

**Dawn Gerbing**

The story of food, the health of the people of the Chesapeake Bay and the health of the Bay wouldn’t be complete without including the smallest members of the community; infants in their first years of life. Breastfeeding was the healthy and only option for all of the native and immigrant peoples of the region until the development of rudimentary cows’ milk and soy-based formulas in the early 1900s. There have (continued)
always been a few infants and mothers needing medical nutrition intervention. However, with the introduction and marketing of commercially produced formulas in the early 1950s, breastfeeding rates plummeted to an all-time low in the early 1970s with fewer than 25% of mothers initiating breastfeeding their baby at all (Gordon 2019).

Through the combined efforts of the National Institute of Health and Human Services, Food and Drug Administration, World Health Organization, Surgeon General’s Office and many health professionals’ organizations, breastfeeding has made a comeback with 75% of mothers in the United States breastfeeding in the hospital after delivery. However, the USDA estimates that approximately 28 billion ounces (83 million liters) of infant formula are sold in the US each year.

The breastfeeding rates for the states of the Chesapeake Watershed are similar to the national average with the exception of West Virginia (Table 3). However, racial disparities mean that African American women are about 20% less likely to initiate breastfeeding than their white counterparts throughout the watershed (Table 4).

The deleterious health impacts of an infant denied breastmilk are lifelong. The Surgeon General points out that formula fed infants are at much greater risk for developing: ear, upper respiratory and gastrointestinal infections, childhood obesity, asthma, diabetes mellitus, leukemia and sudden infant death syndrome. Also, formula feeding mothers are at greater risk for breast and ovarian cancer (Office of Surgeon General 2019).

The environmental impacts of formula production include not only the production of the cow’s milk and transporting that milk to processing plants, but the bottles, packaging, and transport to market. For every one million formula-fed babies, 150 million containers of formula are consumed with most containers ending up in landfills (Torgus and Gotsch 2004). Add to these factors the amount of medical waste for each hospitalized child that may have been protected by breastmilk and the environmental impacts are significant.

When examining how the youngest people of the Chesapeake Bay Watershed are fed, it is important to consider that for a small amount of additional food each day, a mother can provide nourishing, protective milk at the right temperature from the perfect container with no harmful impacts known.

Turning Wasted Food into a Resource North Americans waste 42% of the available food supply. This is about twice the rate for the rest of the world. On a global basis, if wasted food were a nation it would be the third largest emitter of GHG. Its annual 4.4 GT of CO₂-eq is behind the national totals for China’s (10.7 GT of CO₂-eq) and the US (5.8 GT of CO₂-eq). In the US, food is lost at all stages of the food system. In terms of calories it’s; 17% during production, 6% in storage and handling, 9% in processing, 7% in distribution and marketing, and 61% during consumption. The consumption stage refers to waste once food is bought by consumers, restaurants or caterers. This includes loss due to spoilage, uneaten portions of meals, and discarded products (Searchinger et al. 2019). Perhaps due to their short shelf-life, animal products account for 73% of all the calories of food loss at retail plus consumer levels (Heller and Keoleian 2014). Since most food waste in N. America occurs with the consumer, the responsibility for correcting the problem lies at the intersection of people and the food system.

Just as the residents of the Chesapeake Bay Region will need to alter their diet to protect their health and that of the environment, they will need to address their own wasting of food. This includes; not over-buying groceries, asking for smaller portions, not leaving food on their plate, and pressing restaurants and caterers to reduce food waste. For example, cafeterias that eliminate trays for carrying plates and

| Jurisdictions     | Ever breastfed | Breastfeeding at 6 months | Breastfeeding at 12 months | Exclusive breastfeeding at 3 months | Exclusive breastfeeding at 6 months |
|-------------------|----------------|---------------------------|---------------------------|-----------------------------------|-----------------------------------|
| US National       | 83.2           | 57.6                      | 35.9                      | 46.9                              | 24.9                              |
| Delaware          | 77.4           | 55.6                      | 33.4                      | 47.2                              | 23.6                              |
| District of Columbia | 83.0      | 65.5                      | 43.6                      | 52.6                              | 29.1                              |
| Maryland          | 91.0           | 66.8                      | 41.1                      | 50.1                              | 26.2                              |
| Pennsylvania      | 83.8           | 59.2                      | 39.0                      | 48.9                              | 25.6                              |
| Virginia          | 81.7           | 62.5                      | 39.3                      | 45.6                              | 26.6                              |
| West Virginia     | 68.6           | 40.1                      | 24.3                      | 36.3                              | 20.2                              |
West Virginia didn’t report breastfeeding rates for African Americans (CDC 2019b).

Table 4 Comparison of breastfeeding initiation rates by race for the jurisdictions of the Chesapeake Bay Watershed Compared

| Jurisdictions       | Breastfeeding initiated White (Non-Hispanic) | Breastfeeding initiated Black (Non-Hispanic) |
|---------------------|---------------------------------------------|---------------------------------------------|
| Delaware            | 73.7                                        | 59.5                                        |
| District of Columbia| 96.3                                        | 65.5                                        |
| Maryland            | 85.4                                        | 75.4                                        |
| Pennsylvania        | 77.8                                        | 64.4                                        |
| Virginia            | 84.2                                        | 67.0                                        |
| West Virginia       | 61.1                                        | –                                           |

Features of a Sustainable Food System for the Chesapeake Bay Region

Moving to an entirely plant-based food system will provide the best health and environmental outcomes for the Chesapeake Bay region (Fig. 13), and for the planet in general (Alexsandrowicz et al. 2016). However, doing such stands in direct contradiction to the longstanding relationship between residents and animal seafood. Fishing is a dominant form of outdoor recreation in the Middle Atlantic, engaging 11.6% of the region’s residents (Lock 2019). The obituary pages of newspapers in the region often feature photos and testimonials documenting the deceased’s devotion to fishing. Automobile license plate frames proclaim, “I’d rather be fishing.” Sportfishing organizations often form alliances with organizations devoted to restoring the environment. Fishers harvest 227 million kg (500 million pounds) of seafood from the Bay annually. This means $4.4 billion of sales and 34,000 jobs in the local economy (CBF 2019). So, proposing to avid fishers that they forgo their passion for the sport doesn’t appear to be a winning strategy for effecting food system change in the region. As it goes, well-regulated local fisheries, along with oyster and clam aquaculture represents a more sustainable source of animal flesh than terrestrial options. However, its difficult to justify the Bay’s main fishery, the very large menhaden reduction-effort that produces animal feed for aquaculture production outside of the region (see chapter “Menhaden, the Inedible Fish that Most Everyone Eats”).

Eliminating terrestrial animal foods will also encounter resistance, as noted above in the discussion of the four N’s. This requires people to learn about the advantages of plant-based foods, and how to prepare them to produce tasty and satisfying dishes. Retraining the pallet also means overcoming addictions to certain foods, such as sugars (see chapter “Sugar Twice Enslaves: Consequences for the People of the Chesapeake”) and dairy. Cow’s milk contains Beta-casomorphins. These opioid peptides promote bonding between calf and cow. They bind to receptors in the brain, leading to the release of dopamine, that confers the sense of pleasure and reward. So when people say they “love cheese,” they mean it (Nguyen et al. 2014). Meat also contains opioid receptor ligands; albumin and hemoglobin, that may form the basis for addiction. Yet, people can also learn to love some plant food in the same way, as spinach and wheat contain similar promoters (Teschemacher 2003).
The sustainable food system of the future will use organic farming practices, eliminating environmentally damaging pesticides and artificial fertilizers. The drastic reduction of land devoted to producing animal-feed will also mean a deintensification of agriculture, reducing energy and water subsidies. Greater emphasis on producing crops for local consumption will reduce the environmental cost of transporting food over great distances.

To address the changing climate, farmers will need to reintroduce biodiversity of crops, finding those cultivars that do best in their particular microclimates and that can thrive in the regime of higher temperatures and different hydroperiods. This goes against the grain of the current industrial-chemical-agribusiness model that thrives on a few genetically uniform crops sustained by massive inputs of pesticides and fertilizers. “...of more than 14,000 edible plant species, only 150–200 are used by humans with only three (rice, maize, and wheat) contributing 60% of the calories consumed by humans. Many underused plant species have excellent nutritional profiles, as well as traits of interest for adapting food production to climate change (i.e., quinoa, millet, sorghum, or teff for grains, or zapote, chaya, or chenopodes for fruits and legumes). These qualities are especially important considering the increasing risk that climate change will pose on crop yields and the nutritional content of foods. However, food system simplification drives loss of these plant species and varieties, reducing options that support healthy diets from sustainable food systems (Willett et al. 2019).” Agriculture scientists and farmers of the Chesapeake Region will need to meet the challenge of developing a variety of crops that provide consumers with diets rich in whole grains, legumes, vegetables, fruits and nuts.

Even the most sustainable organic farm requires energy subsidies for powering its various operations. The farms can potentially create all the energy they need. Some farms in portions of the watershed (coastal and higher elevation areas) may have sufficient average windspeeds to drive turbines for producing electricity. Photovoltaic solar panels on the roofs of farm structures can provide clean energy. And certain shade-loving crops produce higher yields under arrays of solar panels placed high enough to allow for tractors to pass below (Barron-Gafford et al. 2019). Such agrivoltaic installations mean that solar farms need not displace food producing fields.

Although half of the US corn crop goes to producing ethanol, such plant to biofuel operations are barely sustainable, requiring land use change, large inputs of fossil fuels, water, pesticides and fertilizer (Searchinger et al. 2008).
Modern photovoltaic panels can convert 22% of the incident energy from sunlight into electricity (Green et al. 2016). Farm-based biofuel operations can’t come close to matching that, as photosynthesis at best converts 6% of incident light energy into biomass (Zhu et al. 2010) and that would only be during the nine-month-long growing season in Chesapeake Bay area. Perhaps 10% of the biomass of a corn plant attributes to its kernels that are used for ethanol production. And only 49% of the energy in those kernels makes into ethanol (Huang and Zhang 2011). This calculates out to about 0.3% efficiency of converting sunlight into biofuel energy.

Ultimately, consumers will drive the changes to produce a sustainable food system. This includes reducing their role in wasting food, as well as demanding healthier plant-based choices with their dollars. The government can promote this change by subsidizing healthy and sustainable foods and taxing those that aren’t (Wirsenius et al. 2010). “Agricultural and nutritional policies that lead to the adoption of plant-based diets at the global level will simultaneously optimize the food supply, health, environmental, and social justice outcomes for the world’s population. Implementing such policies is not free of political challenges but is perhaps the most rational, scientific, and moral path for a sustainable future of the human race and other living creatures of the biosphere that we share (Sabaté and Soret 2014).”

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