THE ECOLOGY OF MEAT

DOUGLAS ALLCHIN, DEPARTMENTAL EDITOR

Not long ago, news media were abuzz with a study by NutriRECS that concluded that consuming red meat was not so unhealthy as everyone had long supposed (Johnson et al., 2019; Kolata, 2019). Unfortunately, the research exhibited many flaws – including hidden conflicts of interest and inappropriate and biased methodology (Harvard School of Public Health, 2019; Parker-Pope & O'Connor, 2019; Zhong et al., 2020). But one core premise of the study was particularly striking. The NutriRECS panel considered just two factors: personal preferences and health risks. They assumed that the only science relevant to dietary choices was nutritional content or long-term health effects – a view widely promoted by others as well (see "The Science of Beef" lessons from the American Farm Bureau Foundation for Agriculture or Diana Rodgers and Robb Wolf's recent book, *Sacred Cow*). Hence, this month's Sacred Bovine.

Here, I take a broader perspective and show how a few *other* biological concepts – basic enough to be found in a typical introductory course – can contribute significantly to how we think about what we eat. Indeed, highlighting those connections can make biology classes more relevant and "human" to many otherwise indifferent students.

As critics of the meat-consumption article noted, taste is not the only personal value involved. Many people see ethics as relevant. They view the slaughter of animals for food as morally unjustified. Others find the treatment of livestock in industrial settings deeply objectionable. However, here I remain within the boundaries of science. I focus on biological facts, not values. How might they *inform* an understanding of the consequences of dietary choices (Hamershlag, 2011; Ranganathan et al., 2016; Godfray et al., 2018; EAT-*Lancet* Commission, 2019; IPCC, 2020)? That leads us to the ecology of meat.

○ Ecosystem Energy

Every biology student learns that energy is lost at each trophic level. Only a fraction of the energy is preserved at each step of a food chain. The result – commonly depicted in textbooks – is an *energy pyramid*. A standard ecological concept.

But now compare two different energy pyramids. One shows cattle as primary consumers, or herbivores, and humans as secondary consumers, or carnivores (Figure 1a). Students can calculate the energy numbers. Suppose there are 100 calories in a patch of grass or a trough of feed corn. Assume that 90% is lost at each stage (the usual figure, convenient for the math). How many calories remain in the cattle? How many remain in the human?

Now, imagine that the human gets that same portion of protein from a plant. That is, on this one occasion, they shift from a meat entree to a plant-based one. That prompts two more easy calculations: (1) How much plant crop is now needed to feed the same human (Figure 1b)? Alternatively, (2) how many humans can be fed with the same amount of plant crop (Figure 1c)?

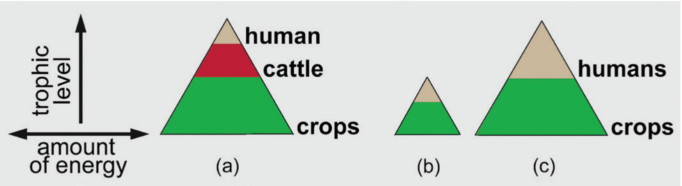

Figure 1. Energy pyramids for different human dietary choices.

The implications are not that difficult to imagine. But active inquiry can bring them out and contextualize the energy lesson. Which dietary option is more energy efficient? By how much, in comparison? Which dietary option would use fewer agricultural resources, for the same nutritional benefit? Or: How many more people could be fed the same serving of protein, if it was plant-based rather than meat? Namely, what happens when someone chooses *just one portion* of plant protein in lieu of meat, in terms of saving resources or feeding more persons the equivalent amount of protein?

(Note two teaching strategies, here – each designed to dispel an impression of moralizing. First, the questions address an anonymous "someone," not "you." Second, alternatives are presented in terms of a single portion of protein, rather than as overall diet (e.g., *not* as a "Meat-eater" or a "Vegetarian"). The analysis is not about lifestyle, ideology, or politicized identity. And definitely not about one type *versus* another. Students also tend to think teleologically – in terms of desired endpoints – so they often unconsciously, but inappropriately, convert *facts* into apparent *norms*. The teacher may note explicitly that the aim is to understand the *causes and effects* to *inform* our reasoning, not to dictate individual decisions [see *Sacred Bovines*, March, 2020].)

Next, the cultural context. Suppose someone did substitute plant for animal protein. What would happen to all that land, now freed up? What would happen with all that additional food? Posed in this way, the science helps transform dietary choices. They are less about some personal preference or virtue and more about bigger societal issues. Namely, meat consumption has significant consequences for feeding a hungry world and for land use. All that hinges on understanding a simple biological concept. But the *implications* may not be fully visible until articulated by the science.

The basic concept invites further inquiry, perhaps – especially about data on the nature and scope of the problem. For example, how severe is world hunger (easy for students to search online or as

The American Biology Teacher, Vol. 83, No. 6, pp. 416–420, ISSN 0002-7685, electronic ISSN 1938-4211. DOI: https://doi.org/10.1525/abt.2021.83.6.416.

homework)? The United Nations reports that >800 million people were undernourished in 2018 – roughly 10% of the world's population. Another 1.2 billion were malnourished, or lacking a full, balanced diet (ironically, even as obesity plagues many affluent nations; https://www.un.org/en/sections/issues-depth/food). Widespread images of African children with distended stomachs may make the problem seem remote. Yet while the global problem is certainly most acute in sub-Saharan Africa, even in the United States and Western Europe, 8% suffer from food insecurity; and 22 million schoolchildren in the United States rely on free lunch programs (that's roughly 40% – a reflection of poverty). How do the ***data*** on meat consumption contribute to our social understanding of this issue? How do the scientific facts ***inform*** – without dictating – value choices?

More relevant data awaits. For example, what are the precise figures on energy for different protein sources, known as ***protein conversion efficiency***? Different types of animal protein vary from the conventional 10% benchmark (see Figure 2). Producing beef is the least efficient, at 2.5%. Other forms of meat protein – pork and chicken – are a bit more efficient: at 9% and 21%, respectively. Protein from dairy and eggs are also more efficient, at 14% and 31%, but still less than the benchmark of 100% for plant protein. Thus, as one group of researchers conclude, even a switch from beef to chicken would have profound consequences for food availability. If Americans completely substituted chicken for beef (unrealistic, of course, but a hypothetical scenario for comparison), there would be equivalent protein available for an additional 140 million individuals (Shepon et al., 2016). That fact is potentially very empowering.

Finally, we may consider briefly the nutritional context. (Here, an enterprising teacher might link the ecology to discussion of nutrition elsewhere in the curriculum.) What are standard human protein requirements? The per capita consumption of beef in the United States in 2019 was 57.8 pounds (U.S. Department of Agriculture; https://www.ers.usda.gov/topics/animal-products/cattle-beef/statistics-information.aspx). That is roughly equivalent to a quarter-pound hamburger every other day (113.5 g). That does not include chicken, pork, or fish – roughly twice that amount, ***in addition***. For context, this is about 1¾ times the global average. Objectively speaking, do we need all that meat for basic nutrition? Protein requirements ***from all sources*** are now estimated at 46–56 g/day (or 37–45 pounds annually – compare to average consumption rate above). Current consumption patterns in the United States are thus (on average) two to five times nutritional needs, ***based on meat alone*** (e.g., EAT-*Lancet* Commission, 2019). How does all this ***inform*** our understanding and dietary choices?

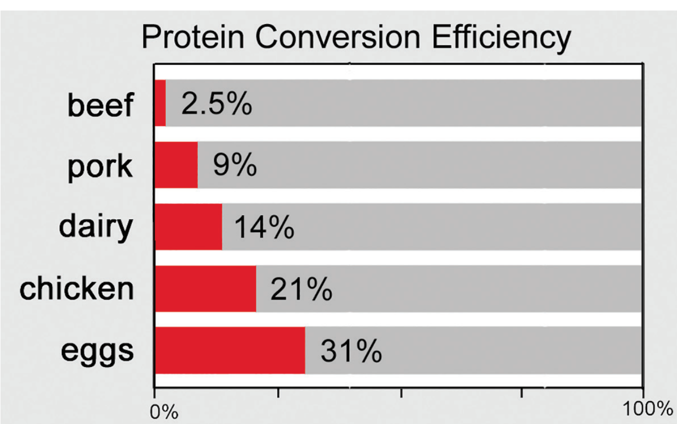

Figure 2. Protein conversion efficiencies for different forms of protein (energy retained on the left [labeled numbers], energy *lost* on the right).

○ Environment

The biological dimensions of meat consumption do not end with the energetic efficiencies of food production. There are environmental consequences as well. As noted above, meat involves land, whether as pasture or as cultivated fields for growing feed (typically corn, or maize). So, as calculated earlier, producing each unit of meat protein involves 4–10 times or more the amount of land as the same unit of plant protein (see also Poore & Nemecek, 2018). How much land in total? The U.N. Food and Agriculture Organization (FAO) estimates that about 30% of the land on Earth (not covered in ice) is directly or indirectly involved in livestock production. As a result of meat production, 83% of the world's farmland provides only 37% of our protein (Poore & Nemecek, 2018).

As meat production has increased, forests have been cleared for pasture. In South America between 1990 and 2005, new pasture claimed 159,000 square miles, an area larger than the state of Montana. That was over twice the amount of forest lost to other land uses (De Sy et al., 2015). Deforestation continues. The Amazon alone has lost another 50,000 square miles since 2005 (to a combination of ranching, farming, and mining; Butler, 2018; Spring & Paraguassu, 2020). Generally, worldwide, two-thirds of forest loss is related to meat production (Poore & Nemecek, 2018).

Loss of forest, of course, reduces or fragments natural habitats for wildlife. That, in turn, reduces species diversity. For those who value biodiversity and nature, it seems worth knowing that the greatest threat to this goal seems to be ongoing (and rising) meat production (Godfray et al., 2018; IPBES, 2019). How many students are aware of the link between a hamburger for lunch and the preservation of tropical wildlife, say?

Fresh water is another concern, although more so in some areas. Agriculture uses about 70% of the world's available fresh water (Clark & Tilman, 2017). Growing feed for livestock uses about one-third of that (Godfray et al., 2018). The water footprint of beef is six times larger than that of plants (pulses), per gram of protein. Overall, meat is responsible for 37% of the food-related water footprint of Americans (Mekonnen & Hoekstra, 2012). So, dietary choices substantially affect freshwater use.

Consider also the waste produced by livestock. Excess nitrogen and phosphorus from manure can contaminate local aquifers (in some cases) or can leach and pollute local waterways (in others). Spillage and illegal discharge from high-density feedlots is frequent (Gurian-Sherman, 2008; Miller & Muren, 2019). Combined with the runoff from excess fertilizers used to grow livestock feed, meat can contribute to eutrophication of aquatic systems, including coastal marine "dead zones." Again, beef has a disproportionate effect – six times that of pork or poultry, whose impact is already several times that of plant crops (Clark & Tilman, 2017). Switching to plant protein exclusively (again, an unlikely extreme as a point of comparison) would halve this agricultural impact (Poore & Nemecek, 2018).

A core theme of ecological science is interconnectedness. The many effects of meat production exemplify this theme, and perhaps make the science more personal and vivid. Without the biological insights, who would have guessed that simply eating a hot dog or slice of pepperoni and sausage pizza could have that much meaning?

○ Climate Change

The most significant environmental impact of meat, however, is through greenhouse gas (GHG) emissions. Namely, metabolism at each trophic level is associated with the release of carbon dioxide (CO_2). So, the various rates of energy loss (Figure 2) also correspond to GHG emissions. Through the greenhouse effect and global warming, GHGs contribute to climate change.

Farming involves other energy inputs as well. Burning fuel generates more CO_2: from machines to sow and harvest, from the production of nitrogen fertlizers, and from food transport (trucks, refrigerated delivery, and so on). In addition, switching land use from forest to pasture (mentioned above for its other environmental effects) releases even more CO_2. Namely, important carbon sinks are lost. More global warming. More stress on climate systems.

Even further, livestock produces nitrogen waste. Denitrifying bacteria (ah, the nitrogen cycle again!) convert it to nitrous oxide (N_2O), another GHG. Although the amounts are relatively small, the global warming potential of N_2O is ~300 times that of CO_2, and so it counts as another significant factor of meat on climate change.

Because of their distinctive digestive systems, beef cattle and other ruminants also release methane. Methane is another potent GHG, 25 times more powerful than CO_2. Methane alone accounts for about one-half to three-fourths of meat's greenhouse impact – so beef has an extraordinary climate impact (Poore & Nemecek, 2018). Indeed, methane itself contributes a substantial 30% of GHGs *for all foods* (Poore & Nemecek, 2018).

When one combines all these sources, livestock accounts for 15% of all anthropogenic GHG impact. Again, relative contributions vary by type of meat, in a pattern that may seem familiar by now (Figure 3). For corresponding grams of protein, beef produces seven times more GHGs than chicken, 11 times more than eggs, and about 50 times more than nuts or pulses (Clark & Tilman, 2018; Poore & Nemecek, 2018). Perhaps it is not surprising that the Intergovernmental Panel on Climate Change (IPCC) concluded in its 2020 chapter on "Food Security" that "products like red meat remain the most inefficient in terms of emissions per kg of protein produced in comparison to milk, pork, eggs and all crop products" (p. 477). "The emissions intensities of red meat mean that its production has a disproportionate impact on total emissions" (p. 479). "Meat – especially ruminant meat (beef and lamb) – was consistently identified as the single food with the greatest impact on the environment, on a global basis, most often in terms of GHG emissions and/or land use" (p. 487).

Thus, with an outlook toward ways to *solve* the challenge of climate change, the IPCC reported more positively that "consumption of healthy and sustainable diets [with less meat and animal products overall] presents major opportunities for reducing GHG emissions from food systems and improving health outcomes (*high confidence*)" (p. 440). Students already oriented to addressing climate change might find here meaningful opportunities for action through personal choice.

○ Being Informed

The information I have surveyed is not that new or hard to find. (Really! Even Wikipedia has an entry on the "environmental impact of meat production.") Nor is it by any means exhaustive. My primary aim here was to challenge the view (epitomized by the high-profile NutriRECS study, and apparently widely held) that ***only*** taste and personal health (or nutrition) are relevant to dietary decisions, especially about red meat. Attuned to the relevant facts, one can see that meat from ruminants has environmental impacts that are 3–10 times those of other animal-based foods and 20–100 times those of plant-based foods, based on five key factors (GHGs, land use, energy use, acidification, and eutrophication; Clark & Tilman, 2017, p. 9; see Figure 3).

Notably, all these facts about the ecology of red meat illustrate basic concepts found in any standard introductory biology textbook: energy loss in food chains, food pyramids, mineral cycles and eutrophication, the water cycle, greenhouse gases and climate change, and biodiversity. No change in curriculum is required to teach about the ecology of meat, only the teacher's choice of examples. This topic provides a ready educational opportunity to reach students who (more than ever) care about the environment and feeding the world's population. It helps convey the concrete relevance of biology to current events and our personal lives. Who knows – perhaps it may spur avid interest in what many regard as the mundane topic of nutrition? Information about the meaning of meat consumption is more available nowadays, educating a culture increasingly oriented to the values of sustainability, biodiversity, and social justice. Teachers may turn to the 2019 EAT-*Lancet*

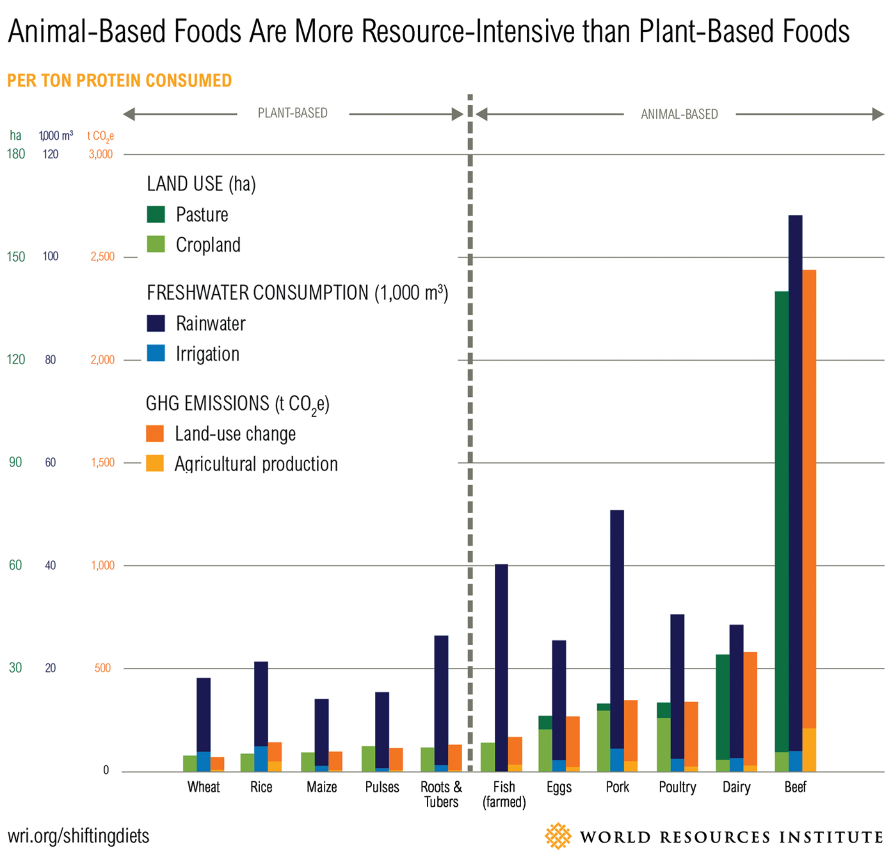

Figure 3. Overall impact of beef, other meats, and other foods on environmental resources.

Commission Report or the Environmental Working Group's *Meat Eater's Guide to Climate Change and Health*. Educators should not dictate personal values, but they may be responsible for helping students understand the context and consequences of their various choices. A focused analysis of the ecological dimensions of meat and various sources of protein opens the way to more fully informed reflection. (For a provocative lesson on *insect* protein, see *ABT*, October, 2020!) One need not adopt an exclusively vegan or vegetarian stance to reduce the meat one eats, or to benefit the environment. For example, the IPCC considers a spectrum of dietary changes for mitigating climate change (Figure 4). Diet is not an all-or-none choice.

A recent study found that Europeans could reduce GHG emissions by 35–40% by halving meat, dairy, and egg intake (IPCC, 2020, p. 490). Another study put it in more everyday terms. "If a four-person family skips steak once a week, it's like taking their car off the road for nearly three months." Or, "if everyone in the U.S. ate no meat or cheese just one day a week, it would be like not driving 91 billion miles – or taking 7.6 million cars off the road" (Hamershlag, 2011). That's the magnitude of the effect of meat, compared to other factors in climate change.

Another study envisioned the dismal effect on the planet if current patterns continue to 2050. But it also found that *up to 70% of the projected increase in GHG emissions* could be offset by a single factor: yes, dietary choices. Namely, reducing consumption of meat had more remedial effect than applying technology, optimizing land use, or controlling waste – all combined (Springmann et al., 2018). Pretty impressive numbers. And perhaps inspiring for some?

Thus, ecology – no less than health or nutrition – can inform our view of dietary choices. Summarize it in a simple color code: a "green" diet includes less and less red meat. Scientific knowledge is not part of the beef industry's public messaging. Sacred bovines, indeed.

References

Butler, R.A. (2018). Calculating deforestation figures for the Amazon. Mongabay. https://rainforests.mongabay.com/amazon/deforestation_calculations.html.

Clark, M. & Tilman, D. (2017). Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. *Environmental Research Letters, 12,* 064016.

De Sy, V., Herold, M., Achard, F., Beuchle, R., Clevers, J. G. P. W., Lindquist, F. & Vercho, L. (2015). Land use patterns and related carbon losses following deforestation in South America. *Environmental Research Letters, 10*(12), 1240904.

EAT-*Lancet* Commission (2019). *Summary Report*. https://eatforum.org/content/uploads/2019/07/EAT-Lancet_Commission_Summary_Report.pdf.

Godfray, H.C.J., Aveyard, P., Garnett, T., Hall, J.W., Key, T.J., Lorimer, J., et al. (2018). Meat consumption, health, and the environment. *Science, 361,* eaam5324.

Gurian-Sherman, D. (2008). *CAFOs Uncovered: The Untold Costs of Confined Animal Feeding Operations.* Cambridge, MA: Union of Concerned Scientists.

Hamershlag, K. (2011). *Meat Eater's Guide to Climate Change and Health.* Washington, DC: Environmental Working Group. http://www.ewg.org/meateatersguide.

Harvard School of Public Health (2019). New "guidelines" say continue red meat consumption habits, but recommendations contradict evidence. https://www.hsph.harvard.edu/nutritionsource/2019/09/30/flawed-guidelines-red-processed-meat.

IPBES (2019). *Global Assessment Report on Biodiversity and Ecosystem Services.* Bonn: IPBES Secretariat.

IPCC (2020). Food security. Chapter 5 in *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems.* https://www.ipcc.ch/srccl/chapter/chapter-5.

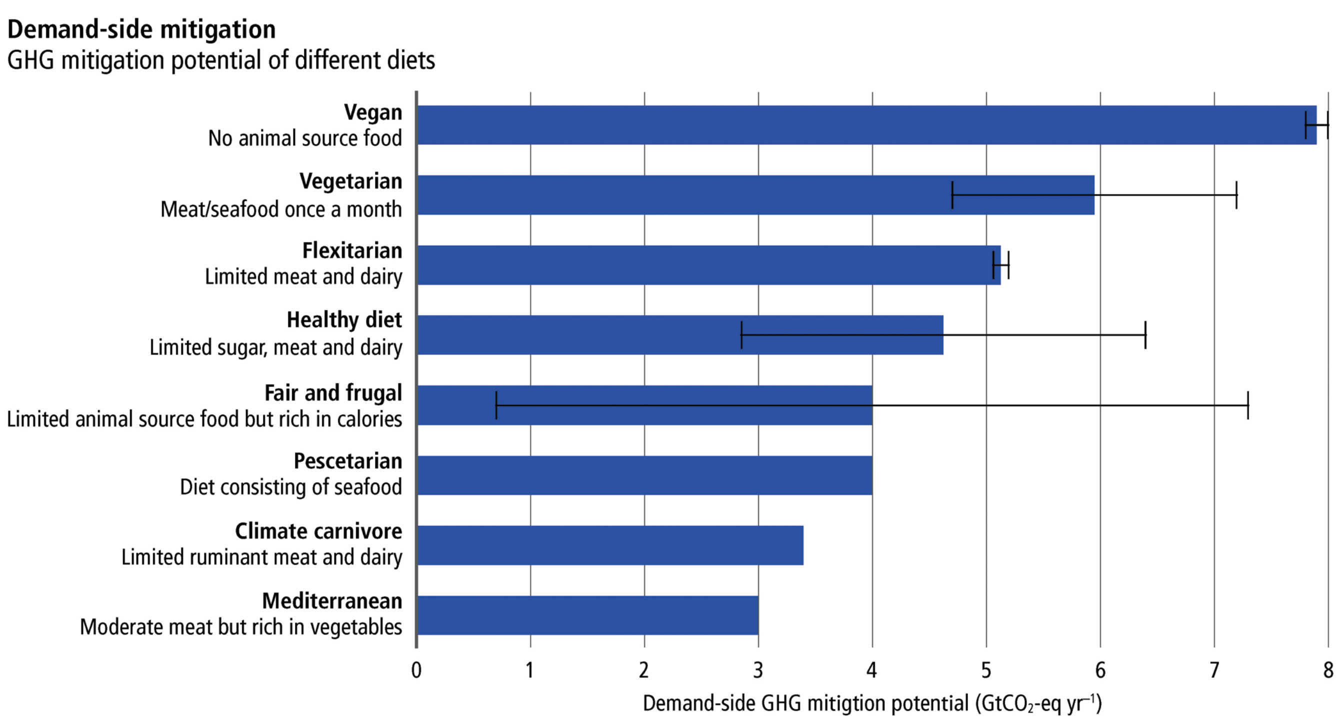

Figure 4. Reduction in GHGs for various diets with varying amounts of meat, plant, and other animal-source protein (IPCC, 2020, p. 488).

Johnson, B.C., Zeraatkar, D., Han, M.A., Vernooij, R.W.M., Valli, C., El Dib, R., et al. (2019). Unprocessed red meat and processed meat consumption: dietary guideline recommendations from the Nutritional Recommendations (NutriRECS) Consortium. *Annals of Internal Medicine,* DOI: 10.7326/M19-1621.

Kolata, G. (2019). Eat less red meat, scientists said. Now some believe that was bad advice. *New York Times,* September 30.

Mekonnen, M.M. & Hoekstra, A.Y. (2012). A global assessment of the water footprint of farm animal products. *Ecosystems, 15,* 401–415.

Miller, D.L. & Muren, G. (2019). *CAFOs: What We Don't Know Is Hurting Us.* Washington, DC: National Resources Defense Council.

Parker-Pope, T. & O'Connor, A. (2019). Scientist who discredited meat guidelines didn't report past food industry ties. *New York Times,* October 4.

Poore, J. & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science, 360,* 987–992.

Ranganathan, J., Vennard, D., Waite, R., Dumas, P., Lipinski, B. Searchinger, Y. & Globagri-WRR Model Authors (2016). Shifting diets for a sustainable food future [working paper]. Washington, DC: World Resources Institute.

Shepon, A., Eshel, G., Noor, E. & Milo, R. (2016). Energy and protein feed-to-food conversion efficiencies in the U.S. and potential food security gains from dietary changes. *Environmental Research Letters,* 105002.

Spring, J. & Paraguassu, L. (2020). Deforestation in Brazil's Amazon skyrockets to 12-year high under Bolsonaro. *Reuters,* November 30. https://www.reuters.com/article/brazil-environment/deforestation-in-brazils-amazon-skyrockets-to-12-year-high-under-bolsonaro-idUSKBN28B3MV.

Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B.L., Lassaletta, L., et al. (2018). Options for keeping the food system within environmental limits. *Nature, 562,* 519–525.

Zhong, V.W., Van Horn, L., Greenland, P., Carnethon, M.R., Ning, H., Wilkins, J.T., et al. (2020). Associations of processed meat, unprocessed red meat, poultry, or fish intake with incident cardiovascular disease and all-cause mortality. *JAMA Internal Medicine, 180,* 503–512.