Health Care Without Harm

Redefining Protein

ADJUSTING DIETS TO PROTECT PUBLIC HEALTH AND CONSERVE RESOURCES

APRIL 2017

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EXECUTIVE SUMMARY

> "How we eat determines, to a considerable extent, how the world is used."
>
> – Wendell Berry

Most food produced in the United States, and increasingly around the world, comes from an industrial agricultural system. This system has considerably increased the food supply over the past century to feed the growing population and has met the rising demand for resource-intensive foods such as meat and dairy. However, it is based on assumptions of climate stability; cheap and plentiful fossil fuel energy; abundant water, land, and other natural resources; and the willingness of the public to accept mounting externalized costs. As these assumptions continue to splinter, this increasingly precarious agricultural system threatens public and environmental health and lacks resiliency to tackle impending threats to global food security.[1]

Transitioning to diets with more plant-based ingredients is an essential action to promote health, food security, and long-term environmental sustainability. However, the impact on health and sustainability outcomes can vary depending on the types of foods with which meats are replaced.

This report aims to guide the complex decision-making process encountered when applying an environmental nutrition approach to food purchases, specifically when reducing and replacing meat on the plate.

While this report analyzes individual food categories, diets should be considered in their entirety when assessing health and environmental impacts. We acknowledge that the nutritional quality and environmental impact of foods consistently vary within food categories depending upon the methods of production used. As such, nutrition and consumption recommendations cannot be separate from recommendations on production changes. Doing so segregates our food choices from potential health risks generated by our agricultural decisions.

An environmental nutrition approach recognizes that healthy food cannot be defined by nutritional quality alone, rather it must come from a food system that conserves and renews natural resources, advances social justice and animal welfare, builds community wealth, and fulfills the food and nutrition needs of all eaters now and into the future.

Health Care Without Harm aims to construct a food system that acknowledges and remedies the public health impact of the entire food lifecycle from production to disposal. Throughout this report, we repeatedly call out examples of integrated crop-livestock systems—a form of mixed production that grows crops and raises livestock primarily on pasture in a way that they can complement each other and maximize resource use. When an integrated farming system applies a regenerative agriculture approach—a model which taps into the strengths of the ecosystem through healthy soil microbiology to reduce the use of synthetic inputs, sequester carbon and preserve clean air, water, and other natural resources—the potential for optimal social, environmental, and human health impacts is amplified.

Fundamental to these well-managed production systems is the cultivation of soil for which pasture-raised animals and nitrogen-fixing, fiber-rich legumes are integral. This promising agricultural model reinforces the need to first reduce our current rates of meat consumption and production while increasing that of nutrient-rich legumes for optimal human and environmental health.

This report summarizes and analyzes the available academic literature on the impacts of whole food protein options alternative to meat, with an emphasis on legumes, nuts and seeds, eggs, seafood, and dairy. The associated resource, "Purchasing Considerations" assists healthcare institutions and others in the foodservice sector in distilling this research into values-driven purchasing guidance to support transitioning menus and purchases to protein options that may optimize health, environmental, social justice, and animal welfare outcomes.

Legumes (pulses and soy)

Legumes, particularly whole legumes and not necessarily processed legume-derived proteins, provide extensive health benefits to consumers. Compared to other food groups, they score the best across indicators of environmental impacts, including greenhouse gas (GHG), land, and water footprints, and—with the exception of soybeans—pesticide and fertilizer use. They also have relatively few social justice concerns directly associated with their production.

Nut and seeds

Nuts and seeds provide many health-promoting nutrients, and regular consumption has been associated with a reduced risk for certain chronic diseases. Due to their caloric density, and environmental and social justice concerns (including water use in almond, walnut, and pistachio production as well as labor concerns with cashew production) associated with increasing their production, nuts should be consumed in moderation. In some cases, seeds may be a healthy and environmentally sustainable alternative to nuts.

Eggs

While the egg white provides most of the protein found in an egg, the yolk contains most of its other key nutrients. Health experts have agreed that moderate whole egg consumption is not likely to lead to an increased risk of cardiovascular disease and mortality for the general population. Eggs have relatively low environmental impacts associated with their production compared to other food groups, though their production contributes to social justice concerns for workers and surrounding communities. The intensification of the egg industry over the past half-century has also elevated key animal welfare concerns about how hens are raised and fed.

Seafood

Regular consumption of seafood—particularly of fatty fish and certain mollusks—has been associated with many health benefits, notably cardiovascular and cognitive function. However, even accounting for the growth of aquaculture, there is not enough fish for everyone globally to consume recommended levels to reap the noted health benefits due to declining wild stocks and loss of marine biodiversity. The diversity of harvesting and farming systems, as well as post-farm processing and transportation choices, also lead to a wide variety of health, environmental, social justice, and animal welfare impacts. Certain harvesting practices (e.g., bottom-trawling) and transportation options (e.g., air-freighting) have particularly harmful impacts. Eating forage fish such as sardines which are lower on the food chain can limit exposure to contaminants. Forage fish, along with bivalve mollusks, are generally more ecologically sustainable. Both wild harvesting and aquaculture production pose numerous concerns for workers and for export-oriented communities.

Dairy

Cow's milk dairy products (particularly milk and yogurt, not necessarily cheese or butter) provide many nutrients, and moderate consumption has been associated with a reduced risk for certain diseases. While dairy products provide calcium, there is weak evidence that dairy consumption protects bone health. Despite traditional dietary advice, little evidence exists to support low-fat dairy consumption for heart health or weight management. Full fat grass-fed dairy products also contain higher (though low compared to fish) concentrations of beneficial fatty acids. The per serving ecological impacts of dairy products are relatively low compared to ruminant meat. However, dairy farms contribute to other ecological, public health, and animal welfare concerns. Research on plant-based milk alternatives is also considered. With the exception of soy milk, these products do not contain nutrition profiles similar to cow's milk but are included because they are increasingly replacing cow's milk as meal components. Based on the limited research available, these alternatives have significantly lower environmental, social justice, and animal welfare impacts per serving than cow's milk, with a few exceptions.

Limitations

Note that this report does not address the impacts of all food groups, nor the full range of food categories that offer protein (e.g., grains). Additionally, limitations exist in various areas of academic literature, especially research on the health impacts of processed legume-based foods; the environmental and social justice impacts of nut and seed production; antibiotic use in layer hens; the impacts of changing feed ingredients for farm-raised fish; per-serving phosphorus requirements and leaching concerns across food groups; and the health, environmental, and social justice impacts of plant-based dairy and egg alternatives.

Table 1: Summary of key findings

Compares relative health, environmental, social, and animal welfare impacts of different food groups. Note that this oversimplifies the large variance in impacts within food groups across species, types of inputs, and regions of production explored further in this report.

	Health	Environmental				Social justice	Animal welfare
		Climate	Land use	Inputs (water, fertilizer, manure, pesticide, antibiotic use)	Biodiversity		
Pulses							
Conventional	SP	SP	SP	MN	MP	N	n/a
Organic	SP	SP	SP	MP	SP	N	n/a
Soybeans							
Conventional	D*	SP	SP	SN	SN	MN	n/a
Organic	D*	SP	SP	MP	MP	N	n/a
Nuts and seeds							
Conventional	MP	SP	MP	SN	MN	MN (SN cashews)	n/a
Organic	MP	SP	MP	MN	MN	MN (unless fair trade)	n/a
Eggs							
Conventional (battery cage)	MP	MP	N	SN	MN	MN	SN
Enriched colony cages	MP	MP	N	SN	MN	MN	MN(D)
Cage-free	MP	N	MN	SN	MN	SN	N (D)
Free-range	MP	N	MN	SN	MN	N	MP (D)
Pasture-raised	MP	N	MN	SN	N	N	MP (D)
Fish+							
Wild (forage fish)	MP^	MP	n/a	n/a	MP	N	D
Wild (all other fish)	MP^	MN (SN trawled lobster)	n/a (SN bottom trawling: seafloor impact)	n/a	SN	SN	D
Wild and aquaculture (bivalve mollusks)	MP^	SP	n/a	SP	SP	N	n/a (D)
Aquaculture (finfish, crustaceans)	MP^	MN	MN	SN (D)	SN	SN	D
Aquaculture (recirculating)	MP^	SN	MP	SP	MP	N	D
Dairy							
Conventional	MP (D)	MN (D)	MP	SN	MN	SN	SN
Grass-fed	MP (D)	MN (D)	MP	N	SP	N	N
Plant-based milk alternatives	N	SP	SP	MN	MN	N (SN cashew milk)	n/a (MN(D): coconut milk)

* Moderate health benefits have been associated with consumption of whole soy foods (e.g., edamame, tempeh, tofu, full-fat soymilk) but not necessarily with processed soy isolates or proteins found in meat analogs, energy bars, and low-fat soy milks, as well as meat extenders.

+ In the case of seafood, labor concerns vary widely between foreign and domestic production. Considering 90% of seafood in the US is imported, ratings pertain to foreign harvesting practices.

^ Not considering contaminant levels

Common types of fish in each category

Wild (forage fish): sardines, herring, anchovies
Wild (all other fish): lobsters, flatfish, cod, haddock, hake, tuna
Wild and aquaculture (bivalve mollusks): clams, mussels, oysters, scallops
Aquaculture (finfish, crustaceans): salmon, catfish, trout, shrimp, prawns
Aquaculture (recirculating): salmon, trout, tilapia

Graphic methodology: This graphic compiles and compares the evaluated research on the health, environmental, social, and animal welfare impacts of different food groups considered in this report. Impacts are categorized as *strong positive (SP), moderate positive (MP), neutral (N), moderate negative (MN), strong negative (SN)*, or *debated/uncertain (D)* based on the relative per-serving impact of that food group compared to other food groups on that impact factor. Health rankings were based on the extent of research demonstrating health benefits or risks associated with consuming that food type. When multiple species and production systems pertain to any one category, a rating was given considering the dominant system from which the largest portion of our food is derived. Strong positives were only granted to foods with positive benefits attributed to frequent consumption; foods were ranked as moderately positive if moderate (but limited) consumption is encouraged. Strong environmental positives and negatives were only given when the food type performs significantly well (i.e., has an extremely low or potential net positive relative environmental impact = strong positive) or poor (i.e., associated with significant or synergistic environmental concerns). For the social justice rankings, no categories were ranked "positive" given the generally poor labor standards in both domestic and international food production. However, foods that have been associated with additional labor concerns specific to their production practices have been noted as moderate or strong negative depending on the extent and strength of concerns. For animal welfare rankings, strong negatives were attributed to food types that have been associated with significant welfare harms; relative improvements in welfare practices (while taking into consideration new potential harms from these practices) are noted as moderately negative, neutral, or moderately positive depending on the extent of the difference.

GLOSSARY

All-cause mortality: all of the deaths that occur in a population, regardless of the cause.

Arable land: land suitable for growing crops.

Bioavailability: the availability of nutrients to be absorbed by humans and animals during the digestive process.

Extensive/pasture-based: a low-input and low-density agricultural production system. In this report, it refers mostly to livestock farms which allow cattle to graze freely on pasture.

Food miles: the distance that food travels from the point of production to that of consumption.

Intensive production: a high-input and high-density agricultural production system that raises large numbers of animals or crops on limited land. In livestock farming, animals are confined and have no access to grazing land; consequently, it is often referred to as factory farming or industrial food animal production (IFAP).

Integrated crop-livestock systems: a form of mixed production that grows crops and raises livestock in a way that they can complement each other and maximize resource use.

Semi-intensive production: combines elements of both intensive and extensive production systems. In livestock farming, animals receive feed in stalls or pens but are allowed to supplement this feed by foraging on natural vegetation and (in the case of chickens) insects.

Land use change: the conversion of natural forest or grassland into agricultural land.

Pesticides: chemical or biological agents used to deter, incapacitate, destroy, or otherwise discourage pests. Common agricultural pesticides include herbicides (to control weeds), insecticides (to control insects), and fungicides (to control fungi); others include insect growth regulators, nematicides (to control nematodes), termiticides (to control termites), and molluscicides (to control slugs/snails).

Reactive nitrogen (N_r): nitrogen compounds, including nitrogen oxides (NO_x), ammonia (NH_3), nitrous oxide (N_2O), and nitrate (NO_3^-), that have been “fixed” from the unreactive nitrogen gas stored in the atmosphere (N_2) to forms of nitrogen that can be used as proteins and nucleic acids to support the growth of organisms.

Regenerative agriculture: A systems approach to agriculture that focuses operations on activating the natural ecosystems tendencies to regenerate by incorporating closed nutrient loops, biological diversity, and primary reliance on the internal systems resources instead of external inputs.

Runoff: water from rain, irrigation, and other activities that collects contaminants—including sediment, nitrogen, and phosphorus from fertilizers, toxic metals, pesticides, oil compounds, and bacteria—from land and carries them to waterways and eventually the ocean.

Virtual nitrogen factor: the amount of reactive nitrogen lost to the environment related to the production and consumption of food per unit of nitrogen consumed.

INTRODUCTION

Health care institutions are beginning to acknowledge the public health imperative of embracing an environmental nutrition framework. In contrast to traditional nutrition approaches which concentrate on obtaining adequate quantity and quality of food to meet dietary needs, an environmental nutrition approach asserts that healthy food must also "come from a food system that conserves and renews natural resources, advances social justice and animal welfare, builds community wealth, and fulfills the food and nutrition needs of all eaters now and into the future."[2] An environmental nutrition lens takes into consideration the many health, environmental, social, and ethical factors associated with food production and consumption.

For instance, Western dietary patterns that are high in the consumption of animal products, along with processed foods, refined sugars, and fats, have been linked to escalating rates of chronic non-communicable diseases.[3] Processed and red meat consumption specifically have been associated with an increased risk for heart disease, stroke, type 2 diabetes, certain types of cancer (most notably colorectal), and all-cause mortality.[4-8] Conversely, dietary patterns rich in a diversity of unprocessed plant-based foods, with moderate to little meat intake (including Mediterranean-style, pescatarian, vegetarian, and vegan diets) reduce the risk for many of the aforementioned chronic diseases and adverse health outcomes.[3,9-11] These considerations are particularly important for healthcare professionals.

Contemporary dietary patterns also contribute significantly to—and will, in turn, be influenced by—the ecological, socioeconomic, and public health challenges associated with global food insecurity, climate change, and resource depletion. Population growth, increasing demand for animal products (associated with rising disposable income), and anticipated declines in crop[12-14] and livestock production[15,16] due to climate change threaten global food security.[17] Livestock production is a major contributor to greenhouse gas (GHG) emissions, and diets lower in animal product intake have far lower climate impacts than typical Western diets.[9] Immediate and substantial reductions in animal product consumption, particularly in countries with the highest per capita intake, will be essential to keep global mean temperature rise below 2°C, the limit agreed upon by world leaders to avoid the most severe and irreversible climate consequences.[18] While even 2°C is projected to have major global impacts, as warming rises above that level, the likelihood of food and water shortages, increased heat-related mortality, and more frequent/intense extreme weather events increases substantially. Moreover, dietary shifts towards reduced animal product consumption have greater potential for decreasing climate footprints than the reduction of food miles or improvements in production practices.[19,20]

Animal proteins also generally require more water and land to produce than plant-based proteins. Hence, in the face of anticipated water[21] and land[22] scarcity, meat production and consumption have been called into question as the most dominant use of finite natural resources in agriculture. Livestock production of all varieties contributes to water and air pollution,[23] and has been implicated in animal welfare concerns.[24] Moreover, intensive animal production, the dominant production system for the majority of meat in the United States, contributes to the growing threat of antibiotic resistance,[25] reduced animal genetic diversity,[26] high fossil fuel energy use,[27] and adverse community health impacts.[28]

Given these considerations, an increasing number of people over the last decade have been reducing their meat intake for health, animal welfare/rights, environmental, and social equity reasons. While the proportion of Americans identifying as vegetarian has remained roughly the same[29] (~3.4% of the population[30,a]), food industry trends suggest a larger shift occurring in the overall American population towards more "flexitarian" eating, in which people consume mostly plant-based diets with the occasional inclusion of animal products.[32] These trends are in line with recommendations that efforts to reduce animal product consumption should be focused among populations with the highest per capita intake.[18] The United States, notably, ranks fifth in per capita meat consumption globally.[33] Consumption estimates indicate that there is ample room in the average American diet to maintain adequate protein intake while decreasing animal product consumption.[34] To reduce health risks from diet-related diseases and climate change, some health experts have proposed a target for global per capita meat consumption (90g/day) that is less than half of the current levels in developed countries like the United States.[35] The 2015 Dietary Guidelines Advisory Committee also advised the U.S. Departments of Agriculture (USDA) and Health and Human Services (HHS) to incorporate guidelines to reduce

a Though market research indicates that vegetarianism is increasing amongst young people aged 18-34.[31]

meat intake into federal government recommendations,[b] in line with the growing evidence in support of dietary patterns that promote health, food security, and long-term environmental sustainability.[9]

Along with other institutional foodservice efforts emerging to encourage food sustainability,[36] Health Care Without Harm's "Less Meat, Better Meat" approach encourages reducing the overall amount of red meat and poultry served and using the cost savings to purchase more sustainably-produced options.

This report aims to assist the health sector in transitioning menus and purchases to protein options that may optimize health, environmental, and social outcomes. It does so by summarizing and analyzing the available scientific literature on the impacts of meat protein alternatives, with an emphasis on legumes (e.g., soy, pulses such as dry beans and lentils), nuts and seeds, eggs, seafood, and dairy (e.g., milk and plant-based alternatives, yogurt, cheese).

Such information is critical because the types of foods with which meats are replaced can significantly impact the health and sustainability of altered dietary patterns.

Diets low in GHG emissions are not necessarily healthy; for instance, processed foods high in sugars, fats, and refined grains can have low emissions profiles. Moreover, all healthy diets are not necessarily environmentally sustainable, especially if they are heavily reliant on air-freighted produce and fish or water-intensive nuts.[3,37] Replacing poultry or pork with cheese can actually increase dietary ecological footprints per serving.[3] Moreover, there are important social justice concerns to consider with some meat alternatives, including certain types of fish and nuts.

FIGURE 1: HEALTH AND ENVIRONMENTAL IMPACTS OF DIFFERENT DIETS

	Dietary diversity	Food energy intake/expenditure	Animal products	Fish & related	Vegetables & fruits	Whole grains tubers & legumes	Processed foods	Food losses & waste	Cooking fuels
Healthier & more sustainable diets	High	Balanced	Low (all parts eaten)	Low to moderate (sustainable)	High (minimally processed)	High	Avoided	Low	Efficient
Diets of the healthy wealthy	High	Balanced	Moderate to high (lean meats)	High	High	Low to high	Avoided	High (consumer)	Heavy use
Western-type diets (global)	Low	Excessive	High	Low to high (unsustainable)	Low	Low	High	High	Inefficient
Diet of the poor in poor countries	Low	Insufficient	Low	Low	Low	High (legumes often low)	Low (but growing)	High (spoilage) Low (consumer)	Inefficient

Graphic reprinted with permission from Garnett, T. (2016). Plating up solutions. *Science*, 353(6305), 1202-1204.

This report aims to guide the complex decision-making process encountered when reducing and replacing meat on the plate. Each of the aforementioned food categories is analyzed in terms of the human health impacts associated with consuming them as well as the climate, water and land use, input (e.g., pesticides, fertilizers), labor, animal welfare, and geographical considerations associated with their production. The summary recommendations provide guidance for food purchasing decisions to optimize impact on human and environmental health. These recommendations are based on existing research in reference to the general population; they are not intended to suggest the proportion of foods to consume or address clinical therapeutic recommendations or restrictions. Limitations of existing research and opportunities for further research are also explored.

b Sustainability considerations were ultimately excluded from the final 2015 Dietary Guidelines for Americans.

OVERVIEW OF KEY IMPACT CATEGORIES

The following section provides an overview of the key impact categories—related to human and environmental health, social justice, and animal welfare—that were used in the assessments of the high-protein food categories in this report, as well as important methodological nuances to guide the analyses of specific food categories to follow.

HUMAN HEALTH CONSIDERATIONS

This impact factor summarizes the human health benefits and risks associated with the consumption of foods from each category. Key nutrients provided, as well as essential nutrients that may be missing from the profiles of each food group, are discussed. Nutrients, allergens, and other ingredients (e.g., additives) of concern are also examined. *It is important to emphasize that the environmental health concerns—including climate change, nutrient pollution, antibiotic use, and indirectly, diminishing ecosystem services and food security—discussed in the subsequent sections also impact human health.*[2] This impact factor concentrates on nutrition-related individual health impacts for organizational clarity.

While animal products contain all the essential amino acids and thus constitute a complete source of protein, there are several plant foods such as soy and quinoa which also contain a full amino acid profile.[38] Although there is some evidence that suggests reduced bioavailability of plant-based proteins, as long as sufficient amounts and a variety of plant-based foods are eaten throughout the day, human health requirements can be adequately met with plant-based proteins alone.[39]

Vitamin B12—essential for red blood cell and DNA synthesis, brain and nervous system health, and energy metabolism—is the single micronutrient that is not present in high enough quantities in unfortified plant-based foods. Diets avoiding all animal products must ensure adequate consumption of B12 through fortified foods or supplementation.[40,41] However, for most omnivores[c] who are simply reducing their meat intake, there should be little concern about not consuming adequate amounts of B12.

The health impacts associated with the types of fatty acids (saturated, monounsaturated, or polyunsaturated) present in foods are discussed in the context of a number of sections of this report. A preponderance of evidence from metabolic, epidemiological, and clinical studies indicates optimal heart health from replacing saturated fats with non-hydrogenated unsaturated fats (particularly polyunsaturated).[43] Omega-3 fatty acids are polyunsaturated fats of critical importance to nervous system growth and development, reducing inflammation, and lowering blood cholesterol levels (thus lowering the risk of heart disease and stroke).[44,45] Long-chain polyunsaturated fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) provide particular benefits, and health organizations suggest a minimum of 250-500 mg/day of DHA+EPA.[46,47] Humans can also convert another short-chain omega-3 fatty acid found in plant foods, alpha-linolenic acid (ALA), into EPA and DHA, although conversion rates are low.[48] Beyond the absolute mass of omega-3s consumed, the *ratio* of omega-3 to omega-6 polyunsaturated fatty acids (typically low in Western dietary patterns) is also an important consideration for achieving positive health outcomes.[48,49]

Additionally, while one can meet all nutritional needs with little to no animal product intake,[39] populations at risk for iron, zinc, vitamin B12, and other micronutrient deficiencies may rely on animal products to prevent health conditions such as anemia and stunting. While these nutrients can be easily obtained from plants, seeds, or fortified foods in food-secure regions of the world, reducing meat and dairy intake may not be in the best interests of public health in places where socioeconomic conditions may not allow for easy access to healthy plant-based alternatives.

ENVIRONMENTAL HEALTH CONSIDERATIONS

Most food produced in the United States, and increasingly around the world, comes from an industrial agricultural system. *This system has considerably increased the food supply over the past century to feed the growing population and meet the rising demand for resource-intensive foods like meat and dairy. However, it is based on assumptions of climate stability; cheap and plentiful fossil fuel energy; abundant water, land, and other natural resources; and the willingness of the public to accept mounting externalized costs.* As these assumptions continue to splinter, this increasingly precarious agricultural system threatens public and environmental health and lacks resiliency to tackle impending threats to global food security.[1] This section summarizes the environmental health impacts that are analyzed related to each food product category in this report. Climate change; the use of land and other inputs including water, nutrients (e.g. fertilizers), pesticides, antibiotics, hormones, and other pharmaceuticals; and biodiversity and ecosystem function are all discussed.

c Adults over age 50 are also advised to obtain most of their vitamin B12 through fortified foods or supplements due to the prevalence of malabsorption of the vitamin from animal sources within this demographic group.[42]

Climate change

Human diets contribute to climate change through emissions of greenhouse gasses (GHG), including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), involved in producing, processing, transporting, preparing, and disposing of food. Agricultural production is the food system stage with the largest climate impacts, so, in most cases, the types of foods people eat and how those foods are produced are more important than how far they travel or how they are processed.[50,51,d] Due to relative efficiencies in producing calories compared to animal products, grains, legumes, and root vegetables have the lowest GHG footprints per serving and per kilogram of protein than eggs, dairy, poultry, and pork, while beef and lamb have the highest profiles, across production systems (e.g., intensive/industrial vs. extensive/pasture-based)(Figure 2).[3,50] This hierarchy of climate impacts is due to the fact that livestock production, as a whole, accounts for 14.5% of global[e] human-related GHG emissions—which is more than the global transportation sector and makes up the vast majority of emissions from agriculture and land-use change.[52]

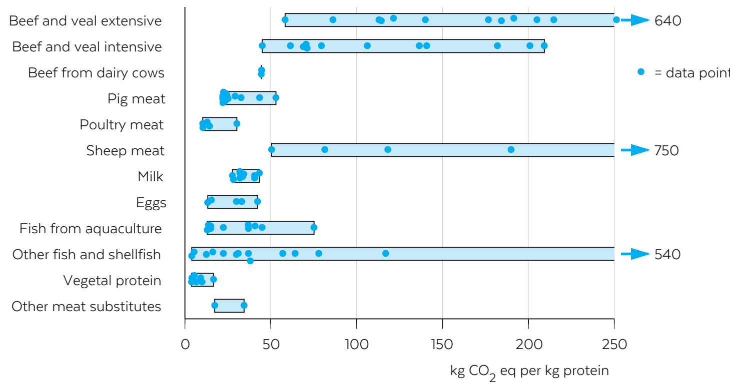
Crop production releases GHG emissions through on-farm energy and machinery use (CO_2), soil management practices such as fertilizer application and tilling (N_2O, CO_2), burning agricultural residues on fields (CH_4, N_2O), rice cultivation (CH_4), and deforestation and grassland conversion to increase cropland (CO_2).[53] Major sources of livestock-related GHG emissions include enteric fermentation (CH_4), manure management (CH_4, N_2O), feed crop production[f] (as discussed in the previous sentence), and deforestation to produce feed crops and pasture (CO_2).[52] The system (e.g., pasture-based/extensive vs. industrial/intensive) and region of production create variances (which are further explored in this report) though differentials in GHG-intensity between animal protein categories almost universally outweigh production system differences.[16,50]

Carbon dioxide equivalents

This unit attempts to express the collective impact of different GHGs in a single number based on a comparison to the amount of CO_2 that would have the same global warming potential, typically over 100 years.[55] Debate exists over the extent to which relatively short-term but more potent methane emissions (of which animal agriculture is the top contributor in the United States[53]) are and should be prioritized through such a metric, and over whether the 100-year potential (or the CO_2eq unit at all) is the most effective way to assess climate impacts across GHGs and sectors.[56,57]

Life cycle assessments (LCAs) of food products generally report climate impacts in carbon dioxide equivalents (CO_2eq) (see Sidebox). This report employs the metric because it is the standard unit used in existing literature on foods' climate impacts.

FIGURE 2: CLIMATE IMPACTS OF DIFFERENT PROTEIN FOOD GROUPS PER KILOGRAM OF PROTEIN



The values above depict emissions associated with production up to the point of retail ("cradle-to-retail"). Note that "vegetable protein" includes pulses and 100% plant-based meat substitutes. "Other meat substitutes" include meat substitutes containing egg or milk protein. The carbon sequestration potential for pasture-based (extensive) beef is not included because most studies do not account for this (see p.14).

Graphic reprinted with permission from Nijdam, D., Rood, T., & Westhoek, H. (2012). The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. *Food Policy, 37*(6), 760-770.

Land use

The production of animal-based foods comprises the majority of global diet-related land requirements[58,59] and land use per unit of protein is lower for plant-based proteins than animal-based ones (Figure 3).[60,61] However, estimates of land use requirements are only meaningful when broken down into which types of land are required to produce different foods: grazing/pasture land vs. arable cropland.[62] Some have pointed out that while beef and other ruminant products appear to be the most land-intensive foods, if they are raised and fed solely on pasture that is unsuitable for growing crops (currently a rare practice in U.S. cattle farming), then shifting diets away from these products does not necessarily free up cropland to feed more people as typically suggested.[62,g] Raising poultry and hogs, on the other hand, may appear less land-intensive, but always relies on feeding grains that could be otherwise consumed directly by humans.[37]

d Transportation, processing and/or cooking can represent a significant proportion of certain foods' impacts.[50] Air-freighting produce and seafood can more than double the GHG footprint of these items. Processing and cooking foods with otherwise low climate footprints may also increase their relative post-farm gate emissions.

e Livestock production represents a smaller proportion of the United States' total emissions (agriculture as a whole contributes only 9%) due to relatively high emissions from the energy and transportation sectors, and the fact that land use change/deforestation is not a big concern compared to other countries.[53]

f Globally, 62% of crops produced by mass are directly consumed by humans, while 35% go to animal feed and 3% to biofuels, seed, and other industrial products. In North America, only 40% of crops are devoted to human food.[54]

g Debate exists over how much land could be used for cultivating crops,[62] but most ruminant meat and dairy (by production volume) in industrialized countries are produced in intensive systems where cattle eat feed grown on arable land. On average globally, ruminant meat relies on cropland, water, and nitrogen resources to the same extent per unit of protein as pork and poultry, placing similar pressure on edible plant production possibilities.[16]

Some agroecology proponents thus encourage raising animals solely on land unsuitable for crop production or in an integrated system (See Sidebox) where they graze on crop residues in the field and supply nutrients in mixed cropping systems.[63,64] One study mapping the land use potential of an agriculture system in which animals were reared only on non-arable pasture, food waste, and agricultural crop remains (i.e., an "ecological leftover" approach) in Western Europe found that meat consumption would still need to significantly decrease, as it would supply only half of the meat currently consumed in the region (45 kg carcass weight/person/year).[65]

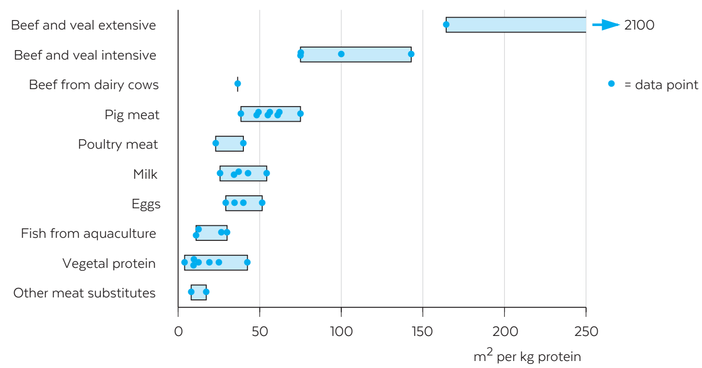
Shifting towards less meat-heavy diets could reduce the demand on land clearing for agricultural use (a leading contributor to global GHG emissions and biodiversity loss), especially in regions of the world such as the Amazonian rainforest where land clearing is the least ecologically favorable.[66,67] It could open up land for other purposes, including reforestation (regrowing vegetation on pastures can lead to substantial – though transient[h] – CO_2 uptake) or biofuel production to reduce reliance on fossil fuels.[68,69] Some also argue that it could be used to preserve extensive (i.e., pasture-based) production systems which may sequester carbon[i] and provide additional biodiversity benefits in certain landscapes.[65]

Integrated Crop-livestock Systems

Integrated crop-livestock systems are a form of mixed production that grows crops and raises livestock in a way that they can complement each other and maximize resource use. Integrated systems decrease the need for inputs such as feed crops for fodder and fertilizer. For example, a herd of ruminants (sheep, goats or cattle) can graze a pasture and build up the soil. The animals are provided with fodder from nitrogen-binding legumes, weeds and other crop residues. They provide draught and manure for crops while enriching the soil with nutrients.[70] When an integrated crop-livestock system applies a regenerative agriculture approach—a model which taps into the strengths of the ecosystem through healthy soil microbiology to reduce the use of synthetic inputs, sequester carbon, and preserves clean air, water, and other natural resources—the potential for optimal social, environmental, and human health impacts is amplified.

Citation: Rodale Institute. Regenerative Organic Agriculture and Climate Change. 2014. Available at: https://rodaleinstitute.org/assets/WhitePaper.pdf

FIGURE 3: LAND USE OF DIFFERENT PROTEIN FOOD GROUPS PER KILOGRAM OF PROTEIN



Note that "vegetable protein" includes pulses and 100% plant-based meat substitutes. "Other meat substitutes" include meat substitutes containing egg or milk protein. The vast majority of livestock in the United States are raised in intensive monoculture systems; this figure does not account for land use from mixed species grazing systems.

Graphic reprinted with permission from Nijdam, D., Rood, T., & Westhoek, H. (2012). The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. *Food Policy*, 37(6), 760-770.

Water use

Assessing how much freshwater is required to produce foods, known as the "water footprint," also requires adopting a more nuanced perspective than conveyed by a single number. The water footprint includes both direct and indirect water use, encompassing water consumption and pollution throughout the full production cycle.[71] **It is typically divided into three components: green water (e.g., rainwater that does not run off), blue water (e.g., water from rivers, lakes, and aquifers used to irrigate or process product), and gray water (e.g., water needed to dilute pollutants generated in production).** Considerable variability exists in both animal and crop production systems and regions in terms of the amounts and distributions of green/blue/gray components.[72,73] The impact of these different components is highly spatially and temporally dependent, contingent on local availability of water resources (both physical and economic), infrastructure, and seasonal precipitation levels.[74,75]

The water footprints of animal-based foods are largely determined by three main factors—feed conversion efficiency of the animal, feed composition, and origin of the feed—in addition to direct water consumption by the animal.[76] The type of production system (e.g., grazing, mixed, or industrial) is important because it influences all three main factors. For instance, ruminants (e.g., cows, sheep) raised completely on rain-fed grass (green water) on grazing land unsuitable for crops have a very different impact on water supplies than ruminants finished at concentrated animal feeding operations (CAFOs), to which water must be delivered (in the form of feed produced

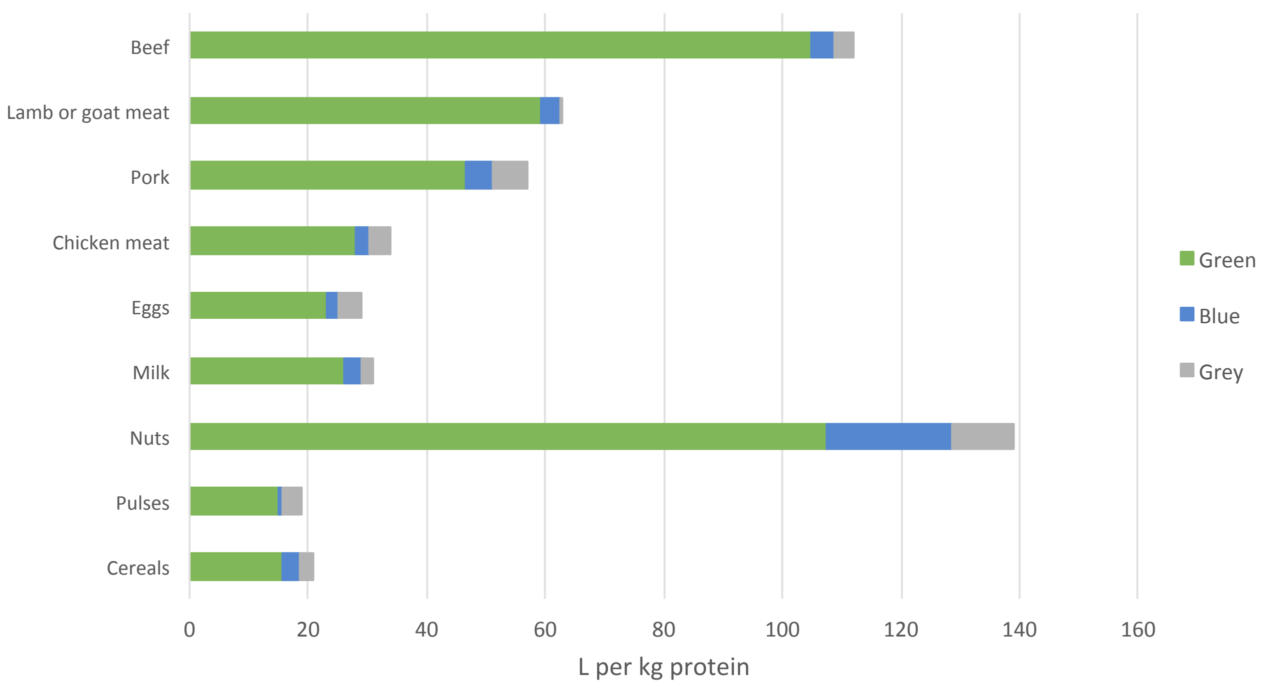
h Any trees cut down or destroyed by fire will return the carbon to the atmosphere.

i Debate exists over the extent to which the carbon sequestration potential of properly managed pastures and rangeland is canceled out by the methane released from ruminant animals' digestive processes (pg. 40).

with green and blue water and blue water in the drinking source for the animal) and from which water-borne waste/pollutants must be diluted (gray water).[76] While green water usage does not put pressure on surface or ground water resources to the same extent as blue water, these footprints are not irrelevant, as green water could theoretically be used more efficiently to produce human food in areas where grassland could also grow crops.[16] Further research on this potential is needed, especially as most water use in global livestock production is related to feed crop cultivation, which uses mostly green water.[16,j]

The water footprint of plant-based foods is determined by the green or blue water necessary for the crop to grow, as well as the gray water necessary to dilute excess fertilizers, pesticides, and other pollutants in surface and ground water associated with crop production.[73] The water footprints of both animal and plant-based foods also account for water use during processing and packaging. Per kilogram of protein, animal products generally have a larger water footprint than crop products (Figure 4). The same is true for water footprint per calorie; the average water footprint per calorie of beef is 20 times larger than that of grains and starchy roots.[76] These trends have thus revealed that vegetarian and other low-meat diets generally have lower water footprints than traditional Western diets.[77-79] Caveats must be made, however, as certain fruits, vegetables, and especially nuts can have relatively high water footprints. Thus, some healthier diets higher in water-intensive produce items have been found to increase water stress, most notably when foods are sourced from areas of water scarcity.[80]

FIGURE 4: **WATER FOOTPRINT OF DIFFERENT PROTEIN FOOD GROUPS PER KILOGRAM OF PROTEIN**



Graphic made by authors. Data used with permission from Mekonnen, M.M., & Hoekstra, A.Y. (2012). A global assessment of the water footprint of farm animal products. *Ecosystems, 15*(3), 401-415.

Fertilizer use

The rapid increase in the use of fertilizers, both synthetically produced and those derived from animal manures, has considerably increased the food supply over the past century. This increase has largely been driven by the Haber-Bosch process, a method of synthesizing ammonia from atmospheric nitrogen (N).[81] While this process has helped us feed the rapidly growing global population, the availability of and endless supply of N has led to excess N accumulation in the environment. The Haber-Bosch process is also very energy-intensive, so the manufacturing of synthetic fertilizer has a high GHG footprint. Meanwhile, phosphorus (P) in fertilizer is derived from mining global phosphate rock sources, which are concentrated in only a few countries—making them vulnerable to geopolitical conflicts—and are expected to be depleted by the end of the century, threatening long-term food production capacities.[82]

When excess reactive nitrogen (N_r) and phosphate (PO_4^{3-}) enter the environment from fertilizers, they degrade the quality of

j Although feed crop cultivation depends mostly on green water, the blue water footprint is still important. In the United States, and particularly in the West, a significant amount of crops and forages grown for animal feed (e.g. alfalfa) are being produced with blue water.

surface and ground water (N_r, PO_4^{3-}) and air (N_r), and contribute to climate change (N_r), stratospheric ozone depletion (N_r), and biodiversity loss (N_r, PO_4^{3-}).[83,84] Nitrate and phosphate runoff and ground water contamination cause eutrophication of freshwater and coastal ecosystems, whereby excess nutrient levels lead to toxic algae blooms that deplete oxygen levels in the water and kill fish, plants, and other aquatic life.[85] Meanwhile, excess levels of nitrate in drinking water have been associated with birth defects following prenatal consumption[86] and with certain types of cancer among adult consumers (stomach, colorectal, non-Hodgkin lymphoma, thyroid, ovarian).[87-89] Reactive nitrogen released into the lower atmosphere increases smog, particulate matter, and ground-level ozone pollution, which cause respiratory illnesses, reduced lung function, and premature deaths. On the other hand, N_r released in the upper atmosphere as nitrous oxide can damage stratospheric ozone and is also a potent greenhouse gas.[84,90]

Researchers have created an N footprint calculator to measure the amount of N_r lost to the environment related to the production and consumption of food, energy, goods, and services.[91] Food production and consumption are responsible for 71% of the average American's N footprint.[91] Although food production, particularly of meat, is responsible for more N emissions than any other footprint component,[91] substantial differences exist between types of meat (poultry and pork are significantly more N-efficient than beef) and plant-based foods (legumes and grains are generally more N-efficient than vegetables).[92,93]

Phosphorous footprints have also been determined. The average American diet is associated with the second highest dietary P footprint in the world, 82% of which was attributed to animal product consumption.[94] P requirements follow a relatively similar hierarchy of resource requirements as N inputs, with beef being the least P-efficient (significantly less than pork and poultry), and pulses and starchy roots being the most P-efficient by far.[95] A plant-based diet dramatically decreases the mined phosphate required to produce the food consumed in a conventional meat-heavy diet.[95] One estimate suggests that if U.S. consumers shifted to a plant-based diet, the country's phosphorus fertilizer demand could decrease by 44%.[96]

While average N and P footprint values help convey the scale and sources of nutrient losses from fertilizer application, it is important to emphasize that the amount of leaching depends on soil and climate conditions, and can differ largely between countries and between regions within the same country.[60] The region where food is produced is also particularly important to consider when assessing the *impacts* of these pollutants. For instance, California's water crisis is amplified by N contamination of ground water from intensive dairy, nut, feed crop (e.g., alfalfa, corn), and produce farms,[97] which disproportionately harms low-income Latino farmworker communities.[98,99] Nitrate-contaminated drinking water has also been an issue for residents in a number of Midwestern states who live in proximity to industrial corn, hog, dairy, and poultry farms.[100,101] Concentrated intensive poultry production in the Delmarva watershed (comprised of parts of Delaware, Maryland, and Virginia) significantly contributes to the eutrophication of the Chesapeake Bay.[102,103] Algae blooms observed in Lake Erie are largely attributable to P runoff from agricultural practices, placing considerable expense on communities who depend on the lake for their water supply.[104] Meanwhile, excess nutrients leached from farms along the Mississippi River Basin are the leading cause of the Gulf of Mexico's Dead Zone,[105] which could even impact aquaculture production in the region.[106]

It is also worth noting that, beyond nutrient pollution, fertilizers derived from animal manure frequently contain hormones, pesticides, and non-metabolized veterinary drugs.[107] Thus, contamination of ground water by non-synthetic fertilizer leaching can also harm humans relying on that water for drinking and other household uses.

Pesticide use

Chemical pesticides (e.g., herbicides, insecticides, fungicides) used in agriculture can measurably improve the yields and quality of crops, and indirectly food security, farmer livelihoods, and consumer affordability.[108] However, their use also contributes to a number of risks to human – most notably for farmworkers and nearby agricultural communities – and environmental health. Farmworkers are at an increased risk of acute pesticide poisoning and other pesticide-related illnesses, including some cancers; nervous system and reproductive disorders; and respiratory, skin, cardiac, liver, and kidney conditions.[109] Residents living in proximity to industrial crop farms with high pesticide use are also at risk for many of these harms.[110] Children's developing organ systems and smaller bodies are especially sensitive to such pesticide exposure.[111,112]

At this time, there is little evidence that pesticide use represents a significant health risk for those consuming conventionally-produced food items,[113] though there is controversy over the extent to which chronic, low-level exposure to pesticides through food consumption (even below established risk thresholds) could pose health risks to consumers. Conventional produce has a 30% higher risk for pesticide contamination than organic produce, and a few studies have found significantly lower urinary pesticide levels among children consuming organic versus conventional diets.[114] However, there is little evidence at this time that these differences would have clinical significance.[114] Questions remain about the possible synergistic effects of consuming low-level amounts of multiple different pesticides, particularly those with a similar mechanism of action.[115] The potential risk is cause enough to limit or avoid pesticide exposure whether through food consumption or in general while additional research is established.

The use of certain pesticides, however, has also been implicated as a threat to other non-target organisms—including birds, amphibians, aquatic organisms, and beneficial insects—especially when persistent in the environment and as a potential surface and ground water contamination threat.[116,117] Pesticides are considered one of the many contributors to the rapidly declining populations of pollinators, threatening future food security given that 75% of crops worldwide depend on insect pollination (mostly by bees).[118] Theories have been put forward that chronic, sub-lethal pesticide exposure may compromise the health of individual bees, and ultimately lead to lethal impacts on colonies already weakened by disease.[118,119] Neonicotinoids, a class of insecticides introduced to the agricultural market in the early 1990s, have become particularly suspect culprits and are increasingly being banned in attempts to support pollinators. Debate remains over the extent to which these specific insecticides contribute to pollinator collapse,[120] especially as other fungicides and insecticides have also been associated with poor colony health.[121] The heavy use of agricultural fungicides has also been implicated in the rise of fungal resistance to anti-fungal medicines (through a similar mechanism as the development of antibiotic resistance), which has particularly serious consequences for immune-suppressed individuals.[122]

Antibiotic, hormone, and other pharmaceutical use

The overcrowded, confined, and often unsanitary living conditions of most food animals in the United States today (p.13) rely on a number of pharmaceutical drugs for disease treatment and prevention. About 72% of "medically important" antibiotics—which come from classes of antibiotics that are medically important to the treatment of human disease such as penicillins, macrolides, and cephalosporins—sold in the United States are used for animal agriculture, not for human medicine.[123] The overuse of non-therapeutic[k] antibiotics in animal agriculture has thus been implicated as a significant contributor to the growing threat of antibiotic-resistant infections because such practices diminish the effectiveness of lifesaving drugs.[124] Antibiotics are not solely used in meat production, however; they are also used in aquaculture, dairy, and egg production, as further discussed in this report.[125,126]

Dairy cows and farmed fish are also commonly fed hormones to increase and sustain their milk production (cows) and for growth promotion[l] (farmed fish).[127] All birds and mammals, including humans, emit hormones in their waste, which eventually ends up in rivers and waterways. Both natural and synthetic estrogens have been associated with negative reproductive (e.g., endocrine disruption) and developmental impacts for aquatic organisms, even at low levels.[128,129] Concerns have been raised that elevated levels of these endocrine-disrupting chemicals in the widespread environment could directly harm humans, too, though more research is needed to determine the extent of risk.[130]

Biodiversity and ecosystem function

Declining biodiversity threatens many important ecosystem services that support long-term food security including pollination, pest control, water retention, soil fertility, and nutrition enhancement.[131-133] Agricultural biodiversity is threatened by a number of agricultural practices including increasing genetic uniformity in crop varieties and livestock breeds, monoculture production systems (to produce crops for both human and animal consumption as well as animal products for human consumption), clearing of biodiverse land (e.g., rainforests, mangroves, grassland) to increase food production, soil management strategies (e.g., tilling), heavy use of pesticides and other agrochemicals, and certain fishing practices.

SOCIAL JUSTICE CONSIDERATIONS

Rapid industrialization, concentration, and vertical integration in the food system over the past century have increased efficiencies of scale, reduced costs for large-scale producers, and lowered consumer prices. These same changes have also contributed to the decline in value of workers' wages and loss of farmers' and citizens' autonomy over food production, processing, distribution, and retail.[36] Industrial food production and processing in the United States also present many physical, mental, and social health concerns, which fall disproportionately on food system workers (most of whom are immigrant and migratory) and their families as well as residents of nearby communities (predominantly of color and low-income). Food production, aquaculture, and food processing are strenuous and dangerous professions with exceptionally high rates of occupational injuries.[109,134] Workers also face increased risk for respiratory illnesses, bacterial infections, digestive tract disorders, and other health conditions from exposure to pathogenic bacteria, pesticides, drug residues, hormones, heavy metals, excess nutrients, and other contaminants.[109,134] These risks are often compounded by poor working conditions, substandard wages and housing, and inadequate labor rights (including lack of workers' compensation and healthcare benefits).[135-137] Residents living in proximity to industrial crop and/or food animal production

k Considerable debate exists over how to classify antibiotic use. The U.S. Food and Drug Administration (FDA) considers disease treatment, control, and prevention to be therapeutic uses, though other public health experts consider disease prevention to be non-therapeutic.[24]

l Although studies have documented how antibiotics can be used for growth promotion in aquaculture, the extent to which antibiotics are used (whether for disease treatment, disease prevention, or growth promotion) is relatively unknown.

operations are at risk for many of the same health concerns as workers due to local air and water pollution.[28,110,138] Neighbors of industrial food animal production operations also report high rates of stress, among many quality of life disruptions.[28,138]

It is important to consider the socioeconomic implications that large-scale shifts towards more plant-based diets could have for current food producers and consumers, domestically and globally. Importing significant amounts of food from other countries displaces the environmental and social impacts associated with their production to the places where the foods are produced. This can be especially concerning when these regions of production have high poverty levels and few labor and environmental protections, making them ripe for exploitation through global market integration. For instance, rampant Amazonian rainforest deforestation over the last two decades to create pasture for cattle grazing or cropland to produce feed for poultry and pigs, meat and dairy cattle, and farmed-raised fish has been implicated in a number of social justice concerns for local residents. These include increased levels of income inequality and accelerated land consolidation, in addition to contributing to rapid degradation of one of the world's most biodiverse hotspots.[139]

Inequities in global trade are not exclusive to animal-based foods. Many plant-based foods highlighted for their superior nutritional profiles (e.g., quinoa, chia seeds, goji berries, millet, teff) are indigenous to other countries, predominantly in the Global South. The importing of such foods by wealthier consumers from the Global North has presented social and ethical questions raised by these trade dynamics. For example, in what some refer to as the "quinoa quandary," debates exist over the degree to which the rapidly increased global demand for quinoa (mainly grown in Bolivia and Peru) has improved the livelihoods of poorer growers by raising its cash value, or priced out local inhabitants who have traditionally relied on quinoa for high-quality nutrients and food security.[140] It may also encourage the adoption of more unsustainable intensive production methods that deplete long-term soil quality and biodiversity, and may raise difficulties for local residents if the boom ends or varieties that grow in other places are developed.[140] Critiques exist about the extent to which fair trade certifications (related to many imported products like coffee) alleviate some of these concerns or reinforce trade, labor, gender and other social inequities.[36]

Wide-scale shifts towards more plant-based diets may also depend on changes in agronomic and horticultural research priorities, food and farm policies (at all jurisdiction levels), extension services, farmer knowledge and training, and infrastructure.[62,141] Livestock production also employs 1.3 billion people and supports the livelihood of 600 million smallholder farmers globally, and it is important to emphasize that messages advocating reducing meat consumption should be concentrated in industrialized countries with high consumption rates and fewer employees of the system.[142,m] On the whole, there is little consideration of the positive or negative impacts that shifting dietary patterns could have on producers, as most literature around healthy and sustainable diets concentrates on public health and environmental impacts. Thus, comprehensive analysis is still needed to assess the macroeconomic and agricultural policy needs for and potential consequences of shifting towards more sustainable and healthier diets.[141]

Each of the following sections provides an overview of key social justice considerations that have been raised about the food product category at hand. This report is not meant to be comprehensive, and given the complexities related to trade markets, many unanticipated socioeconomic consequences of scaling up or scaling back consumption of any food product are likely to occur. Nevertheless, by prioritizing the procurement of food from suppliers that work to avoid—or, if necessary, mitigate—these social injustices, hospitals and other healthcare facilities may help shift the infrastructure of the current food system toward one that supports the health and wellbeing of workers and communities.

ANIMAL WELFARE CONSIDERATIONS

Rising demand for meat has facilitated rapid intensification of food animal production in the United States, and increasingly around the world, since the 1950s. Animals are often raised in large numbers, confined in small spaces, and subject to poor conditions that contribute to numerous physical and psychological harms, including illness, painful body alteration, and extreme stress.[24] They are often fed antibiotics, hormones, and other drugs to prevent disease and increase growth rates, but these may also harm animals and human workers, surrounding communities, and public health in general (p.12). Animal welfare concerns are not exclusive to conventional farms, and also exist on organic or more "natural" farms.[24,143] Reducing demand for meat products may mitigate some of these concerns, although many also occur in the production of dairy, eggs, and fish. This report discusses important animal welfare considerations related to these foods, and the supplementary recommendations review key animal welfare considerations to prioritize when purchasing meat alternatives from these categories.

m Efforts to *moderate* increasing animal product demand will also be required in rapidly industrializing countries to ensure long-term global food security.[56]

LIMITATIONS OF THIS REPORT

EXCLUDED FOODS

This report does not address the full range of food categories that offer protein, a non-trivial exclusion given that other foods not typically categorized as "protein foods" contribute nearly half of the protein available in the U.S. food supply and a majority of the protein consumed worldwide.[34,144] For instance, whole grains may provide significant amounts of protein, varying from 5 g per cup of cooked brown rice to 10 g (20% of the daily value recommendation for adults) per cup of cooked wheat berries, teff, or amaranth.[145] The environmental impacts of grains also varies greatly.[146,n] Some grains are used to make products used as alternatives to traditional animal products, including seitan, oat milk, and brown rice protein powder. Moreover, emerging sources of proteins, such as mycoproteins (e.g., "Quorn"), edible insects, microalgae, in-vitro meat, and lab-grown dairy products,[147-149] were excluded due to their relatively rare presence in current food supply chains, though they represent opportunities for further research.

FUNCTIONAL UNIT SELECTION

The health and environmental impacts of animal and plant-based foods can vary in significant ways depending on which functional unit is used to compare them (e.g., per kilogram of protein, per kilogram of product, per serving, per calorie).[56] This issue came into the spotlight recently as a study garnered media attention for its statement that lettuce was "three times worse in GHG emissions" than bacon and associated claims that vegetarian diets were worse for the environment.[150] This quote was based on a per calorie comparison, which can be misleading given that these foods have substantially different caloric densities and are not typically consumed in similar calorie amounts.[151] Since vegetables, unlike root crops and legumes, are not primarily consumed for calories or protein, some experts recommend comparing them on a per serving basis.[3] Others urge comparing the impacts of meals containing similar nutritional value[152] or entire dietary patterns[153] rather than individual foods to avoid such problems. Given that this report seeks to guide the process of choosing protein foods, comparisons are made on a per kilogram of protein basis, though per serving comparisons are also included given that, although they contain adequate amounts of protein, plant-based diets generally do not fully replace original animal-based protein intakes when avoiding meat products.[146] Per kilogram of product comparisons are only used when no other functional units were available in the study being cited and the data was deemed important enough to include.

DATA LIMITATIONS

When estimating contributions to climate change from foods or dietary patterns, it is important to clearly identify the boundaries of consideration. For example, estimates of GHG emissions that focus on food production up until a food leaves a farm (or landing site, in the case of wild seafood) may differ considerably from those that evaluate emissions from production all the way to consumption.[56,154] The latter includes post-production transport, processing, packaging, storage, distribution, and preparation whereas the former does not. Most studies cited in this report were based on lifecycle assessments (LCAs) of foods from just the production phase to maintain methodological consistency when comparing LCAs. Given this limitation, important considerations for other lifecycle stages are noted when possible (e.g., emissions for processing milk into cheese or soybeans into processed soy products, or high-impact transportation methods). Water footprint methodologies generally report impacts from production through to retail stages, so these concerns were less of a concern for those data.

The type of allocation method, meaning how one accounts for "co-products" like the meat that comes from retired dairy cows or parts of plants that are not consumed directly but used in other forms (e.g., straw derived from wheat or rice; almond hulls, shells, and biomass that can be used for feed, bedding, or electricity generation) can significantly change the environmental footprints associated with many foods.[61,155,156] Lifecycle assessments results also vary depending on whether soil organic carbon stocks—and hence soil carbon emissions or sequestration potential—are considered. Debates remain over whether the potential of regenerative farming practices such as grazing cattle on well-managed pastureland to sequester carbon is profound[157,158] or overstated.[159] Given the profound uncertainties and assumptions underlying it, most LCAs of current production systems do not include carbon sequestration potential.[60,61]

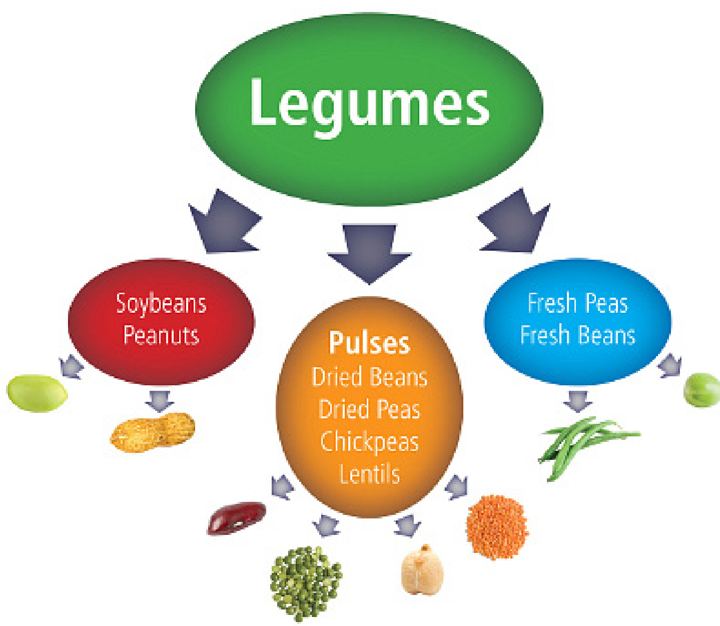
Regional physical and socioeconomic variations can also lead to different crop yields and feed conversion factors.[16,50] Most LCA reviews present global averages for different ecological impacts, and hence do not go into depth on such differences. This report included many such reviews because of their comprehensive scope and useful summary analyses. However, it does incorporate references to studies that account for the differential geographical impacts of production to highlight key considerations to keep in mind when choosing the source of certain food items.

n For example, rice has a GHG footprint four times greater per serving than that of oats, rye, and wheat, though it is still significantly lower than that associated with meats on a per serving basis.[146]

LEGUMES (PULSES AND SOY)

The term "legume" refers to plants with fruit enclosed in a pod. Legumes are a large family of plants including more than 600 genera and more than 13,000 species.[160] Well-known legumes include alfalfa, clover, dry beans, fresh peas, soybeans, peanuts, lupins, and mesquite. This section assesses the health, environmental, and social impacts of producing and consuming pulses and soybeans. Due to their similar nutritional profiles, peanuts are often grouped with tree nuts and are thus assessed in the nuts and seeds chapter (pp.21-24). Note that some studies describe the impacts of legumes as a whole; others specify their results apply to only pulses or soy. For each impact discussed below, this report uses the term described in the original source cited.

FIGURE 5: **WHAT ARE LEGUMES?**



Graphic reprinted with permission from Pulse Canada.

Legumes play a critical role in supporting food security, agricultural sustainability, and overall ecosystem resilience through their unique capacity to increase soil fertility and promote agro-biodiversity.[161] Symbiotic bacteria that live on the roots of legumes "fix" nitrogen gas from the atmosphere into biologically active forms of nitrogen that can be used by plants. With legumes' ability to replenish soil nitrogen (and in some cases, also free soil-bound phosphorous[162,163]), rotating leguminous crops with other crops can increase nutrient availability to benefit the crops to follow and thus provide a more ecologically sound and sustainable form source of nutrients compared to synthetic fertilizers.[164] Planting legumes in rotation with cereal crops also reduces disease potential and helps control weeds and insects in both crops.[163,165]

Pulses (i.e., grain legumes) are a subset of food legumes, a term restricted to those used for the dried seed. Dried beans, lentils and peas are the most common varieties.[166] The most popular available dry bean and pea varieties in the United States include pinto, navy, black, great northern, garbanzo (chickpeas), kidney, lima, and mung beans; as well as black-eyed and pigeon peas.[167] They can be prepared and consumed in many forms including whole or split, ground into flour, or fractionated into protein, fiber, and starch.[160] As the practice of incorporating leguminous plants into crop rotations grows, pulse production in the United States is rising.[168] The principal growing regions of dry beans, lentils, and peas are the Northern Plains states (North Dakota, Nebraska, Montana), upper Midwest (Michigan, Minnesota), eastern Washington, northern Idaho, and northeast Oregon.[168] Production in the Northern Plains is the most rapidly growing, where pulses fit well into established crop rotations.[167] That said, the United States exports 43% of the dry beans and 83% of the other pulses (excluding soybeans) it produces while importing 63% of the supply consumed (predominantly from Canada).[169]

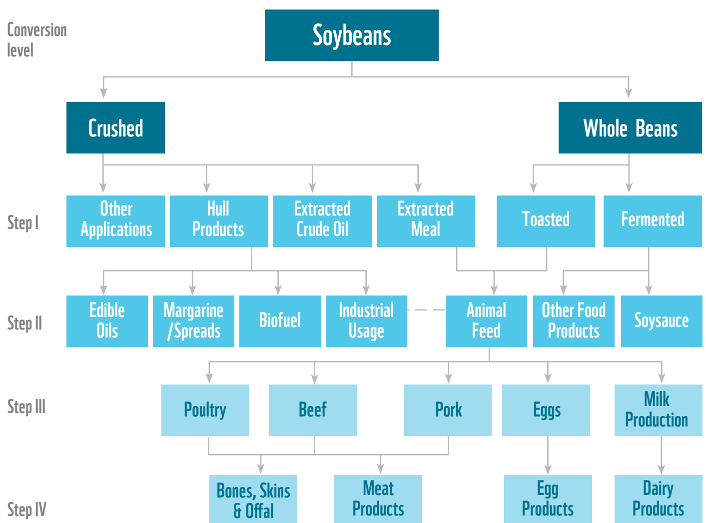
Global soybean production has grown tenfold over the past half century—from 27 million tons in 1961 to 278 million tons in 2013[170]—and is expected to grow another 33% by 2050.[139] Soybeans are now the second-most-planted field crop in the United States after corn, with *83.7 million acres planted in 2016.[168] Of that, 94% was planted in genetically modified herbicide-resistant varieties (see Sidebox, pg.20).[168] Fewer than one percent of total soybean acres was in organic production.[171]* More than 80% of soybean acreage is in the upper Midwest (the "Corn Belt"), where corn-soybean rotations are common, although significant amounts are planted in the South and Southeast.[172] While the United States is the world's second largest soybean producer, it also imports significant quantities (>15,000 tons, in some cases over 300,000 tons) of soybeans (SB), soybean meal (SM), soybean oil (SO), and soy sauce (SS) from Canada (SB, SM, SO, SS), China (SB, SS), Argentina[o] (SB), and India (SB).[169]

About 85% of the world's soybean crop is processed into meal for animal feed and vegetable oil.[139] Two percent of that meal

o Numerous social justice and environmental concerns have been implicated with the export-driven soy industry in Latin America, including adverse health and environmental impacts for nearby communities associated with heavy agrochemical use, land consolidation and displacement of indigenous communities, and elevated climate impact due to land use change/deforestation.[139,173-175] This report concentrates on the impact of soy production in the United States given that it accounts for the vast majority of soy consumed in the country directly or indirectly via animal feed (for domestically raised livestock) or processed foods. The United States does import significant amounts of farm-raised fish, however, which may be fed soybean meal derived from Latin America (further research needed).

further processed into soy flours and derivatives for food use (e.g., lecithin, an emulsifier). Soy oil is used for cooking, in margarine, and also for other goods including soaps and cosmetic products. Approximately 6% of soybeans are used directly as human food.[139] Food uses of soybeans include whole soybeans (e.g., edamame, soy nuts), traditional soy foods made from whole full-fat soybeans (e.g., tofu, full-fat soymilk) and fermented soybeans (e.g., miso, tempeh, soy sauce, natto), as well as processed meat analogs, energy bars, and low-fat soy milks made from soy protein isolate, soy protein concentrate, or textured soy protein (i.e., TVP). Meat processing companies also commonly use TVP as a "meat extender" to make meat products cheaper.[176]

FIGURE 6: PRODUCTS DERIVED FROM SOY



Graphic reprinted with permission from World Wide Fund for Nature (2014). *The Growth of Soy: Impacts and Solutions*. Gland, Switzerland: WWF International. Available at http://wwf.panda.org/what_we_do/footprint/agriculture/soy/soyreport/index.cfm

HUMAN HEALTH CONSIDERATIONS

Pulses

Pulses are part of the legume family, but the term "pulse" refers only to the dried seed and does not include fresh beans or peas. Although they are related to pulses because they are also edible seeds of podded plants, soybeans and peanuts differ in that they have a much higher fat content, whereas pulses contain little fat.

Pulses are rich in fiber and protein and have high levels of minerals including iron, zinc, magnesium, and potassium as well as folate and other B-vitamins.[177] Regular consumption of pulses has been associated with various health benefits, including decreased risk of cardiovascular disease, diabetes, obesity, and colorectal cancer.[178,179] These benefits may be increased when pulses are combined with tree nuts and whole grains in diets rich in fruits and vegetables.[180,181] The large prospective, observational Nurses' Health Study II reported that substituting one serving/day of legumes for one serving/day of red meat in young adulthood was associated with a 15% lower risk of breast cancer among all women and 19% lower risk among premenopausal women.[182]

Iron from pulses is not particularly well absorbed by the human body (i.e., bioavailable) but this can be increased by eating pulses with vitamin C-containing foods (e.g., squeezing lemon juice onto lentil or chickpea dishes). Pulses are quite low in fat and relatively low in caloric density. Although they have a fairly high carbohydrate content (50%–65%), they are slowly digested. The glycemic index of pulses varies with cooking and processing; for instance, the glycemic index of canned beans is higher than dry, cooked beans, although still lower than bread.[183]

Pulses contain low levels of several compounds often called "anti-nutrients," including enzymes, enzyme inhibitors, and lectins. These compounds can interfere with various digestive enzymes, including trypsin, chymotrypsin, and amylase, reducing the bioavailability of some nutrients. Their effect is sharply reduced, however, with cooking and especially sprouting, which denature the anti-nutrients and improve nutrient absorption from and overall digestibility of pulses.[184,185]

Soy

Whole soy is a complex food containing protein, carbohydrates, fat, and fiber. Soy provides a "complete" plant-based protein source, meaning that it contains all essential amino acids.[186] Soybeans also contain many compounds that impact human health, including saponins, lecithin, phytates, protease inhibitors, phenolic acids, phytosterols (including phytoestrogens like isoflavones), and omega-3 fatty acids.[187] Many of the health impacts related to consuming soybeans and soy-based food products depend on whether the soy is consumed in a whole food form or as a more processed product made from isolated soy protein or extracts.
The health benefits associated with consuming soy in observational studies of humans are related to whole soy food consumption; there is conflicting evidence about whether processed soy isolates (including soy supplements containing isolated phytoestrogens/isoflavones) may cause adverse health effects.[188]

Moderate consumption (e.g., 1-2 servings/day) of whole soy foods (e.g., edamame, tofu, tempeh, full-fat soymilk) has been associated with cardiovascular benefits, including improved blood cholesterol profile and modestly lower triglycerides, particularly in people whose baseline levels are elevated.[189,190] There is no evidence of this effect from isolated soy proteins or extracts (e.g., soy found in processed soy meat analogs, energy bars, and low-fat soy milk).[191] Whole soy dietary protein is associated with modestly improved measures of bone health and, in a large prospective study of Chinese women, with reduced risk of fractures.[192,193] Fermenting may also increase the bioavailability of iron and zinc from soybeans.[194,195] Consumption of soy (in all forms, whole, isolated, supplements) has also been associated with reduced menopausal symptoms including hot flashes.[196]

There has been controversy over whether isoflavones in soy, which can act like estrogens in the body, can cause cancer. However, isoflavones also have *anti*-estrogen properties (depending on the tissues they are in),[197] as well as anti-oxidant and anti-inflammatory effects that work to suppress cancer growth. Observational studies have found that higher consumption of dietary whole soy products is associated with modestly decreased breast cancer risk.[198] This association is even stronger with higher whole soy consumption in childhood and adolescence. Ultimately, whole soy is a complex food with a mixture of isoflavones and many other compounds that should not be considered in isolation. Thus, the health benefits may not apply to fractionated soy supplements. The American Cancer Society recommends against taking soy *supplements* due to the unnaturally high isoflavone concentration, but recognizes that moderate consumption of soy *foods* is considered safe, indeed protective.[199]

Highly processed soy foods are often high in sodium and commonly filled with additives including artificial flavors, gums, colorings, and preservatives. Controversy exists as to the real safety of the approved food additives on the market. For example, many of the approved food additives in the United States are banned in other countries due to conclusions by regulatory agencies of a lack of safety.[200] One consumer group, the Center for Science in the Public Interest, ranks a list of common food additives based on human health and safety risks associated with their consumption.[201]

ENVIRONMENTAL HEALTH CONSIDERATIONS

Compared to other food groups, legumes generally have the lowest environmental impacts associated with their production across indicators, including GHG, land, and water footprints, and—with the exception of soybeans—pesticide and fertilizer use. Legumes may also enhance soil, above-ground vegetative and invertebrate biodiversity, and benefit an entire agricultural operation in various ways when they are planted as components of cropping rotations or even integrated crop-animal systems.

Climate change

When GHG impact (up to point of retail) is compared per unit of protein, legumes by far have the lowest values (4 – 10 kg CO_2-eq/kg protein) compared to other animal protein sources, such as poultry (10 – 30), eggs (15 – 42), pork (20 – 55), and beef (45 – 640).[61] Processing legumes into meat substitutes raises their GHG impacts: slightly for vegetable-based substitutes (6 – 17), and significantly for substitutes that include egg or milk protein isolates (17 – 34). A more recent LCA review of global average values (though considering only production phase) found even more striking results, with pulses having 3.7% the GHG-intensity per unit of protein as eggs, 2.7% the footprint of dairy, 2.5% the footprint of poultry and pork, and only 0.4% the footprint of ruminant meat.[3]

Some studies have also analyzed the emissions associated with completely plant-based meals in contrast to meals containing meat or other animal products. These comparisons may add additional nuance, such as by differentiating animal products based on what they were fed or adding in the impacts of additional ingredients, which can significantly change the overall climate impacts associated with meals.[202] For instance, one analysis of farm to retail emissions found that a meal with tomatoes, rice, and pork was estimated to have nine times higher emissions than a meal of potatoes, carrots, and dry peas.[152]

The Dirt on Your Plate: How much of an environmental impact do different meals have?

One study compared GHG emissions from farm to consumer associated with four different meals containing equivalent amounts of protein and calories.[202]

The components of the meals were 1) pork chop produced with conventional soy-based feed, plus potatoes, tomatoes and bread, 2) pork chop produced with feed based on peas and rapeseed, plus potatoes, tomatoes and bread, 3) sausage in which 10% of the animal protein has been replaced with pea protein, plus bread and tomatoes, and 4) a fully vegetarian pea burger plus bread and tomatoes.

The authors concluded that the vegetarian meal had approximately half to two-thirds (it studied the meals in two different locations) of the global warming potential than all of the meals with animal protein. However, in terms of energy use alone, a completely vegetarian pea burger meal required the same amount of energy as other meat-containing meals; more energy-efficient processing of vegetarian products would reduce their climate impacts.

Land use

Pulses also have a relatively low land footprint. One LCA review reported the land footprint for pulses to range from 10 – 43 m^2/kg protein[p] and meat substitutes from 4 – 25 m^2/kg protein.[61] These values were slightly lower or roughly comparable to farmed seafood (13 – 30 m^2/kg protein), poultry (23 – 40 m^2/kg protein), milk and cheese (26 – 54 m^2/kg protein), and pork (40 – 75 m^2/kg protein). They were all much lower than the land footprint for beef, which ranged from 37 m^2/kg protein for culled dairy cows to 1430 – 2100 m^2/kg protein for cattle raised on extensive pastoral farms. Another study comparing the land used to produce meat protein (including land used to grow feed) versus a processed soy protein product found that the land requirements to produce the same amount of meat protein were 6–17 times larger for meat protein.[203]

Some studies have also compared land footprints based on dietary patterns, providing a more holistic view of the land use requirements for more plant-based diets versus diets with various amounts of meat and animal product intake. One analyzed the land requirements in New York state for 42 diets ranging from 0 – 381 g/day (0 – 12 oz./day) of meat and eggs and 20 – 45% total calories from fat.[204] The authors found a nearly five-fold difference in per capita land requirements across diets. Ultimately, meat increased the land requirements of diets more so than fat, but diets which included modest levels of meat and fat consumption could feed slightly greater numbers of people than vegetarian diets which provided significant quantities of fat (due to the need to grow additional oil crops). They concluded that *diet should be considered in its entirety when assessing environmental impacts, including land use.*

A recent study also compared land-use requirements of ten different diets in the United States.[62] The baseline diet reflected current dietary consumption data. It was compared with a series of dietary patterns beginning with a healthy omnivorous diet meeting USDA dietary guidelines and then progressively altered by adding increasing percentages of people following an ovo-lacto vegetarian diet. Three completely vegetarian dietary patterns (which excluded all animal flesh) were also included: ovo-lacto vegetarian, lacto-vegetarian, and vegan. Land requirements decreased steadily across the five healthy omnivorous diets as meat intake declined. The total land requirements for the three vegetarian diets were all low, though the authors emphasized that the kind of land (grazing, perennial cropland, or cultivated cropland) impacted by these diets varies considerably. The differential in terms of land saved by eating less or no meat was smaller when considering only cultivated cropland requirements instead of full land use requirements. This is significant given that much land in the U.S. is not suitable for growing food crops and hence any grazing land saved would not necessarily feed more people (though it could be used for other purposes – see p.9).

Water use

Global average water footprints of pulses and soy are generally considerably lower than those of animal protein sources, whether calculated per ton of product or per unit of nutritional value.[76] The water footprint per gram of protein for milk, eggs, and chicken meat is about 1.5 times larger than for pulses.[76] For beef, the water footprint per gram of protein is six times larger than for pulses. The water footprint breakdown for pulses is 78% green water, 3% blue water, and 18% gray water. When growing, legumes fix nitrogen (N) into the soil, which reduces the need for chemical fertilizers. But depending on cropping systems, soil type, rainfall, and management practice (e.g., crop rotations, fallowing, tilling vs. no-till), N leaching from legumes into surface and ground water can be significant, particularly after harvest and during a fallow period.[205] The larger relative global average gray water footprint of pulses compared to many other crops is based on estimates of N leaching and the water necessary to dilute it to safe levels and can vary widely. A vast majority of soy in the United States is entirely rain-fed and has little or no blue water footprint during production. It does, however, contribute to gray water requirements and require blue water during processing.

Fertilizer use, nitrogen leaching, and gaseous emissions

In addition to their food value, legumes are also important in cropping systems for their ability to fix N and increase the fertility of the soil. This role derives from the symbiotic relationship that legumes have with bacteria that are able to fix atmospheric N into a form that is usable by plants. Before the development and use of synthetic N fertilizers, legumes were often included in integrated cropping systems to supply and replenish soil nitrogen. They still are common in certain instances, such as corn-soy rotations. With synthetic N fertilizer, many farmers rely less on legumes, but they are essential in organic operations which do not rely on manure or compost.

As with N-fertilized fields (pp.10-11), N can leave legume-based cropping systems through leaching into surface or ground water, or through gaseous emissions as ammonia, nitric oxides, nitrous oxide (N_2O), or nitrogen gas (N_2).[164] The greatest risk of N leaching from legume-based systems occurs during fallow periods after crop residue has been incorporated into the soil and before a subsequent crop. This can be minimized with the appropriate use of cover crops where possible. N_2O releases from N-fertilized and legume fields are similar but the total global warming potential is much greater in fertilized fields largely because of the energy required to make N fertilizers.[164]

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p These land use requirements are averages of the square meters occupied *per year* per kilogram of protein.

Ammonia releases can be minimized or even eliminated by incorporating amendments into the topsoil.[164] No-till cropping in an N fertilized field helps increase soil carbon sequestration but does not offset the energy requirements for N fertilizer production. A legume-based system is superior in terms of reduced contributions to global warming.

One study that compared a variety of food groups found that pulses (along with nuts) have the lowest total N_r lost to the environment per kilogram of protein consumed—known as the virtual N factor—at 64 g N lost/kg protein.[206] The difference between pulses and other commonly consumed "protein foods" was stark: fish and poultry had a six-fold greater N factor than pulses; milk, cheese, eggs, and pork had a 9-fold greater N factor, and beef had a 17-fold greater N factor.[206] Another study found that the production of one kilogram of pork yielded a six times greater eutrophication potential and required 3.4 times as much fertilizer as the same amount of dry peas. [207]

Pesticide use

Pesticide use varies greatly among legumes. Depending on the seed variety, soil type, and growing conditions, pulses can be vulnerable to several different fungal diseases, including ascochyta blight, leading to the use of fungicides in conventional systems. Selection of more resistant varieties for planting helps reduce the need for fungicides. A variety of other herbicides, seed treatments, insecticides, and fumigants are approved for use in pulse production and storage operations but the specifics of their use differs with region, soil type, and cropping system particulars.[208] Although dry beans and peas generally have low levels of pesticide residues themselves, a number of these pesticides have been associated with farmworker poisoning, long-term chronic health problems for farmworkers and people who live near farms, water contamination, and wildlife and pollinator toxicity.[209]

28,656 acres of dry beans and 17,887 acres of dry peas and lentils were grown organically in 2011 (2.3% and 1.4% of total acres planted in those crops, respectively).[210,211] Without using chemical insecticides, herbicides, or fungicides, weed control and fungal diseases are challenging, but organic operations use well-designed crop rotations and production practices to maintain yields.

Conventional soybean farmers have long used a variety of pre- and post-emergent herbicides, insecticides, and fungicides to control weeds, insects, and fungi, respectively. Since the development of the first genetically modified crops in the early 1990s (see Sidebox, p.20), farmers have rapidly adopted the use of herbicide-tolerant (Ht) varieties,[q] which comprise over 94% of soybean acres now planted in the United States. Glyphosate-tolerance is the most common Ht variety of soybeans. Consequently, glyphosate is the top pesticide used on soybeans in the United States, with over 100 million pounds applied to 89% of planted acres in 2012, followed by chlorimuron-ethyl (11%), 2,4-D, 2-EHE (11%) and flumioxazin (11%).[212] Insecticides were applied to 18% of soybean acres and fungicides to 11%. Many pesticides approved for use in conventional soybean production are associated with long-term chronic health problems for people who work on and live near farms, water contamination, and wildlife and pollinator toxicity.[213]

Organic soybeans were planted on 132,411 acres, comprising 0.18% of the total soybean acres planted in the United States in 2011.[210,211] The vast majority of these organic soybeans are used to produce whole soy foods for human consumption like tofu, tempeh, and soymilk.

It is more efficient to consume plant protein directly rather than use it to feed livestock. Farm animals eat fairly large amounts of plant-based feed compared to the smaller amount humans need to receive the same amount of calories and protein. This animal feed is derived from crops that were sprayed with pesticides, thus meats and other animal products can have more pesticides embedded throughout their production process than associated with crops for direct human consumption. For instance, one study found that producing one kilogram of pork involved 1.6 times as much pesticide use as the same amount of dry peas.[207] Another study found that meat protein required six times more biocides (pesticides and disinfectants) to produce than the same amount of soybean-based vegetable protein.[203]

Biodiversity and ecosystem function

Legume-supported cropping systems significantly impact agricultural biodiversity both above and below ground. Through their capacity to fix nitrogen into soil (through symbiotic relationships with microorganisms), legumes may enhance soil biodiversity by increasing microbial biomass and activity in the soil, although this depends on management practices including soil disturbance (e.g., tilling), chemical pest control, nutrient (e.g., fertilizer) inputs, and duration of cropping.[165] Soil biodiversity promotes resistance and resilience against disturbance and stress, improves water and nutrient use efficiencies in crop production, and suppresses soil-borne disease.[224] By improving N availability and soil structure and chemistry as well as increasing the structural complexity of vegetation (indirectly increasing pollination services and habitat availability), legume cropping may also improve above-ground vegetative and invertebrate biodiversity.[165]

Additionally, legumes can benefit an entire agricultural operation in various ways when planted as components of multiple cropping systems—e.g. intercropping, crop rotation,

q There are no insect-resistant (i.e., Bt) varieties of soybeans as there are with corn and cotton.

and agroforestry.[165] These systems feature diversity rather than monoculture. Animals in appropriate numbers for the scale and region of the operation can also be introduced and, when managed properly, add value. Collectively, an integrated crop-animal system may improve the use of resources (e.g., energy, light, and water), soil fertility, and yields, while also diminishing risks of crop failure.[163]

SOCIAL JUSTICE CONSIDERATIONS

Many soy-based meat analogs and other foods containing isolated soy protein are processed with hexane.[225] This solvent is a neurotoxin and highly explosive, posing serious health and safety risks to workers in food processing plants. It is also a hazardous air pollutant, contributing to the formation of ground-level ozone and its associated health impacts (p.11). U.S. Department of Agriculture organic regulations restrict the use of hexane in food processing, though only soy products with the USDA organic seal guarantee its absence (foods "made with organic ingredients" may still utilize ingredients extracted with hexane).

Workers on pulse and soybean farms often experience poor working conditions, inadequate labor rights, substandard wages and housing, and high rates of occupational injuries and health hazards similar to other farmworkers in the United States (pp.12–13).

HERBICIDE-TOLERANT CROPS

Ninety-four percent of soybean, 89% of cotton, and 89% of corn acreage planted in the United States are now genetically modified (GM) to be herbicide-tolerant,[a] meaning the crop is not harmed when using "broad-spectrum" herbicides that kill a wide range of weeds in a single quick application.[214] Herbicide tolerant (Ht) crops may also reduce the need to till fields, theoretically lowering soil erosion and carbon emissions, though conservation tillage is not always linked to Ht crops in practice.[215-217]

Glyphosate-tolerance (i.e., "Roundup Ready") is the most common variety of Ht crops.[218] After decades of glyphosate use in corn-soy rotations, the growth of "superweeds" resistant to the herbicide have become a growing problem. To counteract this problem, some farmers have been applying more and multiple herbicides, leading to what some refer to as an "herbicide treadmill."

A recent study found that the use of Ht crop technology led to a 239 million kilogram increase in herbicide use in the United States between 1996 and 2011 compared to what would have been applied in the absence of Ht crops.[218] Soybeans accounted for 70% of the total increase across the three Ht crops. Even accounting for decreased insecticide applications due to the use of Bt crops (another GM trait – see footnote below), overall pesticide use increased by about 7%. New varieties of "stacked" GM soybeans which combine resistance to both glyphosate and 2,4-D (Enlist Duo) or dicamba (Roundup Ready Xtend) were recently approved and entered the market in 2016. Some fear these new additions could lead to the development of multi-herbicide-resistant superweeds.[219]

Significant debates exist over health impacts related to these herbicides. The International Agency for Research on Cancer (IARC) classified glyphosate as "probably carcinogenic to humans" and 2,4-D as "possibly carcinogenic to humans" in 2015 based on evidence of human exposure and animal experiments.[220,221] Other review panels convened by the U.S. Environmental Protection Agency (EPA), European Food Safety Authority, and United Nations Food and Agriculture Organization (FAO) and World Health Organization (WHO) have recently disagreed with IARC's classification regarding glyphosate, concluding that glyphosate is unlikely to cause cancer in humans.[222]

A recent study has also raised concerns about the potential contribution of these herbicides to the growing antibiotic resistance crisis, as low levels of dicamba; 2,4-D; and glyphosate were found to induce antibiotic resistance in *E.coli* and *Salmonella* bacteria, and certain combinations of the three herbicides could cause even greater effects.[223] While these herbicides were not found in sufficient quantities to induce antibiotic resistance through food consumption, they could lead to resistance developed among farmworkers, nearby residents within a "spray drift" range, and honeybees (which are sometimes treated with antibiotics to cure bacterial infections).[223]

a Herbicide tolerance is one type of GM trait; others include insect resistance (through the insertion of the gene for the soil bacterium Bt, *Bacillus thuringiensis,* which is toxic to certain insects), virus resistance, drought tolerance, micronutrient biofortification, growth promotion, and consumer benefits. Traits for herbicide tolerance and insect resistance comprise 99% of the acres of commercially available GM crops planted over the past 20 years.[216,217]

NUTS AND SEEDS

Tree nuts are defined as "a hard-shelled dry fruit or seed with a separable rind or shell and interior kernel."[226] This report focuses on the most commonly consumed nuts in the United States: peanuts, cashews, almonds, pistachios, pecans, and walnuts,[227] though in some cases it highlights considerations for alternatives to common nuts like seeds (e.g., sunflower, pumpkin/pepita, sesame, hemp, chia) that may be more affordable, less allergenic, and less-resource intensive. Although peanuts are actually a legume, not a tree nut, they are typically categorized as a nut due to their nutrient profile similarities[228] and therefore are included in the broad category of "nuts" in this report.

A large proportion of nuts available in the United States are produced domestically. California supplies nearly 100% of the country's almonds, walnuts, and pistachios,[229] and a significant proportion of these nuts globally (including 82% of the world's almonds and around 40% of its pistachios). Georgia, Florida, and Alabama supply the majority of peanuts.[230] Georgia is the country's primary producer of pecans.[231] Most cashews, however, are imported from Vietnam and India.[169,232] With the exception of sunflower seeds, which primarily come from North and South Dakota,[233] most of the edible seeds in the United States are imported. Sesame seeds mainly come from India and Guatemala,[169] hemp seeds from Canada (though as domestic production begins with recent state legislation, this will likely change[234]), and chia seeds from Argentina and Bolivia[235] (domestic production is also beginning[236]).

While demand for most nuts has remained relatively stable, Americans now consume over five times as many almonds per capita as in 1965, and almonds recently surpassed peanuts as the most eaten nut (as a snack, not including nut butter) in the country.[237] California nut production has responded to meet rising domestic and global demand. The number of acres planted with bearing almond trees has increased from 100,000 acres in 1964 to 590,000 in 2005 to 870,000 in 2014.[238,239] Pistachio production has more than doubled since 2005 (from 105,000 to 221,000 acres) and walnut production has increased by a third (from 215,000 to 290,000 acres).[239]

HUMAN HEALTH CONSIDERATIONS

Nuts are nutritional powerhouses. Although nuts are high in dietary fat, these unsaturated fatty acids and monounsaturated fats are essential to healthy body function. Described as a "heart healthy" food due to their protective effects against coronary heart disease and diabetes,[240] nuts are rich in macronutrients such as protein and fiber, as well as potassium, calcium, iron, phosphorus, zinc, copper, and thiamin.[227,228] Certain nuts and seeds including walnuts, flax, chia, and hemp seeds are also notably high in the omega-3 fatty acid, ALA.[241] Additionally, nuts are an efficient way of reaching adequate intake of vitamin E and magnesium, for which the majority of Americans do not meet the recommendations.[227] Nut consumption has also been negatively correlated with both total and cause-specific mortality, meaning that eating nuts can decrease one's risk of death due to diseases such as cancer, heart disease, and respiratory disease.[242]

Due to the high prevalence of nut allergies in the United States, serving nuts in cafeterias could be hazardous. Peanut and tree nut allergy is the leading cause of fatal allergic reactions in the United States and prevalence is also on the rise.[243] Thus, this protein alternative may be an unrealistic or unsafe meat replacement in some settings and for some people.

Most seeds are not common allergens, and sunflower seed "butter" is becoming an increasingly common and affordable alternative to peanut or almond butter.[244] Sunflower seed butter is also an excellent source of magnesium, phosphorus, copper, manganese, and selenium, and a good source of protein, zinc, and niacin.[244] Tahini, a paste made from sesame seeds, is also rich in nutrients including niacin, thiamin, calcium (particularly in unhulled tahini), iron, and phosphorus, though it is typically not consumed in similar recipes as other nut or seed butter.[245] While nut and seed butter contain relatively similar amounts of calories and grams of fat per serving, they differ with regards to their fatty acid composition (e.g., the proportions of saturated, monounsaturated and polyunsaturated, including omega-3 and omega-6, fatty acids).[244]

Peanuts, tree nuts, and some seeds[r] are often contaminated with aflatoxins, a family of natural toxins produced by a certain species of mold in warm, humid conditions. Chronic, sub-lethal exposure to aflatoxins has been shown to cause liver cancer in humans (particularly among those infected with hepatitis B).[246,247] Though the risk for aflatoxin harm is small in the United States compared to countries where groundnuts are dietary staples, it is not insignificant.[248] Aflatoxins often accumulate

r Other grains, animal foods, and spices are also susceptible to aflatoxin contamination.

during food storage. Consumers Union research from 2002 found that peanut butter that is ground fresh in health food stores (which may be stored in conditions ample for fungal growth and have infrequent turnover) has higher aflatoxin levels than its highly-processed and regulated conventional counterparts.[249] Organic foods may also be more likely to be contaminated with aflatoxin due to the avoidance of synthetic fungicides in organic farming methods.[250]

ENVIRONMENTAL HEALTH CONSIDERATIONS

Research on the environmental impacts of nut production is limited compared to that of other food categories. While nuts have relatively low GHG, land use, and N footprints per serving, significant amounts of water and pesticides are used in their production.

Climate change

The carbon footprint of nut production is relatively low compared to that of other foods, particularly meat. A review of LCAs found that the global warming potential (up to the point of retail) for tree nuts ranged from 0.43 – 3.77 kg CO_2-eq/kg, with an average global value of 1.42 kg CO_2-eq/kg.[50] Chestnuts had the lowest GHG-intensity (.43 kg CO_2-eq/kg), while sunflower seeds, cashews, walnuts, pistachios, and almonds all had relatively similar average values (1.41 – 1.74 kg CO_2-eq/kg). Because of their status as legumes, peanuts required only 61% of this footprint (0.87 kg CO_2-eq/kg). Because this data was only available on a per kilogram of product basis, it is difficult to directly compare to other food groups, since nuts are not typically consumed in similar volumes as other meat and animal products. Further research that provides this data on a per serving[s] or per kilogram of protein basis would offer a more meaningful comparison to other food groups.

The effects of climate change, coupled with California's drought conditions pose challenges for future almond production. Successful agricultural production of almonds relies heavily on cooler winter temperatures, known as "winter chill," which are vital for producing homogeneous and economically sufficient yields.[251] With average temperatures on the rise, declining crop yields, crop quality, or even complete crop failures may result.[251] In fact, the number of safe winter chill hours in Central Valley, the primary nut growing region of California, is predicted to decrease 30-60% by mid-century (compared to 1950 levels) and by up to 80% by the end of the century.[251] Additionally, higher average temperatures have caused snowmelt from nearby mountains to decline, requiring many nut growers to tap into ground water wells from which the water supply is already diminishing.[252]

Land use

There is limited information available on the land use involved in nut production, making it difficult to assess this aspect of nuts' environmental impact. One study found California almond production required 21.2 square meters of land to produce per kilogram of protein, which was greater than kidney beans (15.5), but less than chicken (32.2), eggs (37.6), and beef (282.6). It did not differentiate this land use based on cropland and pasture.[253]

Water use

Arguably the largest environmental impact related to nuts concerns the amount of irrigation water needed to produce them, especially for those grown primarily in drought-ridden California. These concerns have been amplified among recent reports of rivers being diverted (threatening endangered salmon) and aquifers being over-pumped to irrigate almond orchards, which require steady supplies of water even during droughts in contrast to crop fields which can lie fallow.[254,255] Most articles on this topic discuss almond production, though pistachios and walnuts carry similar vulnerabilities as production acreages increase while the state's drought causes surface water deliveries to fall.[256] Consequently, yields have declined for both almonds, due to kernel size and weight decrease, and walnuts, due to a sets-per-tree decrease.[229]

Based on global averages, nuts have the highest water footprints per unit of protein (139 L/g protein) compared to pulses (19), eggs (29) milk (31), chicken (34), pork (57), and beef (112).[76] A relatively high proportion of this global footprint (15%) comes from its blue water footprint related to nuts' irrigation needs. Seven and half percent is related to its gray water footprint, while its green water footprint comprises the other 77%. Chestnuts, peanuts, and walnuts have substantially smaller water footprints than almonds, cashews, pistachios.[73,257] Another study, however, found that California almonds specifically have a green plus blue water footprint of only 23 L/g protein, compared to a beef protein water footprint of 109 L/g protein.[253]

More research is needed to clarify these large discrepancies between the global average and California-specific water footprints. Part of the discrepancies may stem from increased irrigation efficiencies, as 70% of California almond producers now use micro-irrigation, which uses 20-25% less water than conventional sprinkler systems by delivering small amounts of water directly to plants' roots.[258,259] These improvements have meant that although almond acreage has increased by 67% since 2000,[260] the amount of irrigated farmland in California has remained relatively constant.[256] It is also worth noting that alfalfa production for animal feed (predominantly used

s Preliminary results from a forthcoming study indicate that nuts and seeds have an extremely low average climate impact per serving, only slightly higher than pulses and soy.[445]

to feed dairy cattle in the state but also for export to China) requires even more of California's water supply resources (15%) than almond production (10%) – and over 30% of the state's agricultural water use directly or indirectly supports animal production, so nuts are not the sole food product of concern in the California water crisis.[261]

Fertilizer use

Research on the amount of fertilizer used to produce nuts is relatively limited. One study found that nuts, on par with pulses, have the lowest amount of N_r lost to the environment through fertilizer application, food processing, and consumer food waste per kilogram of protein consumed (virtual N factor).[262] Fish and poultry had a six-fold greater N factor; milk, cheese, eggs, and pork had a 9-fold greater N factor, and conventional beef had a 17-fold greater N factor.[262] There are currently no comparisons of the amount of mined P fertilizer required to produce different types of food per serving or per unit of protein consumed. A comparison based on mass of the food (which has limitations given that people do not consume similar volumes of food per serving across food groups – see p.14) shows that tree nuts require about 17 times as much P per kilogram of food as pulses and starchy roots, twice as much as grains, 1.5 times as much as milk, half as much as eggs, a third as much as poultry meat, 22% of pork, and 11% of beef.[263]

Pesticide use

There is limited research on the impacts of pesticide use in nut agriculture. Cashew production in India relies heavily on endosulfan, a highly toxic pesticide associated with numerous health disorders for villagers living near farms where it has been aerially sprayed.[264] The pesticide is illegal in over 80 countries and it is being phased out by 2022 in India.[264] California-grown nuts are also heavily treated with pesticides, with almonds second to wine grapes as the crops treated with the greatest amount of pesticides in 2014.[265] The rise of the almond, walnut, and pistachio industries have been accompanied by a significant growth in the number of acres treated with fungicides, herbicides, and insecticides.[265] Glyphosate is the most common pesticide used on nuts (nuts represent nearly half of the total acreage treated with this herbicide in California) and has been increasing due to the development of herbicide-resistant "superweeds" (see Sidebox, p.20).[265] Another pesticide of concern, chlorpyrifos, are also heavily used in California almond and walnut production,[265] despite being recently classified as a California restricted material for their associations with adverse neurodevelopmental effects, endocrine disruption, and lung cancer, with the risks disproportionately experienced by farmworkers and their families, rural school children, and other residents.[266,267] A number of other pesticides approved for use in almond, walnut, pistachio, peanut, cashew, pecan, chestnut, and hazelnut production have been associated with farmworker poisoning, long-term chronic health problems for farmworkers and people who live near farms, water contamination, and wildlife and pollinator toxicity.[268] One study found that pesticide use was the only category of inputs in which almond production was more resource-intensive than beef production,[t] with a pesticide ratio of 103.6 grams (almonds) to 93 grams (beef).[253]

Pesticide use varies greatly depending on production practices. In a paper assessing the sustainability of various Florida crops, Florida pecans were given a moderate sustainability score due to the advancement of sustainable pest control methods, such as using ladybug beetles to control aphids and using leguminous cover crops to control or maintain other pest populations.[269]

Biodiversity and ecosystem function

The almond industry has also been implicated in the collapse of pollinator populations. 1.4 million colonies (about 60% of the country's managed colonies) are transported across the country to California each year to pollinate almond trees during the spring.[270] According to the Pollinator Stewardship Council, up to 25% of these "mercenary pollinator bees" were damaged by the end of the 2014 almond bloom, due to the mixed spraying of pesticides and fungicides on the almond trees.[271] Given that almond pollination represents a significant proportion of beekeepers' incomes (more than selling honey), improved transparency and management practices around pesticide use by almond producers are necessary to maintain the codependent relationships of these industries.

SOCIAL JUSTICE CONSIDERATIONS

Recent reports have brought attention to the poor working conditions and inhumane treatment of workers involved with cashew production in Vietnam and India.[272] In the difficult process of extracting cashew nuts from the shells, workers are exposed to two corrosive chemicals: cardol and anacardic acid.[273] Moreover, contact with cashew resin can cause itching and burning of the skin.[274]

In India, thousands of workers have gone on strike for higher pay, as most currently earn $2.50 for a ten-hour day.[273] In Vietnam, thousands of noted drug users (though a fraction of the country's total cashew producers) are forced into cashew production as "treatment" for their addiction.[274] In these "treatment centers," that offer no legitimate form of therapy or treatment, workers must meet a daily quota of cashews to husk and peel, typically 4,800 nuts, requiring work of up to six or seven hours below the minimum wage.[275] Even more alarming are workers' reports of physical abuse in the form of electric shocks, beatings, and being locked in "punishment rooms."[274]

t This accounts only for pesticide use to produce animal feed. It does not account for insecticides used to control pests on animals directly.

Relatively few labor concerns have been implicated specifically in domestic nut production, however, poor working conditions, inadequate labor rights, substandard wages and housing, and high rates of occupational injuries have been reported by workers on nut farms similar to other farmworkers in the United States (see pg.12-13). These include 370, 79, and 22 reported incidents of acute farmworker pesticide poisoning in Californian almond, walnut, and pistachio production, respectively, from 1992-2010.[268] Additionally, N contamination of groundwater from intensive nut production contributes to California's water crisis,[276] which disproportionately harms low-income Latino farmworker communities.[277,278]

LIMITATIONS

Research on the environmental impacts of nut production is limited compared to that of other food categories, and relative to evidence about the health impacts of their consumption. The majority of research regarding the relationship between nut production and environmental health focuses on almond agriculture's water use and vulnerabilities due to California's drought. Information is relatively lacking on the water use, especially region-specific, of other nuts and seeds. Although there is a growing amount of research regarding the GHG emissions resulting from nut production, data and relevant units vary, making it challenging to compare results across studies. Lastly, further research is needed on the land and pesticide use involved in nut production.

Pecan plant. Florida pecans were shown to incorporate sustainable pest control methods (Nodigio/flickr)

EGGS

While many different types of eggs are consumed, including duck, quail, roe, and caviar, chicken eggs are by far the most commonly consumed eggs in the United States and are the focus of this section. Prior to World War II, most eggs in the United States came from a large number of producers with small flocks (<400 hens).[279] With the adoption of new technologies and a consolidated, specialized industry, egg production has intensified incredibly over the past half-century and, though remaining slightly lower in per capita availability, has more than doubled in terms of total production volume.[279,280] Raising over 100,000 hens at one facility is now common; 77% of laying hens in the U.S. are located on such farms,[281] with some farm flocks totaling over five million hens.[279] The United States is the third largest egg producer in the world, after China and the European Union.[282] In 2015, commercial farmers in the United States produced over 95.7 billion table eggs for human consumption from a flock of 330—366 million laying hens at any one time.[283] Approximately half of laying hens are located in only five states: Iowa, Ohio, Indiana, Pennsylvania, and Texas.[283] There are very few exports or imports in the U.S. egg market.[282,284]

Eggs are produced in a number of different housing systems including cages (e.g., battery cages and enriched colony cages), aviary operations (i.e., barn-raised), free-range, and pasture-raised.[u] The vast majority of commercially sold eggs produced around the world, with the exception of a few countries in the European Union, are laid by caged hens.[282] A recent industry estimate indicates that 94% of eggs in the United States come from caged hens.[285] Conventional battery cage operations house 200,000 hens per site, while enriched colony and aviary operations house 50,000 hens.[286] Free-range and pasture-based systems are relatively small scale and niche operations in the United States,[282] with an average of 300 hens/farm documented in one study of California pasture-based farmers.[287] Increasingly, institutions, retailers, and consumers are demanding eggs that do not come from battery cages, and due to these pressures (and legislation in certain states—most notably, California), many operations are transitioning to either cage free barn-raised aviaries or to enriched colony cages, which include perches, nesting areas, and material to encourage foraging and dustbathing.[282] Both of these housing systems may also include deep-litter bedding which allows animals to express more of their natural behaviors, absorb manure, and provide warmth for animals in cold weather.[24]

In the past few years, some companies have begun developing and marketing plant-based egg substitutes, intended to replace eggs in processed foods such as mayonnaise, cookie dough, and other baked goods. While these may provide environmental, health, and social benefits compared to traditional egg-based products,[288] no peer-reviewed research currently exists assessing these alternatives.

EGG HOUSING SYSTEMS

Battery cages: The conventional housing system for 94% of hens in the United States which confines hens in indoor cages (<80 square inches/hen), preventing them from performing natural behaviors including perching, nesting, foraging, and even spreading their wings. Conventional operations house hundreds of thousands of birds in one facility and over five million in some operations.

Enriched colony cages: Provide hens more freedom of movement than conventional battery cages (116 square inches/hen) and raise hens in smaller groups (60 hens/cage) than cage-free aviaries to reduce natural aggressions. They include perches, nesting areas, and material to encourage natural behaviors such as foraging and dustbathing. Typical operations house about 50,000 hens.

Cage-free barn-raised aviaries: Hens are housed indoors and can roam freely in an open floor area and multiple floor levels where they can perch, scratch, forage, nest, and dustbathe. Hens are raised in flocks with around 50,000 hens and do not necessarily have outdoor access. They have about 144 square inches of floor space per hen.

Free-range: Hens are provided outdoor access, though third-party certification systems vary in terms of minimum outdoor time (from no minimum to at least six hours/day) and space (from 288 to 3,139 square inches) requirements. The outdoor area does not necessarily need to have any living vegetation.

Pasture-raised: Hens can range and graze on pasture (covered by substantial amounts of growing vegetation) to supplement their grain-based diet. Third-party certification systems vary in terms of minimum outdoor time (from no minimum to at least six hours/day) and space (from 576 to 15,552 square inches) requirements. These are relatively small scale and niche operations in the United States, averaging about 300 hens/farm.

Sources: Coalition for Sustainable Egg Supply (2016) and the Humane Society of the United States (2016)

u In contrast to ruminants such as cows, who can rely solely on grasses and pasture for food, pasture-raised hens are still fed a grain-based diet; it is merely supplemented when they graze pasture.[76, 284]

HUMAN HEALTH CONSIDERATIONS

Eggs contain a number of important nutrients, including choline, selenium, biotin, B vitamins (including B12), iodine, molybdenum, and omega-3 fatty acids. While the egg white contains most of the protein found in an egg, the yolk contains most of its other key nutrients, including omega-3 fatty acids; fat-soluble vitamins A, D, E, and K; carotenoids, most other B vitamins, and choline. Choline is critical for preventing liver disease, atherosclerosis, and possibly neurological disorders, and egg yolks are the most concentrated source of the nutrient in American diets.[289,v] The Institute of Medicine recommends adult women consume 425 mg of choline per day (and men, 550 mg/day), though most Americans fall short of this recommendation. One large egg contains 125 mg of choline.

One egg also contains 212 mg of cholesterol. Previously, health experts recommended limiting egg yolk consumption to keep dietary cholesterol intake less than 300 mg/day, as it was believed that dietary cholesterol intake was linked to higher blood cholesterol levels (a risk factor for cardiovascular disease). A growing number of studies have shown that moderate egg consumption is not likely to lead to an increased risk of cardiovascular disease and mortality for the general population.[290] Thus, the most recent 2015 Dietary Guidelines for Americans removed its claim that cholesterol is a "nutrient of concern for overconsumption" on the grounds that there is not adequate evidence to support a quantitative limit, though it still encourages eating patterns relatively low in dietary cholesterol.[47] Some experts have advised a more cautious approach to dietary cholesterol intake that acknowledges that for certain populations, egg consumption could play a role in the development of diabetes for those who are at risk, cardiovascular disease in those with diabetes, and worsening coronary risk factors for "hyper-responders to dietary cholesterol" (about 25% of the population).[291] Others have questioned the fact that most of the studies (11/12 in one highly influential review) refuting eggs' influence on raising blood cholesterol levels have been funded by the egg industry.[292]

The nutrients found in an egg vary based on the feed consumed by the hen. Hen feed is increasingly being enriched with omega-3 fatty acids from flaxseed (which increases egg yolk concentrations of ALA, and also, to some extent, DHA that hens convert from ALA), fish oil or microalgae (both of which yield eggs rich in DHA and, to a lesser extent, EPA).[293] Studies have found that consuming these omega-3 enriched eggs, which can contain up to 200 mg of DHA per yolk (health organizations suggest a minimum of 250-500 mg/day of DHA+EPA[294]), may lower risk factors for cardiovascular disease.[293] A few studies have also demonstrated that raising hens on pasture, where they can graze legumes rich in omega-3 fatty acids (e.g., clover, alfalfa) and grasses can also double DHA concentrations (providing 150-169 mg per yolk) in eggs compared to conventionally fed caged hens.[295,296] Pasture-feeding hens, particularly of grass, can also more than double the vitamin E content of egg yolks.[295]

ENVIRONMENTAL HEALTH CONSIDERATIONS

Climate change

Eggs have a relatively low GHG emission profile. Per kilogram of protein, eggs have a GHG emissions profile (15 – 42 kg CO_2eq/kg protein) relatively comparable to milk (28 – 43 kg CO_2e/kg protein), chicken (10 – 30 kg CO_2eq/kg protein) and pork (20 – 55 kg CO_2eq/kg protein).[3,60,61] However, when comparing climate impacts *per serving*, eggs require less than half the GHG emissions as dairy, poultry, and pork, though legumes retain the lowest profile by far.[3] Some studies have found slight differences in climate impact based on the type of production system: free-range eggs have a modestly (10 – 18%) larger GHG footprint than caged eggs,[297,298] but these increases are generally outweighed by eggs' much lower relative footprint than dairy and meats. Some suggest that deep-litter cage systems hold the greatest potential for improvements in reducing emissions than conventional battery cage systems.[297]

Land use

A review of four LCAs of eggs found that eggs require about 29—52 m^2 per year to produce per kilogram of protein, roughly the same amount of land to produce as chicken (23—40 m^2/kg protein), milk and cheese (26—54 m^2/kg protein), and pork (40—75 m^2/kg protein).[61] In contrast, beef production requires 37—2100 m^2/kg protein. This specific review did not differentiate based on cropland vs. pasture needs, though other studies have noted that the land footprint of layer hens, even pasture-raised ones, relies entirely on cropland (~76% from corn grain, and 24% from soybean meal).[299] When looking at solely the cropland required for annual feed crop production, meat cattle, chickens (both broilers for meat and layer hens for eggs), hogs, and turkeys require relatively similar amounts, whether compared per unit of edible energy or per unit of protein.[299] Milk production requires roughly half as much annual cropland per unit of edible energy and a third less per unit of protein.[299]

Due to the high density/concentration of battery cage systems, these systems have a lower land use footprint; to raise the same number of hens without cages requires four times the land area needed in conventional cage systems.[300] These "efficiencies," though, must be considered in light of serious concerns about animal welfare. In addition, integrated crop-animal systems such rotational grazing of chicken in cropland can offer benefits such as pest control, even distribution of manure, and decreased need for inputs including feed, fertilizer, and pesticides.[301]

v Other dietary sources of choline include chicken, turkey, salmon, shrimp, soy beans, chickpeas, beef, lentils, scallops, cod, collard greens, broccoli, and Brussels sprouts.[145]

Water use

Per kilogram of protein, the global average water footprint for eggs (similar to milk and chicken meat) is approximately 1.5 times larger than for pulses.[76] The largest proportion of the water footprint comes from green water (79%), followed by 13% from gray water and 7% from blue water. The water footprint associated with grazing/pasture-based poultry (and consequently, their eggs) is generally higher than that of mixed or industrial/caged systems, due to a lower feed conversion efficiency.[72]

Fertilizer use and eutrophication potential

The manure from laying hens is either collected, dried, and stored to be later applied to cropland as fertilizer or soil amendments, or—in the case of pasture-raised hens—is directly excreted onto pastures. Poultry manure enhances soil fertility and improves crop and/or pasture growth, however, proper management is essential to avoid excessive application or runoff from rainfall, even in pasture-based operations.[300] Phosphate is of particular concern, given that poultry manure has relatively low levels of nitrogen (N) compared to phosphorus and plants need about eight times more N than phosphorus (P). Thus, when applying poultry manure to cropland to meet the N requirements of plants, P concentrations and loads can build up and run off into nearby freshwater systems. Phosphate runoff—and its eutrophication implications—is the biggest water quality issue related to hen management.[300] There are currently no comparisons of the P footprint for different types of food per serving or per unit of protein consumed. A comparison based on mass of the food (which has limitations given that people do not consume similar volumes of food per serving across food groups – see p.14) shows that eggs require significantly more mined P fertilizer to produce than pulses (31 times more), milk (nearly three times more), and tree nuts (nearly twice as much), but less than poultry (66% as much), pork (40% as much), and beef (21% as much).[95]

Nitrogen runoff from manure, in addition to N losses that occur to produce the feed animals consume, is also a concern. One study comparing the amount of N_r lost to the environment per unit of protein consumed (virtual N factor) for various food groups found eggs to have a virtual N factor of 608 g N lost/kg protein, which was higher than pulses and nuts (64), fish (416), poultry (432), and milk and cheese (576), though equivalent to pork (608) and almost half of beef (1104).[206]

One LCA review looking more closely at different egg production systems found that more intensive industrial/caged systems had slightly lower eutrophication potential than cage-free systems from phosphate and nitrate leaching per kilogram of eggs.[60]

Pesticide use

Layer hens depend on feed comprised solely of corn and soy,[299] and thus producing their feed contributes to the increasing rate of glyphosate use (the "pesticide treadmill") in corn and soy monocultures to control the development of herbicide-resistant superweeds (see p.20). Given the relatively efficient feed conversion ratio of chickens compared to ruminant animals, the pesticide use per output of poultry products is lower than for larger animals fed similar crop-based feeds. One study comparing the environmental impacts of producing different protein foods found that one kilogram of eggs required 12.7 g of pesticide inputs, only slightly higher than the same amount of kidney beans (8.9 g), lower than chicken meat (15.5 g), and substantially lower than beef (93 g) and almonds (103.6 g).[253]

Antibiotic use

Antibiotics are used to increase egg production and improve feed efficiency among layer hens on intensive farms, though consumer and advocacy groups may not monitor the use of antibiotics as closely in this species as they do for other food animal species. Medically important antibiotics approved by the FDA for use in egg layers include Erythromycin Thiocyanate, Bacitracin Zinc, and Bacitracin Methylene Disalicylate.[302]

Biodiversity and ecosystem function

Layer hens depend on feed comprised solely of corn and soy,[299] thus their production is directly implicated in biodiversity concerns (along with other health and ecological concerns) related to monoculture crop production and heavy agrochemical usage (p.20). Pasture-based hen operations vary greatly in terms of which breed types are raised, which may help counteract trends towards genetic uniformity in livestock breeds.[287] When integrated into a crop-livestock farm, pasture-raised hens can also improve species richness on farms, pollinator habitats, and weed and pest management, through the benefits of adding pasture to crop farms and hens' consumption of weeds and insects (which decrease the need for external inputs of pesticides and the biodiversity harms associated with them).[303]

SOCIAL JUSTICE CONSIDERATIONS

The different production systems used to raise laying hens have varying impacts for farmers, farmworkers, and surrounding communities. One study found that European egg producers fared better economically from operations in which hens had outdoor access than other housing operations.[297] The higher costs associated with the feed, labor, and infrastructure needed to produce cage-free eggs do not always benefit producers, however. For instance, another study in the United States concentrating specifically on pasture-based operations found that only 50% of such operations were directly profitable to farmers.[287] The authors noted though that 78% of the pastured poultry farmers surveyed reported indirect profits due to attraction of new consumers; enhanced customer loyalty; and savings on fertilizer, fuel, and pest control.

Farmworkers also face different health and safety risks depending on the production system. Studies have found that workers in cage-free barns or aviary houses are exposed to significantly higher concentrations of airborne particles, ammonia, and endotoxin, which pose respiratory health risks, than workers in conventional or enriched houses.[286,304] The poorer air quality comes from the fact that many non-cage systems use litter bedding on the floor to collect manure instead of manure belts.[300] Given the lower stocking densities associated with these operations, ventilation is minimized to conserve heat during cold weather. However, less ventilation means ammonia emissions and airborne particulates from the manure and dust concentrations from the litter are higher than in non-cage systems. Elevated levels of ammonia also harm hens' health and decrease egg quality, and when released to the atmosphere, contribute to acid rain. Moreover, as with other animal farms (p.13), these increased air emissions can reduce air quality for nearby residents.

ANIMAL WELFARE CONSIDERATIONS

Industry practices for housing and treating laying hens have increasingly come under scrutiny over the past few decades. There are disadvantages for hen welfare associated with both conventional cage and non-cage systems.[282] The confined housing quarters and high density associated with conventional battery cage systems have been criticized for the restrictions they impose on hens' movement and behavior. Similar to broiler chickens (i.e., those intended for meat consumption), laying hens commonly have their toenails, spurs, and beaks clipped—often without anesthesia or other forms of pain relief—in industrial farms to control the animals' aggressive behavior when they are under extreme stress.[24] Beak cutting also occurs

Free-ranging chicken at a Midwest farm and portable coop. When integrated as a crop-livestock farm, pasture-raised hens can improve soil health and promote weed and pest management (Lindsey J. Scalera)

in many cage free and free range operations. Meanwhile, the primary concerns associated with non-cage systems relate to hen health. One study comparing the behavior of chickens found that those living in non-battery cage systems and who had outdoor access were better able to perform natural behaviors.[297] However, they were also at risk for new harms, including increased mortality from cannibalism and higher disease incidence. Better-managed farms were able to effectively reduce most of these additional risks. Additionally, hens from all systems are typically purchased from hatcheries that kill (often by live maceration or shredding) the hundreds of newborn male chicks hatched in the United States per year, though this practice will likely be phased out by 2020 with the application of sex-selective abortion technology.[305]

LIMITATIONS

Research on antibiotic use in layer hens as well as the environmental and social justice impacts of different hen caging systems is relatively limited. The impacts of plant-based egg alternatives should also be thoroughly assessed.

A woman weighs fresh local eggs at Tillian Farm Development Center in Ann Arbor, MI (Lindsey J. Scalera)

SEAFOOD

Americans consider the term seafood to encompass all edible aquatic life from both the ocean and freshwater sources, including fish, shellfish, and sea vegetables. Given that the impact of terrestrial vegetables is not thoroughly assessed in this report, sea vegetables (e.g., seaweed, algae) are also not assessed, though their relatively high concentrations of protein and other micronutrients may prompt further exploration as a meat alternative in the future.[306]

Fish and shellfish may be fished/hunted from wild fisheries or farmed in aquaculture facilities, either in ponds, near or off-shore enclosures in large lakes or oceans, or inland tanks. Given that most of the world's fisheries are now fully exploited, depleted, or recovering, and global catches have continued to decline since their peak in 1996,[307] aquaculture is becoming increasingly common. In fact, aquaculture now supplies approximately half of all seafood consumed by humans[307] and has surpassed global beef production.[308] Aquaculture is still relatively rare within U.S. seafood production: U.S. commercial fisheries landed approximately 7.8 billion pounds (3.5 million metric tons) of edible fish and shellfish, while freshwater plus marine aquaculture produced an additional 608 million pounds (276,000 metric tons) in 2014.[309] However, Americans consume a significant amount of aquaculture-produced fish given that 90% of the fish Americans consume (by edible weight) is imported, including domestic varieties processed overseas (and 41% of what is caught in U.S. commercial fisheries is exported).[309] This disparity comes from the fact *that the United States exports much of its highest quality, wild fish to other countries, and imports mostly farm-raised fish, both for cheaper prices and to satisfy the limited palate of American consumers compared to those in other countries.*[310] Less than two percent of imported seafood is inspected, raising concerns about the traceability of production, harvesting, labor, and food safety practices.[311] Thus, while such imports provide healthy and affordable nutrients for many Americans, this trade could be supporting industries harmful to human health, social justice, and environmental sustainability.

HUMAN HEALTH CONSIDERATIONS

The health benefits of fish and shellfish are largely based on their categorization as a lean fish, fatty/oily fish (e.g., large pelagic fish as well as small forage fish), mollusk or crustacean. Fatty fish and certain mollusks (e.g., Pacific oysters, mussels) are particularly high in the two "marine" omega-3 fatty acids EPA and DHA,[312] and dietary patterns incorporating regular fish consumption have been associated with a reduced risk of cardiovascular disease in adults and improved cognitive development in infants and young children.[47,313] Some have suggested a role for omega-3 in dementia prevention and improved cognitive function for older people, as well as decreased inflammatory-related conditions, allergies, and skin health, though the evidence supporting these health benefits is limited at this time.[314] Most fish and shellfish also provide good sources of protein, selenium, vitamins D and B12, taurine, choline, and iodine.[315] To achieve many of the health benefits associated with fish, the 2015 Dietary Guidelines for Americans recommend that the general population consumes at least 8 oz. (two servings) of a variety of fish and shellfish per week, including some fatty fish, to benefit from many of these different nutrients.

Some canned seafood (e.g., anchovies) may be high in sodium, so health experts recommend checking nutrient labels to choose lower-sodium options. Some shellfish, especially crustaceans, contain relatively high levels of dietary cholesterol, though recent advice indicates that this is not as much of a concern as once thought for the general population (see p.26).

DIFFERENT TYPES OF FISH

lean fish	fatty/oily fish	bivalve mollusks	crustaceans
demersal fish:	large pelagic fish:	clams	shrimp
cod	salmon	mussels	prawns
haddock	mackerel	oysters	crabs
pollock	trout	scallops	lobster
flatfish	albacore tuna		
	small forage fish:		
	sardines		
	herring		
	anchovies		

Pollutants from human industrial activities and agricultural pesticides often end up in streams, rivers, and oceans, causing heavy metals (e.g., mercury, cadmium, lead) and persistent organic pollutants (e.g., DDT, PCBs, dioxin, and some flame retardants) to accumulate in the tissues of aquatic animals and plants.[316] Some studies have found that farm-raised fish fed with wild forage fish have higher levels of persistent organic compounds like dioxins and PCBs than wild fish,[317] though a meta-analysis by the 2015 Dietary Guidelines Advisory Committee found no significant differences in the levels of mercury and dioxins in wild versus farmed fish. Despite the risks associated with consuming fish from any source, experts agree that in general, the benefits of fish consumption still outweigh the potential health risks from contaminants, but consumers should be aware of fish advisories, including in their states, and preferentially consume fish with lower contamination levels.[313,318,319] Even for the most at-risk consumers – pregnant or lactating women and young children – the FDA and EPA recommend a minimum of 8 oz. and maximum of 12 oz. of fish consumption per week, though they are encouraged to avoid fish with the highest levels of methyl mercury contamination: shark, swordfish, king mackerel, and tilefish.[320] Contaminants accumulate most heavily in older, larger, predatory fish, so eating fish lower on the food chain is an important way to limit exposure. As with other foods, experts also recommend eating a diversity of seafood to reduce contamination from a single source.[47]

The nutrients and contaminants in seafood may also vary based on whether it was farmed or wild-caught. Concerns have been raised about the fact that many of the nutritional benefits of seafood may not be as strong in fish raised via aquaculture compared to wild fish. However, a recent literature review of data from feeding trials and farmed/wild comparison studies found that farmed fish can share similar nutrient profiles as wild fish and may have higher total levels of polyunsaturated fatty acids (omega-3 + omega-6).[106] However, these profiles vary greatly based on the predatory status of the fish species and feed ingredients. The 2015 Dietary Guidelines Committee noted that farmed carnivorous fish (e.g., Atlantic salmon, rainbow trout, and cod) had equivalent or higher levels of EPA+DHA compared to wild fish due to supplemented feed, while herbivorous/omnivorous fish (e.g., tilapia, catfish, carp) had lower levels compared to their wild counterparts.[321] Additionally, compared to fish fed with feed derived from fish oil, farmed fish fed vegetable oil-derived feed (mostly herbivorous/omnivorous fish yet increasingly carnivorous species too) generally have lower relative fractions of omega-3s to omega-6s, which may not provide many of the health benefits associated with fish consumption.[106]

ENVIRONMENTAL HEALTH CONSIDERATIONS

While current dietary recommendations encourage increased seafood consumption (especially of oily fish), others have pointed out that these conflict with efforts to address declining wild stocks and marine biodiversity, especially in face of global population growth and socioeconomic and food security concerns for populations of poorer, fish-exporting countries.[313,322] Aquaculture systems do not mitigate these challenges, due to additional environmental impacts as well as constraints on their growth associated with their dependence on marine and terrestrial food supplies.[106,w] Moreover, there is not enough fish for everyone globally to consume as recommended for health benefits, even including the growth of aquaculture.[323]

The environmental impacts of fish and shellfish consumption are far from equivalent, however, as the diversity of harvesting and farming systems, as well as post-farm processing and transportation choices, lead to a wide variety of environmental impacts. Certain harvesting practices, most notably bottom-trawling in which nets are dragged across the ocean floor, have harmful implications for climate, biodiversity, and marine ecosystem integrity and function.

Aquaculture practices also range greatly. Bivalve mollusks, for instance, filter surrounding water to obtain nutrients and thus do not require feed or other inputs. Their filtering services also confer positive environmental benefits. On the other hand, farmed carnivorous finfish rely on feed made with wild fish, which provide superior nutritional profiles of farmed fish as previously discussed, but can further stress wild fish stocks.[106] Meanwhile, feeding fish terrestrial crops shares many similar ecological and social concerns associated with the production of other animal feed, especially as soy is the most used terrestrial aquaculture feed ingredient[324] (see p.20).

The development of recirculating aquaculture systems (which treat and reuse wastewater) and aquaponics systems (which combine recirculating aquaculture with hydroponic vegetable production) may provide some environmental benefits over conventional systems, though also have steep energy (and thus climate), labor, and feed costs.[325] This section summarizes the varying environmental impacts of different fish and shellfish species and harvesting/production systems.

Climate impact

The GHG emissions of fish vary the most of any other food group assessed in this report. On the lowest end of climate emissions are herring, pilchard, and certain mussels, which rival pulses and meat substitutes as some of the least-GHG intensive protein foods, responsible for about 4 kg CO_2eq/kg protein (up to point of retail).[61] At the highest end is trawled lobster, which requires 540 kg CO_2eq/kg protein, far higher than poultry, eggs, pork, or dairy (which range from 10—68 kg CO_2eq/kg protein) and higher than certain types of beef (industrial beef ranges from 45—210 kg CO_2eq/kg protein while extensive/pasture-raised beef range from 58—643 kg CO_2eq/kg protein).[61]

When comparing to other fish, global warming potential is often assessed based on the mass of edible fish. Pilchard, herring, pollock, carp, mackerel, and certain mussels all have GHG profiles (up to point of retail) around 1—2 kg CO_2eq/kg edible fish.[50,61] Tuna, sea bass, haddock, and cod average around 3 kg CO_2eq/kg edible fish, though these can be as high as 6 kg CO_2eq/kg edible fish.[50] Lobster has the highest climate impact, at up to 28 kg CO_2eq/kg edible fish.[50] Part of the wide variance relates to how fish are harvested. Fish caught through bottom-trawling—including lobsters, redfish, flatfish, cod, and hake—can have some of the highest climate impacts (nearly three times the GHG-footprint of non-trawled seafood in one review[3]).

w Resources (land, water, fertilizer) are not available to support an aquaculture industry that significantly increases in size unless accompanied by dietary shifts away from beef and pork to chicken and farmed fish and/or aquaculture production is expanded solely for species that do not require feed (oysters, clams, mussels, some types of carp, seaweed).

Some of these fish can also be caught or produced in other ways such as midwater trawling above the seabed (cod, hake), longlines (cod), traps (crustaceans like lobsters), or aquaculture (flatfish).[61] Midwater trawling generally takes significantly less energy, and therefore has a lower climate impact, than bottom-trawling or longlines.[326]

Farmed pangasius, a type of catfish, has a GHG-footprint of 3 kg CO_2eq/kg fillet, while farmed salmon and trout average around 4 kg CO_2eq/kg fillet (ranging from 2 – 8 or 6 kg CO_2eq/kg fillet, respectively).[50,61] Aquaculture farms using near or off-shore enclosures in the ocean (e.g., salmon, sea trout, sea bass) are relatively less energy-intensive than land-based recirculating aquaculture systems farming carnivorous species (e.g., salmon, turbot, trout, shrimp), which are energy-intensive and require high-protein feed. Tropical shrimp and prawn fisheries and farms also have relatively high climate impacts, with an average GHG footprint of 15 kg CO_2eq/kg edible fish.[50] Given that shrimp is the most popular type of seafood in the United States (representing 26% of per-capita seafood consumed, by mass[309]), this is an important impact to consider.

New, and still relatively rare, recirculating aquaculture systems have particularly high energy requirements and therefore climate impacts—higher than every other food group per serving except ruminant meat.[3] That said, they can provide other sustainability benefits including significant water savings (p.32), efficient use of land otherwise unsuitable for food production, and improved conditions for cultured fish such as enhanced feed conversion efficiencies and reduced risk of disease outbreaks.[325]

Though transportation accounts for only 11% of the GHG emissions associated with food products in general, it can play a relatively large role in seafood emissions (15-55%).[61] Air freight is the most energy intensive transport form, followed by truck transport, and then bulk shipping carriers which have the lowest energy use by far. These are important considerations to take into account when purchasing seafood, given its status as the most traded food commodity globally[327] and the high demand for fresh fish, whose perishability often necessitates air freight.[328]

In addition to contributing to global climate change, fish harvesting and production are also experiencing new vulnerabilities due to climate-related stresses on marine ecosystems and species including ocean acidification, rising water temperatures, and declining biodiversity.[329,330] Although fish stocks are expected to increase in some regions, the total impacts of climate change and ocean acidification, combined with other anthropogenic pressures (e.g., overfishing, habitat modification, and nutrient runoff/eutrophication discussed on p.11) will be severely negative on a global scale.[331] These factors contribute to the decline of wild fishing stocks, and also harm aquaculture operations through mortality of shellfish from acidic water, reduced catches of feed fish, increased severity of floods to fish and shrimp ponds in tropical coastal areas, and increased risk for disease in freshwater fish.[331]

Land use

Although one might not typically consider seafood to have a terrestrial land footprint (and indeed, many studies assessing diet-related land footprints leave out seafood[62,68]), the production of aquaculture feed increasingly relies on terrestrial crops for soybean meal (as a protein source to replace wild fish) and vegetable oils (e.g., soy, corn, canola, palm, and sunflower).[106] Farmed aquatic species generally have a superior feed conversion efficiency (lower or comparable to chicken, and significantly lower than hogs and beef cattle), which means that fewer feed inputs, and associated land use, are required to produce the same amount of animal protein.[106] One LCA review quantifying this impact found that farmed fish fed vegetal feed required between 13 – 30 m^2 of terrestrial land per year to produce the feed per kg protein, which was comparable to meat substitutes (4 – 25 m^2/kg protein) and dry pulses (10 – 43 m^2/kg protein), as the protein foods with the lowest land use requirements.[61] Only four percent of animal feed crops produced globally are currently used in aquaculture operations, but this is expected to continue increasing.[332] Experts do not expect an increase in aquaculture production to decrease demand for other forms of land-animal production, nor for an increase in terrestrial feed crops in aquaculture to reduce pressure on wild forage fish or total crop-based feed (from higher relative feed efficiency of fish), because of rising global demand for meat and fish.[106]

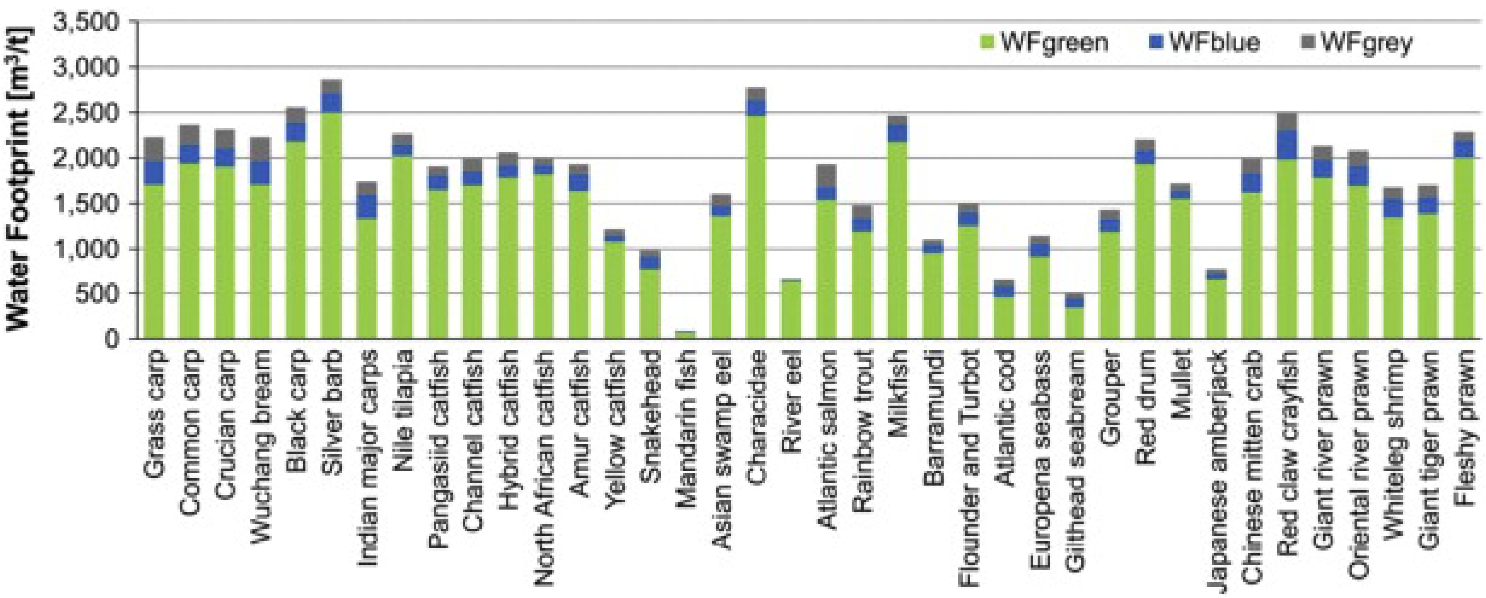
It may also be important to view the land footprint of fish and shellfish in terms of the land area (and consequently biodiversity and ecosystem function – see p.33-34) impacted by harmful fishing practices like bottom trawling.[61] One study found that the area of the sea floor affected by bottom trawling to be approximately 100 times larger than the land area needed to produce the chicken feed for production of a 0.2 kg fillet.[333]

Water use

Water inputs are another measure not typically associated with seafood production and are not included in most water footprint comparisons.[76] However, it is required both directly on-farm in certain aquaculture systems as well as indirectly through the production of feed for farmed fish. One study found that the water needed to produce fish from conventional inland (e.g., pond) aquaculture systems was significantly higher than the amount of water needed to produce equivalent amounts of eggs and dairy.[334] Most (98%) of the water use in terrestrial animal production is related to the production of animal feed, whereas most of the water footprint of inland (outdoor pond) aquaculture systems comes not from feed uses (on average, 33%) but from the need to replace pond water due to evaporative losses. Water use on inland conventional aquaculture farms varies widely, however, ranging from 3,000 – 45,0000 L/kg of seafood (averaging 5,200 L/kg), with the highest footprints being extensive (low-density) inland ponds.[325] Intensifying the number of fish in ponds can decrease this impact, but the greatest decreases in water footprints comes from indoor recirculating aquaculture systems (RAS) which may use as little as 16 L/kg (marine RASs with artificial saltwater) to 50 L/kg (freshwater RASs) including the water use in feeds.[325] Almost no freshwater inputs are required for coastal marine RASs that use saltwater. These represent best-case scenarios, however, and it is important to remember the trade-offs that might need to be made given the high energy requirements (and thus climate impacts) of RASs (see p.31). It is worth mentioning that one study found that 90% of global aquaponics operations (which incorporate RAS with hydroponic vegetable production) use drinking water as an input, so such operations could put a further strain on resources in water-scarce regions.[335] More research into aquaponic systems is warranted to fully weigh the costs as compared to benefits. The pollution of freshwater resources with nutrients, drugs, and chemicals from the effluents of aquaculture systems must also be considered though has not been quantified yet.[336]

While feed production comprises a relatively smaller proportion of the water use related to aquaculture than on-farm use (especially for pond systems), aquaculture production also contributes to the growing pressures on freshwater resources through terrestrial feed ingredients. One study has quantified the green, blue, and gray water footprint[x] associated with the fish feed needed to produce one kilogram of edible fish from a variety of species (Figure 7).[336] These feed-related water footprints vary greatly. The average (weighted by production volume) water footprints of farmed fish and crustaceans fed commercial aquafeed were 1974 L/kg (83% green water, 9% blue water, and 8% gray water), which is lower on a per ton basis than other kinds of intensively produced meats.[y]

FIGURE 7: FEED-RELATED WATER FOOTPRINTS OF FARM-RAISED FISH



Green, blue, and gray feed water footprints are reported per ton of fish and crustacean for the species investigated. Mean values are shown where applicable.

Reprinted with permission from Pahlow, M., Van Oel, P.R., Mekonnen, M.M., & Hoekstra, A.Y. (2015). Increasing pressure on freshwater resources due to terrestrial feed ingredients for aquaculture production. *Science of the Total Environment, 536,* 847-857.

x Note these water footprint figures are based on global averages. The water footprints may vary considerably based on whether certain species rely more on feed ingredients produced in irrigated or rain-fed regions.

y Though feed inputs represent the largest proportion of meats' water footprints, these figures are not directly comparable because the aquaculture water footprints only look at the water used for feed.[336]

Fertilizer and pesticide use

Some aquaculture systems use pesticides (often called parasiticides) directly in their operations to treat or prevent infectious bacterial, viral, or parasitic diseases and to control algae growth on nets.[337] For instance, shrimp farms and hatcheries commonly use organophosphates (neurotoxins), malachite green (a potential carcinogen), and organotin compounds (endocrine disruptors) to control burrowing shrimp; kill insects, fungi, parasites, wild crustaceans, and other pests; and for hatcheries.[338] Many of these pesticides, which are illegal on U.S. fish farms, are used on shrimp farms abroad and then imported[z] into the United States.[338] Other pesticides commonly used in salmon aquaculture operations (often to treat infestations of sea lice) include pyrethroids, avermectins, hydrogen peroxide, and Chitin synthesis inhibitors.[337] The health impacts of consuming fish raised with these pesticides have not been thoroughly assessed, though some negative effects on non-target organisms (from discharges of fish farms into surrounding waters) have been reported, which could indirectly reduce biodiversity of surrounding areas.[337]

Other aquaculture systems which incorporate feed derived from vegetable oil rely on fertilizer (and associated nitrogen and phosphorus pollution) and pesticide use associated with the production of the feed ingredients.[106] Given that soy is currently the most used terrestrial aquaculture feed ingredient,[324] increasing demand for farm-raised fish can contribute to growing concerns over the increasing rates of pesticide use (the "pesticide treadmill"); the development of herbicide-resistant superweeds; and (if imported from Latin America) Amazonian deforestation and negative health, social, and ecological impacts for nearby communities (see p.20). Nutrient pollution also enters aquatic ecosystems directly from uneaten feed and the discharge of fish wastes from some aquaculture systems, many of which are not treated.[339]

On the other hand, some aquaculture systems have relatively few negative impacts. Oysters, mussels, and other filter feeding species require virtually no inputs. Similarly, some closed recirculating aquaculture systems producing low trophic-level finfish (e.g., tilapia) have been found to require little to no agrochemical and pharmaceutical inputs. Incorporation with hydroponic vegetable production can also decrease the need for fertilizer and pesticide inputs in vegetable production (though energy and water inputs can be significantly high, which can make these operations costly and ecologically concerning in certain regions).[335]

Quantifying the N_r losses to the environment associated with both production and consumption (virtual N factor), fish is associated with 416 g N lost/kg protein.[206] This value accounts for 50% wild-caught fish and 50% farmed fish to reflect typical consumption trends in the United States. The virtual N factor of wild-caught fish is only 18% of farmed fish because there are not any anthropogenic N inputs for producing wild-caught fish; N_r losses only occur from processing and food waste. Farmed fish production, on the other hand, also includes N_r losses related to feed inputs and waste management. In comparison to other food groups, the average N factor of fish is higher than pulses and nuts (64), relatively close to poultry (432) and milk and cheese (576), and significantly lower than beef (1104).[206] Current comparisons of P footprints across food groups do not include fish.[95,96,263]

Antibiotic use

A growing area of concern related to the aquaculture industry relates to its contributions to antibiotic resistance. Most aquaculture operations in the United States rely on vaccines to prevent disease rather than antibiotics as opposed to terrestrial animal agriculture, which up until recently also allowed the use for growth promotion. Thus, in the United States, medically important antibiotics are only used in aquaculture operations to treat diseases for which there is no vaccine. Nevertheless, many other countries from which the United States imports farmed seafood (predominantly from Asia) have less strict regulations regarding antibiotic use, and also add antibiotics to fish baths and feed to prevent disease.[340] Moreover, given the ease with which antibiotics and resistant genes can spread through water, even low and legal levels of antibiotics used in domestic aquaculture operations can significantly contribute to the problem.[340] If antibiotic residues remain on farmed fish that have been dosed with antibiotics, or if they reach wild fish and shellfish nearby that are also consumed by humans, antibiotic use in aquaculture may also contribute to food safety problems.[337]

Biodiversity and ecosystem function

Aquatic ecosystem biodiversity is threatened by some common industrial fishing practices, including bottom trawling and dredging, which destroy the seabed and maintain high by-catch rates.[341] Meanwhile, farmed fish fed terrestrial soybean meal and vegetable oils are directly implicated in biodiversity concerns (along with other health and ecological concerns) related to monoculture crop production and heavy agrochemical usage (p.20).[106] Shrimp farming has also caused the destruction of 38% of the world's mangrove forests (and other fish farming an additional 14%), which are important habitats for many key species and also protect tropical and sub-tropical coastlines from sea erosion, tidal waves, and hurricanes.[342]

Some fishing and aquaculture operations can support biodiversity and general aquatic ecosystem health. One study ranked ecological (including impacts on local habits

z The FDA inspects less than two percent of seafood imported into the United States, so it is likely that shrimp contaminated with detectable levels of pesticide residues are reaching consumers.

and biodiversity, use of native species, use of fishmeal and derivatives,[aa] stocking density, waste treatment) and socioeconomic (including whether the product supplies international or domestic demand, the use of chemicals and pharmaceuticals, traceability, and employment practices) indicators for fish production and consumption.[343] The authors noted that mollusks and sea vegetables tend to be farmed more sustainably than finfish or crustaceans. Thus, countries that produced the most bivalve mollusks (e.g., mussels, oysters, and cockles) received the highest scores, due largely to the strong socioeconomic benefits associated with their production. Those who intensively farmed shrimp and salmon were considered some of the least sustainable options, due to their high use of pharmaceuticals, export-oriented focus, and poor waste management practices. These filter-feeding shellfish purify water by removing or reducing nitrogen and other nutrients (thereby reducing the impacts of eutrophication discussed on p.11), particulate matter, silt, bacteria, and viruses, as well as clarifying it.[344] Thus, beyond their role in moderating important nutrient cycles, bivalves help create and sustain marine biodiversity by improving the habitat and providing protection for other aquatic organisms. Bivalve beds have been found to have a higher variety and biomass of invertebrates and finfish than similar areas without bivalves.[344] A number of studies have also found that integrating finfish farming with bivalves and seaweeds (creating a polyculture operation) offers a more sustainable approach to aquaculture, most notably of salmon.[345]

SOCIAL JUSTICE CONSIDERATIONS

Both wild harvesting and aquaculture production pose a number of concerns for workers and export-oriented communities, especially in the Global South. A number of investigations have reported on human trafficking and modern-day slavery conditions in fisheries around the world, from Southeast Asia (most notably in Thailand, Indonesia, and Myanmar) to Hawaii, where boys and men in have been enslaved to meet the demand for low-cost fish (especially shrimp).[311,346,347] These operations have been implicated for low wages and even non-payment, brutal working and living conditions, child labor, and lack of rights to associate and collectively bargain. These fishing boat operations remain notoriously difficult to monitor and regulate, especially as they are often delivered fuel and other supplies by additional ships so the fishing boats do not have to land for years.

Commercial fishing and aquaculture workers also face a number of occupational health and safety risks. Commercial fishing is one of the most hazardous and deadliest occupations, with a fatality rate 31 times the average rate for workers.[313] Workers generally face extreme weather conditions, long working hours, strenuous physical labor, and confined living conditions. Meanwhile, aquaculture workers may be exposed to a number of toxic chemicals and harmful gasses that increase their risks for respiratory and skin illnesses, as well as poisoning events.[348] They may also be exposed to dust aerosols containing antibiotics which could increase their risk for contracting bacterial infections (including antibiotic-resistant strains) and potentially create problems related to allergies or toxicity.[337]

Fish harvesting and farming also impact the socioeconomic wellbeing of producers and communities domestically and abroad. Export-oriented fish harvesting reduces the food security of local populations who have traditionally relied on wild fish as a primary protein source. Meanwhile, some have suggested that export-oriented aquaculture can support poorer economies by providing employment opportunities. However, analyses accounting for both the environmental and socioeconomic impacts of aquaculture operations have found that export-oriented aquaculture externalizes the environmental costs associated with its operations to these places, risking their marine food security and long-term sustainability of their ecosystems to produce these exports.[343] Projected increases in global aquaculture production are also expected to threaten the food security of lower-income populations who rely on the feed ingredients (terrestrial crops and wild forage fish).[332] This is particularly concerning following reports of forced land evictions of smallholder terrestrial farmers in countries such as Bangladesh to make way for flooding lands for more shrimp farming.[349] Additionally, the falling prices and market oversupply that have accompanied the transformation of certain fishing industries (e.g., shrimp) from primarily wild-harvested to primarily aquaculture has had social ramifications for smaller farms and hatcheries who cannot compete with the larger firms.[350]

ANIMAL WELFARE CONSIDERATIONS

The growth of the aquaculture industry has been accompanied by increased attention to the welfare of farmed fish. Studies have demonstrated that fish have the capacity to suffer and feel pain, albeit in a different way than terrestrial animals.[351] Concerns have been raised about how aquaculture practices related to stock densities, water and environmental quality, infection rates, handling, netting and grading, transport, and genetic manipulation can impact stress, pain, and suffering experienced by fish including during killing and processing.[351, 352] Current certification schemes for aquatic animals tend to focus on environmental sustainability considerations though may briefly mention animal welfare.

aa Considered a negative ecological indicator in this study for its impact on wild stocks (herbivorous fish were automatically given a score of 10/10 on this indicator), though as discussed in other parts of this section, the ecological impacts of terrestrial feed are not insignificant.

LIMITATIONS

More research is needed on the health, environmental, social, economic, and animal welfare impacts of transitioning to more sustainable aquaculture operations. It will be especially important to track and monitor changing nutritional profiles and ecological impacts as feed ingredients change. Additionally, while the U.S. government has begun to leverage its role as a major fish importer to pressure industry to reduce illegal, unreported, and unregulated fishing, challenges remain due to mislabeled seafood and the limited availability of seafood certified according to comprehensive third-party standards.

Hospital chefs display creative seafood food meals for the Rhode Island Seafood Throwdown, an event hosted by Health Care Without Harm and the Northwest Atlantic Marine Alliance (Northwest Atlantic Marine Alliance)

Angenette, Captain Ron Borjeson and his grandson landing fluke, a seasonally abundant but underutilized white fish from the Northwest Atlantic waters. (Northwest Atlantic Marine Alliance)

DAIRY (MILK, CHEESE, YOGURT) AND PLANT-BASED ALTERNATIVES

Dairy products include milk and its derivatives such as cheese, yogurt, butter, ice cream, and whey protein powder. Globally, milk from a variety of animals, including cows, goats, buffaloes, sheep, horses, and camels, is used for dairy products for human consumption.[353] The vast majority of dairy products in the United States, however, come from cows' milk, with 9.3 million milk cows in the country compared to only 375,000 milk goats.[354,355] This section thus concentrates on the impacts of cow's milk dairy products. Given the recent proliferation of plant-based alternatives to dairy products, research available on these products will also be touched upon. Although plant-based dairy alternatives are not nutritionally similar to cow's milk dairy (with the exception of soy milk), they are included in this report because people often consume them when replacing animal products, and often assume they are high protein foods while that is not often the case.

Despite having less than 1% of the world's milk animals, the United States produces 12% of the world's milk (the second largest producer after India) and 25% of the world's cheese (the top producing country).[170] In 2015, 208 billion pounds of milk were produced, much of which was transformed into the 11.8 billion pounds of cheese, 4.7 billion pounds of butter, 2.3 billion pounds of dry milk powders, and 1.4 billion pounds of frozen dairy products produced.[354,356] One-third of milk production (by sales) in the United States comes from California and Wisconsin, with other top producing states in the West and North.[357] There are also regional differences in herd sizes, as dairy herds in the Southwest and West are much larger than those in the Upper Midwest and Northeast.[358] Most dairy products consumed in the United States are produced domestically, though some specialty cheeses are imported from Europe.[169]

Rapid consolidation has occurred within the dairy industry over the last few decades, with over 49% of cows in 2012 raised on farms with over 999 cows (compared to only 10% in 1993) and less than 17% of cows raised on farms with fewer than 100 cows (compared to 49% in 1993).[359] The size of very large farms has also grown exponentially: while only 31 farms in 1993 had over 3,000 milk cows, by 2012, there were 440 such farms, many with over 5,000 cows.[359] The intensification of dairy farms has had implications for the feeding practices of dairy cattle—most intensive operations rely on large proportions of concentrates such as grains and other crops in feed and little to no meadow grazing,[ab] as well as environmental, animal welfare, and social justice implications to be further explored in this section.

The U.S. Department of Agriculture estimates that when examining *milk equivalents*, per capita dairy consumption has increased by 16% since 1975.[360] Others, looking at the *mass (in pounds)* of dairy products available, note that per capita consumption has decreased by 19%.[361] This discrepancy comes from the fact that fluid milk and cream consumption has decreased significantly, while the consumption of dairy products which require larger amounts of milk-equivalents to produce per serving than drinking milk directly have increased. Cheese consumption, for instance, has nearly tripled since 1970.[361]

Some of the decreases in fluid milk consumption may be due to consumers switching to plant-based alternatives to dairy products. Market trends demonstrate a rapid proliferation over the last decade of consumer interest in milk, yogurts, creamers, and ice creams made from almonds, soy, and coconut (and less commonly, flax, hemp, rice, cashews, oats, sunflower, hazelnuts, or quinoa).[362] These beverages are created by suspending dissolved or disintegrated plant material in water to create a liquid that resembles milk.[363] Plant-based cheese alternatives are also becoming more popular, including those made from soy, tapioca starch, cashews and other nuts. Plant-based dairy alternatives represent a relatively low (8%) share of the total "milk" market[364] but are expected to continue increasing.[362,365] Additionally, some companies are also developing ways to produce milk by creating milk proteins through the fermentation of cow DNA with other nutrients. The first "animal-free" dairy product is anticipated to be on the market in 2017,[366] so no peer-reviewed research on the environmental, health, and social impacts of these alternatives currently exists.[367]

HUMAN HEALTH CONSIDERATIONS

Cow's milk dairy

The health benefits and risks associated with dairy consumption have been the subject of much debate over the past few decades. Cow's milk dairy products offer many nutrients, including calcium, phosphorus, vitamin B12, protein, potassium, zinc, choline, magnesium, and selenium.[47] The nutritional benefits vary based on the type of product. Milk and yogurt have the healthiest nutrition profiles, providing more potassium and vitamins A and D (due to fortification), and less sodium and saturated fat than cheese and other processed dairy products.[47] However, as nutrition experts increasingly

ab Less than five percent of lactating cows in the United States have year-round access to grazing pasture.[425]

emphasize the importance of focusing on the impacts of dietary patterns and not of single macronutrients, the effects of consuming dairy products within dietary patterns have been debated.

For instance, conventional nutrition advice discourages the consumption of whole milk and other high-fat dairy products in favor of low-fat milk and dairy. These recommendations were adopted on the basis that replacing saturated fats with polyunsaturated fats both lowers blood LDL-"bad"-cholesterol levels, thereby reducing the risk for cardiovascular disease, and reduces calorie intake, thereby promoting better weight management.[47] Some recent studies have critiqued such advice, emphasizing that there is no clear evidence to support the association between saturated fat intake from dairy and cardiovascular disease,[368-370] nor of health benefits gained from switching to low-fat (and thus lower-calorie[ac]) dairy products for weight management.[371] Others argue that concerns remain, which are likely due to differences between and among saturated fats of various chain lengths.[372] If saturated fats are replaced with polyunsaturated fats, the types of polyunsaturated fats substituted in also influence the impacts of the switch, with higher omega-3:omega-6 ratios being the most health-promoting.[369,373]

Meanwhile, even though dairy products are rich in calcium, there is weak evidence that dairy product consumption protects bone health.[374] Meta-analyses and long-term epidemiological studies have found that no clear association between milk/dairy consumption (or calcium-only supplementation) and reduced bone fracture risk.[375-377] There was also controversy in the 1990s (much of which still persists online[378]) that high animal protein intake contributes to the leaching of calcium from bones. More recent evidence from epidemiological, clinical, and meta-analysis studies contradicts this claim and actually suggests that dietary protein works synergistically with calcium to improve calcium retention and bone health.[379,380] Ultimately, while calcium intake is an important nutrient for bone health, other critical factors include an adequate intake of vitamin D (found in fortified milk and plant-based alternatives, and can be made by skin exposed to the summer sun), weight-bearing physical activity, and vitamin K intake (in green leafy vegetables).[381] Calcium absorption and bone health are also heavily associated with genetic dispositions. Approximately 61% of people globally are lactose-intolerant, affecting up to 100% of American Indians and Asians, up to 80% of African Americans, Latinos, and Ashkenazi Jews, and up to 15% of people of northern European descent.[382,383] For many people with these ethnic backgrounds, dietary calcium needs might not be nearly as high as people of northern European descent.[384] Given these differences, some have even suggested that dietary recommendations emphasizing dairy consumption are racially biased.[385] Beyond dairy products and fortified dairy alternatives, many other foods are good sources of calcium (with varying bioavailability), including leafy green vegetables[ad] (e.g., collard greens, kale, broccoli, bok choy, and Brussels sprouts), canned fish with bones, calcium-set tofu, black-eyed peas and white beans, sesame seeds, and almonds.

Beyond its implications for bone health, studies have found that moderate (1-2 servings/day) dairy product consumption (particularly of milk and not necessarily cheese or butter) is associated with a lower risk for colorectal cancer, high blood pressure, stroke, type II diabetes, and bladder cancer.[386-388] Emerging research is also indicating that fermented[ae] dairy products (e.g., soured milk, yogurt, certain cheeses) may play a beneficial role in the human gut microbiome and immune function, provide particular cardiovascular health benefits, and have better bone health implications than non-fermented dairy products, though more research on this area is needed.[377,387]

A few studies have posited that modern-day dairy farming practices (in which milking cows are nearly always pregnant and thus have elevated levels of estrogen and progesterone) may be contributing to accelerated sexual maturation in children,[390] male reproductive disorders,[391] and hormone-related cancers (e.g., breast, ovarian, uterine, prostate, endometrial).[392] One study which quantified the levels of two estrogen hormones in milk samples found that the concentrations of these hormones increased in dairy products with greater percentages of milk fat and in organic milk products. However, the concentrations of these hormones—in all milk samples—were minuscule relative to the levels of these hormones naturally produced by and circulating in the human body.[393] Other evidence to date has not found a clear association between dairy product consumption and breast, ovarian, or endometrial cancer.[394-396] High intake (>2,000 mg/day) of calcium in general, however, is associated with an increased risk of prostate cancer, with limited evidence suggesting that milk and dairy products are a cause.[397-399]

Some studies have also assessed how different farming systems and feeding practices of dairy cows affect the nutritional quality of dairy products. Grass-feeding has been found to increase the concentration of omega-3 fatty acids and conjugated linoleic acid (CLA), a beneficial fatty acid produced by ruminants, in animal products including milk, compared

ac Note that many low-fat dairy products have added sugars, which growing evidence suggests are harmful to health,[403] or flavorings to recover some of the taste lost when fat is removed.

ad Due to their high oxalate concentration (which inhibits calcium absorption), some leafy green vegetables (e.g., spinach, chard, beet greens) should not be considered good sources of calcium.[388]

ae These possible benefits to the microbiome are not exclusive to fermented dairy products; they may also be provided through fermented vegetables and legumes, though more research is needed.

to cows lacking routine access to pasture and fed substantial quantities of grains.[400] Given that these benefits are found in the fat of milk, only full-fat grass-fed dairy products can be considered good sources of these nutrients. As organic regulations require a minimum amount of pasture feeding, organic milk has been found to have higher concentrations of omega-3 fatty acids and possibly beneficial trans-fatty acids, and significantly lower (i.e. healthier) omega 6 to omega 3 ratios.[114,373] High-fat organic milk products should still not be considered significant sources of omega-3 fatty acids, however, as the quantities provided are significantly lower than those found in fish and those recommended by health experts (250-500 mg/day of DHA+EPA). Three servings of full-fat organic dairy products only provide 35 mg of EPA and no DHA, in contrast to conventional dairy products which provide 27 mg of EPA.[373]

Plant-based dairy alternatives

Plant-based dairy alternatives vary greatly in their nutritional profiles. Fortified soy milks contain similar amounts of protein, calcium, and vitamin D as cow's milk, and are thus the only plant-based milk alternatives considered an equal replacement to milk in the Dietary Guidelines.[47] Many other milk-alternative beverages and yogurts are also fortified with calcium and vitamins A, D, B2, B12, and E, but they do not provide as much protein as soy or cow's milk. To avoid any negative health implications for those replacing cow's milk with these alternatives, it is important to ensure adequate protein is consumed from other foods in the diet (for most Americans, this should not be a concern[34]), and that one has chosen fortified products (Table 2).[363] The calcium in fortified plant milk can be absorbed at similar rates as cow's milk when the type of calcium added is calcium carbonate; the absorption rate is slightly lower when tri-calcium phosphate is added.[401] It is important to shake the beverages before pouring, as the calcium settles to the bottom of the container and without being dispersed, may not be consumed.[402]

Given the growing evidence base against the consumption of added sugars,[403] the sugar content of plant-based dairy alternatives must be considered. Unsweetened products can contain as little as 0 g of sugar, but some sweetened beverages can contain up to 19 per serving. Other ingredients, including flavorings, sodium, and stabilizers are often added. The stabilizer carrageenan, a seaweed derivative, is commonly used,[af] despite extensive, though controversial, research demonstrating that the additive is associated with gastrointestinal inflammation and higher rates of intestinal lesions, ulcerations, and malignant tumors.[404] Frequent consumption of rice milk may also be a concern, particularly for young children, given the relatively high levels of arsenic.[405]

Cows walk through a field at the Double J Jerseys organic dairy farm near Monmouth, OR. Over a billion pounds of U.S. organic milk products were sold during the first five months of 2016, a 5.4% increase from last year, and the highest sales volume ever recorded by the USDA. (Lynn Ketchum)

af Carrageenan is also found in other processed foods including flavored cow's milk and yogurts, ice cream, processed meats, frozen dinners, and chewable vitamins.

TABLE 2: KEY NUTRITIONAL AND OTHER CONSIDERATIONS OF DIFFERENT MILK PRODUCTS

	calories	protein (g)	fat (g)	sugar (g) (naturally occurring)	other nutrients	environmental considerations	social justice	animal welfare
cow's milk								
whole milk	149	8	8	12	calcium (30%), vitamin B12 (16%), vitamins A and D may be added	relatively high GHG and water footprint compared to other milk beverages	numerous concerns for workers and surrounding communities	significant concerns re: housing conditions, feed, and treatment of dairy cows
reduced fat (2%)	122	8	5	12				
skim	83	8	0	12*				
plant-based milk alternatives								
soy milk	80	7	4	1* (all low-fat varieties have added sugar)	often fortified with calcium (30-45%), vitamins B12 (25—50%), A, D, and E	pesticide use (particularly for non-organic soy)	non-organic soy processing poses health and safety risks to workers	
almond milk	30—40	1—2+	3	0*		blue water footprint	high pesticide use poses risks to workers and communities	
coconut milk (beverage)	45—60	0—1	4—5	<1*				monkey harvesting ethics
rice milk	70	0—1	2.5	0*		relatively high GHG footprint		
flax milk	25	0+	2.5^	0*				
hemp milk	70	2—3 g	5^	0*				
cashew milk	25	<1+	2	0*			significant labor concerns	
oat milk	130	4	2.5	12—19				

Nutritional info per 1 cup (8 oz.) of unsweetened product.

*Some products may have added sugars (and consequently higher calorie counts), including "original" flavors of plant-based milk beverages (which may contain 7—14 g per serving).

+ Some products may have added pea or rice protein concentrate.

^May contain omega-3 fatty acids (approximately 1.2 g serving)

Sources: USDA ARS (2016), Food Composition Databases: Nutrient Lists and websites of leading companies, including Silk, DREAM, Pacific, Living Harvest, and Good Karma Foods.

ENVIRONMENTAL HEALTH CONSIDERATIONS

Relative to ruminant meat, milk has a relatively low climate, land, and water footprint, however, that does not negate its environmental impact. Whole milk generally has the lowest ecological footprint per serving, with slightly higher impacts associated with skim milk as well as (skim and full-fat) yogurt and cheese due to processing. While the intensification of dairy farms over the last two decades has lowered the climate, land, and water footprints of dairy products on a per serving basis, it has also contributed to a number of other ecological, public health, and animal welfare concerns, including nitrate leaching and contamination of drinking water, antibiotic resistance, and adverse worker and community physical, mental, and social health impacts.

Based on a limited number of mostly non-peer-reviewed studies, plant-based dairy alternatives seem to have significantly lower impacts on most environmental metrics per serving than cow's milk, due to the relatively lower impacts of their primary ingredients (e.g. soybeans, almonds, etc.) and avoided impacts from animals, manure, and feed production. However, it is important to recognize that this comparison is not completely equal given the lower amounts of protein (in all products except soy milk) and nutrients (though these may be added through fortification).

Climate change

Cow's milk dairy

The global dairy sector accounts for 4% of total anthropogenic GHG emissions.[406,ag] The vast majority (78-83%) of these dairy-related emissions in industrialized countries comes from

ag This includes the emissions associated with culled dairy cows that become beef because these are byproducts of the dairy system and would not be produced on their own.

on-farm activities (i.e., excludes processing and transport).[406] A review of LCAs of dairy products found that the GHG footprint of milk (from production through to point of retail) ranges from 28 – 43 kg CO_2-eq/kg protein and cheese ranges from 28 – 68 kg CO_2-eq/kg protein.[61] These ranges are comparable to the GHG-intensity of eggs (29 – 52 kg CO_2-eq/kg protein) and poultry (23 – 40 kg CO_2-eq/kg protein).[3,60,61] Although producing one kilogram of cheese generally requires 6-7 kg of milk, the serving size of cheese is much smaller (one serving milk = one cup = 244 g; one serving of cheese = one oz. = 28 g). Thus, a typical serving of milk and cheese contain roughly similar amounts of milk and have similar GHG-footprints (though the extra processing of cheese raises it slightly[61]).[3] The energy use and global warming potential required to process milk into dairy products like cheese is smaller relative to the processing of meat products, which is one reason for the differences between milk and meat protein.[60]

Compared to cattle for meat production, livestock management systems of dairy farms do not vary as greatly in climate impacts. Studies have shown how raising cattle in extensive pastoral systems (i.e., grass-feeding) results in more GHG emissions per unit of beef compared to those fed higher proportions of concentrate feed.[407-410] This is due to differences in how starches and forage pasture are digested, the slower growth rates and reproductive cycles of extensive systems, and the relatively improved feed conversion efficiency in intensive systems due to the fact that animals do not/cannot walk as much to find food.[61] Some suggest that accounting for the carbon sequestration potential (see p.14) of well-managed pastureland through cattle grazing can more than offset these differences,[407,411,412] however, others indicate that intensive feedlot production is still more GHG-efficient even accounting for carbon sequestration potential.[409,410,413] In dairy systems, however, feed conversion efficiency ratios do not vary as much because even extensive systems require grazing to take place relatively close to milking facilities so animals do not walk very far.[61] Because of this, the GHG intensity of milk between systems only varies from 1 – 1.5 kg CO_2-eq/kg milk, compared to beef which varies from 9 – 42 kg CO_2-eq/kg beef (industrial systems) to 12 – 129 kg CO_2-eq/kg beef (extensive pastoral systems).[61] Nevertheless, the higher intensities of grass-fed dairy are related to lower milk productivity per cow combined with lower digestibility of feed.[406]

The impacts of climate change on animal agriculture have not received as much attention as its contributions. However, climate change is anticipated to harm livestock health and productivity by decreasing the quantity and quality of feeds (both crops and grazing pastures); contributing to heat and water stress for animals; changing the distribution of and increase the prevalence and intensity of livestock diseases; and contributing to genetic diversity losses among livestock breeds.[15,414] Heat stress caused by extreme summer temperatures can significantly impact milk production and birthing rates of cattle.[415] One study that assessed the potential impact of climate change on dairy cow performance in the United States projected substantial declines in milk production (10-20%) and conception rates (up to 35%) during summer season production and reproduction, with some regions (the Southeast and Southwest) expected to face the greatest declines.[416] Another study found that milk production in the Northeastern United States could decline by 10-25% by the end of the century.[417]

Plant-based dairy alternatives

The climate impact of plant-based dairy alternatives depends on the primary ingredient with which it was made, whether that be almonds (p.22), soybeans (p.17), or other seeds, nuts, or grains. On a per-serving basis, the few products that have been tested have been found to have lower GHG-intensities compared to cow's milk. The average GHG-intensity of almond and coconut milk (from production through to retail) is 0.42 kg CO_2-eq/L, while soy milk values average 0.88 kg CO_2-eq/L.[50] Tetrapaks have a slightly lower impact than cartons.[418] In comparison, the climate impact of cow's milk in North America averages 1.34 kg CO_2-eq/L.[50]

When switching to plant-based dairy alternatives, it is important to not assume there is a reduction in climate emissions (or land use) without decreasing meat demand to offset the loss of culled dairy cows.[419] Additionally, when transitioning farms to accommodate more plant-based diets, crop rotations that include perennial crops (e.g., grass—clover) should be incorporated to maintain soil structure and sequestration benefits.[419]

Land use

Cow's milk dairy

Milk and cheese production share a roughly similar land use footprint per kg of protein (26 – 54 m^2/kg protein), with eggs (29 – 52 m^2/kg protein), poultry (23 – 40 m^2/kg protein), pork (40 – 75 m^2/kg protein); whereas beef production requires up to 2100 m^2/kg protein.[60,61] Given that cows are ruminant animals which can graze on pastures unsuitable for crop production while poultry and hogs cannot, these land use footprints must be differentiated in terms of cropland and pasture land (see pp.8-9). Broken down in this way, milk (from cattle raised using 30% concentrate feed, 70% forage pasture) requires significantly less cropland per kilogram of protein compared to ruminant meat, pork, and even pulses, with cropland needs rising with increasing proportions of concentrate feed in the diet.[68] This particular efficiency for dairy cows supports the findings of one study that compared the land use requirements of entire dietary patterns in the United States. It found that the cultivated cropland needs (0.12 ha/person/year) for lacto-vegetarian diets (e.g., vegetarian diets that include dairy products) were lower than those for strictly vegan diets (0.13 ha/person/year), both of which were significantly lower than the needs for the baseline average American diet (0.18 ha/person/year).[62]

Dairy farming on peat soils (i.e., unsuitable for growing food crops) has higher land efficiency than dairy farming on sandy soils.[16] One study measured this in terms of a land use ratio (LUR), finding that the LUR for dairy cows on sandy soils was 2.10, meaning that twice as much human digestible protein could be produced if this land were used directly to grow crops. Dairy cows on peat soils, however, had a LUR of 0.67, meaning that the animals produced more human digestible protein per square meter than crops and were thus efficient in contributing to global food supply.[420] Grass-fed/pasture-based/extensive dairy production requires slightly more (6%) land per unit of protein than intensive and semi-intensive systems because of its lower feed conversion efficiency, a consequence of lower reproduction rates and milk yields.[16] However, nearly all (>99%) of this land is permanent grassland, while 25% of the land footprint of intensive and semi-intensive systems is arable cropland.[16] Dairy production in the United States is dominated by intensive systems (see p.36).

Plant-based dairy alternatives

Few studies have evaluated the land required to produce plant-based milk alternatives. Given that the land use efficiency of dairy cows depends on the type of soil and system of production, direct comparisons for plant-based products cannot be easily made.

Water use

Cow's milk dairy

Nineteen percent of the global water footprint of farm animal production is attributable to dairy cattle.[76] Milk production requires, on average globally, approximately 31 L of water per g protein (85% green water, 8% blue water, and 7% gray water).[76] This is about 1.6 times the water footprint of pulses (19 L/g protein), and roughly similar to eggs (29 L/g protein) and chicken (34 L/g protein).[76] It is almost half the water footprint of pork (57 L/g protein) and less than one-third the water footprint of beef (112 L/g protein).[76]

Plant-based dairy alternatives

As most plant-based dairy alternatives do not have high protein contents, a per-serving comparison of the water footprint to conventional dairy products is more meaningful than comparisons based on units of protein. The global average water footprint—which includes green, blue, and gray water—for cow's milk[ah] is 1020 L/kg.[76] The average water footprint for soymilk[ah] is 376 L/kg.[421] Given the high blue water footprint of almonds (p.23), almond milk has been blamed for contributing to California's water crisis.[254] However, based on the protein content of a typical serving of almond milk, only a small amount of almonds is present in almond milk. Thus the water footprint of almond milk[ah] is not as high as one might think: approximately 238 L/kg of almond milk.[ai]

When comparing only the *irrigation* water needs of these products, almond milk's blue water footprint is relatively higher at 56 L/kg; this is still lower than cow's milk at 86 L/kg,[76] but significantly higher than soy milk at 12.3 L/kg.[73] Another (non-peer-reviewed) study that assessed the water required to produce plant-based milk alternatives,[aj] including processing and packaging water needs, found that almond milk required 67 L/kg to produce, while coconut milk and soy milk required less, at 3 L/kg and 23 L/kg, respectively.[418] One may argue, however, that while the per serving total or solely blue water footprints of almonds are smaller than dairy milk, the increasing demand for almond milk is incentivizing farmers to continue planting almond trees in California, which could further intensify the water crisis there. Conversely, dairy production could occur anywhere, though it is worth re-emphasizing that California is the top dairy-producing state in the country. Given that oats, sunflower seeds, and hemp seeds have less than one-third of the water footprint per ton compared to almonds or other nuts,[73] and that these crops can be grown in a diversity of climates outside of California, plant-based milk alternatives made from these crops would have significantly lower water footprints.

Fertilizer use and eutrophication potential

Cow's milk dairy

By one USDA estimate, the manure from just 200 milking cows produces as much nitrogen (N) as sewage from a community of 5,000 to 10,000 people.[422] One study comparing the amount of N_r lost to the environment per kilogram of protein consumed for various food groups found milk and cheese have a virtual N factor of 576 g N lost/kg protein, which was higher than pulses and nuts (64), relatively close to fish (416) and poultry (432), and significantly lower than beef (1104).[206]

While semi-intensive dairy production requires approximately one-third more land per unit of protein than intensive systems, intensive dairy systems (which raise the vast majority of dairy cattle in the United States) require around 10 – 15% more new-fixed-nitrogen per unit of protein due to the synthetic fertilizer needed to produce their feed.[16] This indicates that intensive

ah Based on ingredients alone; does not include packaging.

ai This value was calculated based on the global average water footprint for almonds at 16,095 L/kg[73] and the assumption that a half gallon of almond milk contains around 28 g of almonds, given that an 8 oz. serving of almond milk contains 1 g protein and a 28 g serving of almonds contains 6 g protein.

aj Although not specified, it was assumed that water use attributed to the ingredients only accounted for blue (i.e., irrigation) water.

dairy adds a net input of N_r, contributing to the disruption of global N cycle, rather than recycling already-existing N from organic manure application. Among pasture-based dairy operations, a recent study found that with no change in N fertilizer use, nitrate leaching actually declined with increasing stocking rate. The authors emphasized that, as long as feed imports are not increased, grazing more cows per acre on well-managed grazing paddocks could reduce the negative impact of dairy farms on local water quality.[423]

There are currently no comparisons of the P footprint for different types of food per serving or per unit of protein consumed. A comparison based on mass of the food (which has limitations given that people do not consume similar volumes of food per serving across food groups – see p.14) shows that milk requires 11 times more mined P fertilizer to produce per kilogram than pulses, but less than that required to produce tree nuts (63% as much), eggs (34% as much), poultry (22% as much), pork (14% as much), and beef (only 7% as much).[263]

Pasture-raised cattle can have a higher P-fertilizer requirement systems per serving compared to intensive feedlot due to its less efficient use of feed.[263] These requirements, however, would be significantly lower if the cattle graze solely on unfertilized rangeland rather than on fertilized fields or if they eat cropped hay during portions of the year. Measures of mined P requirements also do not account for how much of this phosphorus leaches into runoff. One study (of beef cattle) found less P in excrement from grass-fed cows compared to those raised in feed lots.[407]

Plant-based dairy alternatives

The fertilizer use and eutrophication potential associated with plant-based dairy alternatives vary based on the type of crop from which the plant-milk is produced and how the land spared from switching from cow's milk products to more these alternatives might be used.[419] Little research has assessed these impacts.

Pesticide use

The vast majority (78%) of dairy cattle in the United States rely solely on concentrate feed, which is comprised of alfalfa, corn, and soy.[299] Given concerns about the increasing rate of glyphosate use (the "pesticide treadmill") in corn and soy monocultures to control the development of herbicide-resistant superweeds (see p.20), increasing demand for non-grass-fed dairy could further exacerbate these problems.

Given the relatively high use of pesticides in almond production (see pp.23-24), pesticide inputs are also a consideration for almond milk production (though again, the amount of almonds in almond milk is so low that it is not as big of a factor as nut consumption directly).

Antibiotic, hormone, and other pharmaceutical use

Cow's milk dairy

In contrast to poultry and swine operations, dairy cows generally receive antibiotics on an individual basis and not at the herd or flock level.[424] However, antibiotics including penicillins, cephalosporins, and other beta-lactam drugs are still widely used both for treatment of clinical mastitis (16% of all lactating dairy cows in the United States receive each year[425]) and to prevent and control future udder or uterus infections (nearly all dairy cows at the end of lactation).[424] Some dairy cattle (17% by a 2007 USDA statistic[426]) are also fed recombinant bovine growth hormone (rBGH) which increases milk production by 11 – 15%, but also causes a smaller but significantly increased risk for mastitis in cows (as well as lameness, foot problems, and other animal welfare harms).[427-429] Increased use of antibiotics to treat increased cases of mastitis may also contribute to the development of antibiotic-resistant bacteria.

Some concerns have also been raised about potential direct health harms from consuming milk produced by rBGH-treated cows, particularly from the hormone's potential to increase levels of IGF-1 in humans. A number of review panels, including those convened by the FDA and American Cancer Society, state that there is no clear evidence that drinking milk with or without rBGH treatment increases levels of IGF-1 to a range significant enough to increase the risk for prostate or breast cancer or other negative health effects.[427,430] However, Health Care Without Harm, along with many other countries and organizations, including Canada, all EU nations, and the American Public Health Association, formally oppose the use of rBGH based on the evidence of harm to animals and possible human health concerns.[431,432]

Even without the use of synthetic hormones, it is estimated that pregnant and cycling cows contribute about 92% of the endogenous (i.e., natural) hormones excreted by livestock species in the United States.[433] Given the number of dairy cattle in the United States, and the fact that dairy waste does not go through wastewater treatment as most human waste does, the natural hormones from dairy cattle may be contributing to reproductive and developmental harms being observed among other organisms in the environment (p.12). One study estimates that the combined natural and synthetic estrogens emitted by dairy cows and swine total more than 10 times the amount of estrogen coming from wastewater treatment plants in the United States.[434] A significant increase in dairy cattle numbers, regardless of whether they are treated with synthetic hormones, would increase estrogen excretions to the environment.[433]

Plant-based dairy alternatives

Plant-based dairy alternatives do not have concerns associated with antibiotic resistance. Some concerns have been raised about the phytoestrogens in soy products, though observational studies have found that consuming whole soy foods may actually provide protective benefits (see pp.16-17). It is worth mentioning that these benefits are associated with the consumption of full-fat (i.e., whole) soy products, as low-fat soy milk is typically made from isolated soy proteins.

Biodiversity and ecosystem function

The vast majority (78%) of dairy cattle in the United States rely solely on concentrate feed, which is comprised of alfalfa, corn, and soy.[299] Increasing demand for non-grass-fed dairy could further exacerbate biodiversity concerns (along with other health and ecological concerns) related to monoculture crop production and heavy agrochemical usage (p.12). Extensively grazing cattle on pasture, on the other hand, can support high species and habitat biodiversity for both plants and animals in certain landscapes through cows' selective defoliation due to dietary choices, treading, nutrient cycling, and seed dispersal (seeds pass through the cow's digestive system and also attach to the cow's skin).[419,435,436]

SOCIAL JUSTICE CONSIDERATIONS

Intensive dairy farming poses a number of concerns for workers and surrounding communities. Accompanying the intensification and consolidation of the dairy industry over the past two decades, dairy farms increasingly rely on hired labor which is often in short supply and experiences rapid turnover.[358] Although opportunities exist for exploiting oneself or one's family as laborers, the increased reliance on hired labor present additional concerns about farmworker rights and wellbeing. Farmworkers on dairy farms in Vermont, organizing through Migrant Justice, launched a campaign in 2014 to protest low wages and wage theft, long working hours, discrimination, subpar housing conditions, and poor health and safety conditions, including lack of access to water or bathrooms.[437] Their Milk With Dignity Code of Conduct, based on the Coalition of Immokalee Workers' Fair Food Campaign, calls for the rights to free speech and association without retaliation; dignified wages; dignified schedules, rest, and leisure; freedom of movement; equal treatment and respect without discrimination; dignified housing; and a healthy, safe, and secure workplace.[438]

As with other agricultural workers, dairy farmworkers also face health risks. Farmworker exposure to airborne pollutants such as particulate matter, pathogenic bacteria, endotoxins, and noxious gases and odors are associated with respiratory conditions.[109] Elevated concentrations of cow allergen have been found inside barns, sheds, stables, and the living quarters of current and former dairy farmworkers, which may increase their risk for allergic sensitization and disease, as well as exacerbate asthma for sensitized individuals.[439,440]

Industrial dairy farms, similar to other industrial food animal operations, can also negatively impact the surrounding community. A recent study found that more than half of the homes in close proximity (<0.25 mile) to industrial dairy operations had levels of the inflammatory agent endotoxin that would be high enough to cause respiratory health problems.[441] Elevated levels of cow allergen were also found, which poses similar health risks as those described above for workers. Moreover, as discussed earlier in this report (p.11), dairy farms in California, Wisconsin, and other Midwestern states are some of the key contributors to elevated levels of nitrate in the drinking water of surrounding communities. These findings are particularly concerning in California where these farms—and their associated threats to health and well-being—are concentrated primarily in communities of color and low-income communities that lack the socioeconomic and political power to prevent, mitigate, or adapt to these environmental inequities.[98,99]

It is also worth considering the ethical implications of purchasing plant-based milk alternatives. Given the poor labor practices associated with the cashew industry (p.24), cashew-based milk and cheese alternatives may not be the most socially just options.

ANIMAL WELFARE CONSIDERATIONS

The health and welfare of dairy cows vary based on the herd size, production volume, and type of production system, though there are not always straightforward solutions to maximizing animal welfare. Conventional dairy farms have come under increasing scrutiny for many common practices. For instance, calves are usually separated from cows shortly after calving and individually housed despite better health and social wellbeing for calves housed in small groups.[358] Dairy cows often have their horns removed or tails docked, or are castrated, without anesthesia or other forms of pain management.[24] Despite the fact that cows are ruminant animals evolved to feed on pasture and grasses, less than 5% of dairy cows in the United States have year-round access to pasture and most are housed in tie-stalls with restricted movement and ability to express social behaviors.[442] Moreover, many farms have adopted breeds that produce high volumes of milk without consideration for the breeds' adaptations to cope with climatic temperatures and diseases, which can lead to compromised health and wellbeing for cows.[358]

Other forms of raising dairy cows provide some improvements to animal welfare. In addition to having more freedom of movement, cows in free stalls or grazing pastures have been found to have lower incidence and prevalence of many diseases, with the exception of lameness.[358] Some studies have found that cows raised on organic farms have less mastitis, lameness, and hock lesions compared to those on conventional farms, but other studies have reported no differences.[358] Some of these discrepancies may be due more to differences in management practices such as cow cleanliness and stall maintenance than to differences inherent in certain production systems. Increased prevalence of many diseases (except lameness) and mortality rates have also been associated with increasing herd size, while increased milk production per cow has been associated with poorer health for the cow.[358]

Plant-based milk alternatives may not seem to be associated with animal welfare concerns at first. However, some may consider the impact that farming coconuts has on monkeys, who are stolen from the wild or bred on farm to harvest coconuts in Thailand. Given their high levels of intelligence, the fact that these animals are employed in chained working conditions raises ethical dilemmas for the continued expansion of the coconut industry.[443,444]

LIMITATIONS

There is very limited published research on the impacts of alternatives to traditional cow's milk dairy products. Significantly more research on the health, environmental (including LCAs), and social justice implications of both alternatives derived from nuts, legumes, and grains, as well as from fermented animal DNA, is merited.

(Lindsey J. Scalera)

Integrated crop-livestock systems are a form of mixed production that grows crops and raises livestock in a way that they can complement each other and maximize resource use. This intercropping includes aubergines, spaghetti squash and chickens. The chickens are pastured free-range in potager and cover crops like lettuce and cabbage (Irene Kightley/flickr)

ACRONYMS

ALA: alpha-linolenic acid, a short-chain omega-3 fatty acid

CAFO: concentrated animal feeding operation

CH_4: methane

CO_2: carbon dioxide

CO_2eq: carbon dioxide equivalent (see Sidebox on p.__)

DHA: docosahexaenoic acid, a long-chain omega-3 fatty acid

EPA: eicosapentaenoic acid, a long-chain omega-3 fatty acid

EPA: United States Environmental Protection Agency

EU: European Union

FAO: United Nations Food and Agriculture Organization

FDA: United States Food and Drug Administration

GHG: greenhouse gas

GM: genetically modified

HHS: United States Department of Health and Human Services

Ht: herbicide-tolerant

IFAP: Industrial food animal production

LCA: life-cycle assessment

N: nitrogen

N_r: reactive nitrogen

N_2O: nitrous oxide

P: phosphorus

PO_4^{3-}: phosphate

RAS: recirculating aquaculture system

rBGH: recombinant bovine growth hormone

USDA: United States Department of Agriculture

WHO: United Nations World Health Organization

Dried legumes for sale at a market (Katjung/flickr)

WORKS CITED

[1] Shannon, K. L., Kim, B. F., McKenzie, S. E., & Lawrence, R. S. (2015). Food system policy, public health, and human rights in the United States. *Annual Review of Public Health, 36,* 151-173.

[2] Klein, K., Thottahthil, S., & Clinton, S. (2014). Environmental nutrition: Redefining healthy food in the healthcare sector. Healthcare Without Harm. Retrieved from https://noharm-uscanada.org/environmentalnutritionwhitepaper2014

[3] Tilman, D., & Clark, M. (2014). Global diets link environmental sustainability and human health. *Nature, 515*(7528), 518-522.

[4] World Cancer Research Fund/American Institute for Cancer Research (2007). *Food, Nutrition, Physical Activity, and the Prevention of Cancer: A Global Perspective*. Washington, DC: American Institute for Cancer Research.

[5] Larsson, S. C., & Orsini, N. (2013). Red meat and processed meat consumption and all-cause mortality: a meta-analysis. *American Journal of Epidemiology,* kwt261.

[6] Pan, A., Sun, Q., Bernstein, A.M., Schulze, M.B., Manson, J.W., Stampfer, M.J., Willett, W.C., Hu, F.B. (2012). Red meat consumption and mortality: results from 2 prospective cohort studies. *Arch Intern Med, 172*(7), 555–563.

[7] Micha, R., Michas, G., & Mozaffarian, D. (2012). Unprocessed red and processed meats and risk of coronary artery disease and type 2 diabetes–an updated review of the evidence. *Current Atherosclerosis Reports, 14*(6), 515-524.

[8] Kaluza, J., Wolk, A., & Larsson, S.C. (2012). Red meat consumption and risk of stroke: A meta-analysis of prospective studies. *Stroke 43,* 2556–2560.

[9] Nelson, M.E., Hamm, M.W., Hu, F.B., Abrams, S.A., & Griffin, T.S. (2016). Alignment of healthy dietary patterns and environmental sustainability: A systematic review. *Advances in Nutrition, 7,* 1005-1025.

[10] Crowe, F., Appleby, P., Travis, R., & Key, T. (2013). Risk of hospitalization or death from ischemic heart disease among British vegetarians and nonvegetarians: Results from the EPIC-Oxford cohort study. *Am J Clin Nutr 97,* 597–603.

[11] Huang, T., Yang, B., Zheng, J., Li, G., Wahlqvist, M.L., & Li, D. (2012). Cardiovascular disease mortality and cancer incidence in vegetarians: A meta-analysis and systematic review. *Ann Nutr Metab 60,* 233–240.

[12] Lesk, C., Rowhani, P., & Ramankutty, N. (2016). Influence of extreme weather disasters on global crop production. *Nature, 529.7584,* 84-87.

[13] Challinor, A.J., Watson, J., Lobell, D.B., Howden, S,M., Smith, D.R. & Chhetri, N. (2014). *A meta-analysis of crop yield under climate change and adaptation. Nature Climate Change, 4,* 287–291.

[14] Marshall, E., Aillery, M., Malcom, S., & Williams, R. (2015). *Climate Change, Water Scarcity and Adaptation in the U.S. Fieldcrop Sector.* Economic Research Report No. (ERR-201). Washington, D.C.: USDA ERS.

[15] Thornton, P. K., Van de Steeg, J., Notenbaert, A., & Herrero, M. (2009). The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural Systems, 101*(3), 113-127.

[16] Herrero, M., Wirsenius, S., Henderson, B., Rigolot, C., Thornton, P., Havlík, P., ... & Gerber, P. J. (2015). Livestock and the environment: what have we learned in the past decade?. *Annual Review of Environment and Resources, 40,* 177-202.

[17] Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., ... & Toulmin, C. (2010). Food security: the challenge of feeding 9 billion people. *Science,* 327(5967), 812-818.

[18] Kim, B., Neff, R., Santo, R., & Vigorito, J. (2015). *The importance of reducing animal product consumption and wasted food in mitigating catastrophic climate change*. Baltimore, MD: Johns Hopkins Center for a Livable Future.

[19] Smith, P., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E.A., ... and Tubiello, F. (2014). 'Agriculture, forestry and other land use' in *Climate change 2014: Mitigation of climate change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., ... and Minx, J.C. (eds.)]. Cambridge, United Kingdom and New York, NY: Cambridge University Press.

[20] Weber, C.L., & Matthews, H.S. (2008). Food-miles and the relative climate impacts of food choices in the United States. *Environmental Science & Technology,* 42(10), 3508-3513.

21 Gerten, D., Heinke, J., Hoff, H., Biemans, H., Fader, M., & Waha, K. (2011). Global water availability and requirements for future food production. *Journal of Hydrometeorology, 12*(5), 885-899.

22 Lambin, E.F., & Meyfroidt, P. (2011). Global land use change, economic globalization, and the looming land scarcity. *Proceedings of the National Academy of Sciences, 108*(9), 3465-3472.

23 Bouwman, L., Goldewijk, K. K., Van Der Hoek, K. W., Beusen, A. H., Van Vuuren, D. P., Willems, J., ... & Stehfest, E. (2013). Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period. *Proceedings of the National Academy of Sciences, 110*(52), 20882-20887.

24 Pew Commission on Industrial Animal Farm Production. (2008). *Putting meat on the table: Industrial farm animal production in America.* Baltimore, MD: Johns Hopkins Bloomberg School of Public Health.

25 Silbergeld, E.K., Graham, J., & Price, L.B. (2008). Industrial food animal production, antimicrobial resistance, and human health. *Annual Review of Public Health, 29,* 151-169.

26 Hoffmann, I. (2010). Climate change and the characterization, breeding and conservation of animal genetic resources. *Animal Genetics, 41*(s1), 32-46.

27 Neff, R.A., Parker, C.L., Kirschenmann, F.L., Tinch, J., & Lawrence, R.S. (2011). Peak oil, food systems, and public health. *American Journal of Public Health, 101*(9), 1587-1597.

28 Casey, J.A., Kim, B.F., Larsen, J., Price, L.B., & Nachman, K.E. (2015). Industrial food animal production and community health. *Current Environmental Health Reports, 2*(3), 259-271.

29 Herzog, H. (2010). *Some we love, some we hate, some we eat.* New York: HarperCollins.

30 Stahler, C. (2015). How often do Americans eat vegetarian meals? And how many adults in the U.S. are vegetarian? Vegetarian Resource Group. Retrieved from: http://www.vrg.org/blog/2015/05/29/how-often-do-americans-eat-vegetarian-meals-and-how-many-adults-in-the-u-s-are-vegetarian-2/

31 Hartman Group (2011). Culture of Millennials. Retrieved from http://store.hartman-group.com/culture-of-millennials-2011/?hcampaign

Packaged Facts and the Center for Culinary Development (2012). Collegiate Gen Y Eating: Culinary Trend Mapping Report. Retrieved from http://www.packagedfacts.com/Collegiate-Gen-Eating-6576735/

Nguyen, A. (2010). Meatless eating is hot on Philadelphia college campuses. *Philadelphia Daily News* (October 14). Retrieved from http://articles.philly.com/2010-10-14/entertainment/24982387_1_vegan-college-students-graduate-student

32 Menayang, A. (2016). What's the latest on the 'flexitarian' trend? Food Navigator USA (July 11). Retrieved from http://www.foodnavigator-usa.com/Markets/Innova-Market-Insights-at-IFT-New-data-on-the-flexitarian-trend

33 UN Food and Agriculture Organization (2015). Food Balance Sheets, Meat Consumption Per Capita, 2011 data. Retrieved April 10, 2015 from http://faostat.fao.org/beta/en/#data/FBS

34 Fehrenbach, K.S., Righter, A.C., & Santo, R.E. (2016). A critical examination of the available data sources for estimating meat and protein consumption in the USA. *Public Health Nutrition, 19*(08), 1358-1367.

35 McMichael, A.J., Powles, J.W., Butler, C.D., & Uauy, R. (2007). Food, livestock production, energy, climate change, and health. *The Lancet, 370*(9594), 1253-1263.

36 Fitch, C., & Santo, R. (2016). *Instituting change: An overview of institutional food procurement and recommendations for improvement.* Baltimore, MD: Center for a Livable Future. Retrieved from http://www.jhsph.edu/research/centers-and-institutes/johns-hopkins-center-for-a-livable-future/research/clf_publications/pub_rep_desc/instituting-change.html

37 Garnett, T. (2016). Plating up solutions. *Science, 353*(6305), 1202-1204.

38 Day, L. (2013). Proteins from land plants–potential resources for human nutrition and food security. *Trends in Food Science & Technology, 32*(1), 25-42.

39 Craig, W.J., & Mangels, A.R. (2009). Position of the American Dietetic Association: Vegetarian diets. *Journal of the American Dietetic Association, 109*(7), 1266-1282.

40 Mangels, R. (n.d.). Vitamin B12 in the vegan diet. Retrieved from http://www.vrg.org/nutrition/b12.php

[41] Messina, G.K. (n.d.). Vitamin B12: A vegan nutrition primer. Retrieved from http://www.theveganrd.com/vegan-nutrition-primers/vitamin-b12-a-vegan-nutrition-primer

[42] Food and Nutrition Board, Institute of Medicine, Standing Committee on the Scientific Evaluation of Dietary Reference Intakes. (1998). *Dietary reference intakes for thiamin, riboflavin, niacin, vitamin B6, folate, vitamin B12, pantothenic acid, biotin, and choline*. National Academies Press (US), 58-86.

[43] Hu, F.B., & Willett, W.C. (2002). Optimal diets for prevention of coronary heart disease. *Jama, 288*(20), 2569-2578.

[44] Lee, J.H., O'Keefe, J.H., Lavie, C.J., & Harris, W.S. (2009). Omega-3 fatty acids: Cardiovascular benefits, sources and sustainability. *Nature Reviews Cardiology, 6*(12), 753-758.

[45] Larqué, E., Gil-Sánchez, A., Prieto-Sánchez, M. T., & Koletzko, B. (2012). Omega 3 fatty acids, gestation and pregnancy outcomes. *British Journal of Nutrition, 107*(S2), S77-S84.

[46] Harris, W.S., Mozaffarian, D., Lefevre, M., Toner, C.D., Colombo, J., Cunnane, S.C., ... & Whelan, J. (2009). Towards establishing dietary reference intakes for eicosapentaenoic and docosahexaenoic acids. *The Journal of nutrition, 139*(4), 804S-819S.

[47] US Department of Health and Human Services & US Department of Agriculture. (2015). *2015-2020 Dietary Guidelines for Americans*. 8th edition. Retrieved from https://health.gov/dietaryguidelines/2015/resources/2015-2020_Dietary_Guidelines.pdf

[48] Simopoulos, A.P. (2002). The importance of the ratio of omega-6/omega-3 essential fatty acids. *Biomed. Pharmacother. 56*, 365–379.

[49] Wijendran, V., & Hayes, K.C. (2004). Dietary n-6 and n-3 fatty acid balance and cardiovascular health. *Annu. Rev. Nutr., 24*, 597-615.

[50] Clune, S., Crossin, E., & Verghese, K. (2016). Systematic review of greenhouse gas emissions for different fresh food categories. *Journal of Cleaner Production*, in press.

[51] Weber, C.L., & Matthews, H.S. (2008). Food-miles and the relative climate impacts of food choices in the United States. *Environmental Science & Technology, 42*(10), 3508-3513.

[52] Gerber, P. J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., ... & Tempio, G. (2013). *Tackling climate change through livestock: A global assessment of emissions and mitigation opportunities*. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO).

[53] US Environmental Protection Agency (2016). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2014*. Retrieved from https://www.epa.gov/sites/production/files/2016-04/documents/us-ghg-inventory-2016-chapter-executive-summary.pdf

[54] Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., ... & Balzer, C. (2011). Solutions for a cultivated planet. *Nature,478*(7369), 337-342.

[55] US Environmental Protection Agency (n.d.). Understanding global warming potentials. Retrieved September 26, 2016 from https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

[56] Garnett, T. (2011). Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)?. *Food Policy, 36*, S23-S32.

[57] Allen, M. (2015). *Short-lived promise? The science and policy of cumulative short-lived climate pollutants*. Oxford Martin School Policy Paper. Retrieved from http://www.oxfordmartin.ox.ac.uk/downloads/briefings/Short_Lived_Promise.pdf

[58] van Dooren, C., Marinussen, M., Blonk, H., Aiking, H., Vellinga, P. (2014). Exploring dietary guidelines based on ecological and nutritional values: A comparison of six dietary patterns. *Food Policy, 44*, 36–46.

[59] Gerbens-Leenes, P.W., Nonhebel, S. (2003). Consumption patterns and their effects on land required for food. *Ecological Economics, 42*(1–2), 185–199.

[60] De Vries, M., & De Boer, I. J. M. (2010). Comparing environmental impacts for livestock products: A review of life cycle assessments. *Livestock Science,128*(1), 1-11.

[61] Nijdam, D., Rood, T., & Westhoek, H. (2012). The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. *Food Policy, 37*(6), 760-770.

[62] Peters, C.J., Picardy, J., Darrouzet-Nardi, A.F., Wilkins, J.L., Griffin, T.S., & Fick, G.W. (2016). Carrying capacity of US agricultural land: Ten diet scenarios. *Elementa: Science of the Anthropocene, 4*(1), 000116.

[63] Eisler, M.C., Lee, M.R., Tarlton, J.F., Martin, G.B., Beddington, J., Dungait, J.A., ... & Misselbrook, T. (2014). Agriculture: Steps to sustainable livestock. *Nature, 507*(7490), 32.

[64] Smith, J., Sones, K., Grace, D., MacMillan, S., Tarawali, S., & Herrero, M. (2013). Beyond milk, meat, and eggs: Role of livestock in food and nutrition security. *Animal Frontiers, 3*(1), 6-13.

[65] Röös, E., Bajželj, B., Smith, P., Patel, M., Little, D., & Garnett, T. (2016). Protein futures for Western Europe: potential land use and climate impacts in 2050. *Regional Environmental Change,* 1-11.

[66] Machovina, B., Feeley, K.J., & Ripple, W.J. (2015). Biodiversity conservation: The key is reducing meat consumption. *Science of the Total Environment, 536,* 419-431.

[67] Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., ... & Swackhamer, D. (2001). Forecasting agriculturally driven global environmental change. *Science, 292*(5515), 281-284.

[68] Stehfest, E., Bouwman, L., Van Vuuren, D. P., Den Elzen, M. G., Eickhout, B., & Kabat, P. (2009). Climate benefits of changing diet. *Climatic Change, 95*(1-2), 83-102.

[69] Albanito, F., Beringer, T., Corstanje, R., Poulter, B., Stephenson, A., Zawadzka, J., & Smith, P. (2015). Carbon implications of converting cropland to bioenergy crops or forest for climate mitigation: A global assessment. *GCB Bioenergy, 8*(1), 81–95.

[70] Schiere, H., & Kater, L. (2001). *Mixed crop-livestock farming: a review of traditional technologies based on literature and field experiences.* Rome: FAO.

[71] Water Footprint Network (n.d.). What is a water footprint? Retrieved August 29, 2016 from http://waterfootprint.org/en/water-footprint/what-is-water-footprint/

[72] Gerbens-Leenes, P.W., Mekonnen, M.M., & Hoekstra, A.Y. (2013). The water footprint of poultry, pork and beef: A comparative study in different countries and production systems. *Water Resources and Industry, 1,* 25-36.

[73] Mekonnen, M.M., & Hoekstra, A.Y. (2011). The green, blue and water footprint of crops and derived crop products. *Hydrology and Earth System Sciences, 15*(5), 1577-1600.

[74] Pfister, S., Koehler, A., & Hellweg, S. (2009). Assessing the environmental impacts of freshwater consumption in LCA. *Environmental Science & Technology, 43*(11), 4098-4104.

[75] Chenoweth, J., Hadjikakou, M., & Zoumides, C. (2014). Quantifying the human impact on water resources: A critical review of the water footprint concept. *Hydrology and Earth System Sciences, 18*(6), 2325-2342.

[76] Mekonnen, M.M., & Hoekstra, A.Y. (2012). A global assessment of the water footprint of farm animal products. *Ecosystems, 15*(3), 401-415.

[77] Vanham, D., Hoekstra, A.Y., & Bidoglio, G. (2013). Potential water saving through changes in European diets. *Environment International, 61,* 45-56.

[78] Vanham, D., Mekonnen, M.M., & Hoekstra, A.Y. (2013). The water footprint of the EU for different diets. *Ecological Indicators, 32,* 1-8.

[79] Hoekstra, A.Y., & Webster, J. (2010). The water footprint of animal products. *The meat crisis: Developing more sustainable production and consumption,* 22-33.

[80] Hess, T., Andersson, U., Mena, C., & Williams, A. (2015). The impact of healthier dietary scenarios on the global blue water scarcity footprint of food consumption in the UK. *Food Policy, 50,* 1–10.

[81] Erisman, J. W., Sutton, M. A., Galloway, J., Klimont, Z., & Winiwarter, W. (2008). How a century of ammonia synthesis changed the world. *Nature Geoscience, 1*(10), 636-639.

[82] Cordell, D., Drangert, J.O., & White, S. (2009). The story of phosphorus: Global food security and food for thought. *Global Environmental Change, 19*(2), 292-305.

[83] Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F.S., Lambin, E.F., ... & Foley, J.A. (2009). A safe operating space for humanity. *Nature, 461*(7263), 472-475.

[84] Erisman, J.W., Galloway, J.N., Seitzinger, S., Bleeker, A., Dise, N.B., Petrescu, A.R., ... & de Vries, W. (2013). Consequences of human modification of the global nitrogen cycle. *Philosophical Transactions of the Royal Society B: Biological Sciences, 368*(1621), 20130116.

[85] Mallin, M.A., & Cahoon, L.B. (2003). Industrialized animal production—A major source of nutrient and microbial pollution to aquatic ecosystems. *Population and Environment, 24*(5), 369-385.

[86] Brender, J.D., Weyer, P.J., Romitti, P.A., Mohanty, B.P., Shinde, M.U., Vuong, A.M., ... & Canfield, M.A. (2013). Prenatal nitrate intake from drinking water and selected birth defects in off- spring of participants in the national birth defects prevention study. *Environmental Health Perspectives, 121,* 1083–1089

[87] Gulis, G., Czompolyova, M., & Cerhan, J.R. (2002). An ecologic study of nitrate in municipal drinking water and cancer incidence in Trnava District, Slovakia. *Environmental Research, 88,* 182–187.

[88] Ward, M. H., Kilfoy, B. A., Weyer, P. J., Anderson, K. E., Folsom, A. R., & Cerhan, J. R. (2010). Nitrate intake and the risk of thyroid cancer and thyroid disease. *Epidemiology, 21*(3), 389.

[89] Inoue- Choi, M., Jones, R. R., Anderson, K. E., Cantor, K. P., Cerhan, J. R., Krasner, S., ... & Ward, M. H. (2015). Nitrate and nitrite ingestion and risk of ovarian cancer among postmenopausal women in Iowa. *International Journal of Cancer, 137*(1), 173-182.

[90] Crutzen, P., & Ehhalt, D. (1977). Effects of nitrogen fertilizers and combustion on the stratospheric ozone layer. *Ambio,* 6(2/3), 112–117.

[91] Leach, A. M., Galloway, J. N., Bleeker, A., Erisman, J. W., Kohn, R., & Kitzes, J. (2012). A nitrogen footprint model to help consumers understand their role in nitrogen losses to the environment. *Environmental Development, 1*(1), 40-66.

[92] Bouwman, L., Goldewijk, K.K., Van Der Hoek, K.W., Beusen, A.H., Van Vuuren, D.P., Willems, J., ... & Stehfest, E. (2013). Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period. *Proceedings of the National Academy of Sciences, 110*(52), 20882-20887.

[93] Leach, A.M., Majidi, A.N., Galloway, J.N., & Greene, A.J. (2013). Toward institutional sustainability: A nitrogen footprint model for a university. *Sustainability: The Journal of Record, 6*(4), 211-219.

[94] Metson, G. S., Smith, V. H., Cordell, D. J., Vaccari, D. A., Elser, J. J., & Bennett, E. M. (2014). Phosphorus is a key component of the resource demands for meat, eggs, and dairy production in the United States. *Proceedings of the National Academy of Sciences, 111*(46), E4906-E4907.

[95] Metson, G.S., Cordell, D., & Ridoutt, B. (2016). Potential impact of dietary choices on phosphorus recycling and global phosphorus footprints: the case of the average Australian city. *Frontiers in Nutrition, 3.*

[96] MacDonald, G.K., Bennett, E.M., & Carpenter, S.R. (2012). Embodied phosphorus and the global connections of United States agriculture. *Environmental Research Letters, 7*(4), 044024.

[97] Tomich, T.P., Brodt, S.B., Dahlgren, R.A., & Scow, K.M. (n.d.) *The California Nitrogen Assessment: Challenges and Solutions for People, Agriculture, and the Environment.* UC Davis Agricultural Sustainability Institute, University of California Agriculture and Natural Resources. Retrieved from http://asi.ucdavis.edu/programs/sarep/research-initiatives/are/nutrient-mgmt/california-nitrogen-assessment/ExecutiveSummaryLayout_FINAL_reduced.pdf

[98] Balazs, C., Morello-Frosch, R., Hubbard, A., & Ray, I. (2011). Social disparities in nitrate- contaminated drinking water in California's San Joaquin Valley. *Environmental Health Perspectives, 119*(9), 1272.

[99] Moore, E., & Matalon, E. (2011). *The Human Costs of Nitrate-contaminated Drinking Water in the San Joaquin Valley.* Oakland, CA: Pacific Institute. Retrieved from http://pacinst.org/app/uploads/2013/02/nitrate_contamination3.pdf

[100] Philpott, T. (2016). This region is twice Flint's size—and its water is also poisoned. *Mother Jones* (August 17). Retrieved from http://www.motherjones.com/environment/2016/08/californias-ag-boom-means-poisoned-water-more-least-212000-people

[101] Grossman, E. (2014). As dairy farms grow bigger, new concerns about pollution. Yale Environment 360 Report. Retrieved from http://e360.yale.edu/feature/as_dairy_farms_grow_bigger_new_concerns_about_pollution/2768/

[102] Boesch, D.F., Brinsfield, R.B., & Magnien, R.E. (2001). Chesapeake Bay eutrophication: Scientific understanding, ecosystem restoration, and challenges for agriculture. *Journal of Environmental Quality,* 30, 303–320.

[103] Fairbrother, A. (2012). The Chesapeake Bay is a polluted mess: Are chickens to blame? *Take Part* (October 11). Retrieved from http://www.takepart.com/article/2012/10/10/who-owns-15-billion-pounds-chicken-poop-delmarva-peninsula

[104] Lake Erie Commission (2013). Ohio Lake Erie Phosphorus Task Force Final Report. Ohio Department of Agriculture, Department of Natural Resources. Retrieved from http://lakeerie.ohio.gov/Portals/0/Reports/Task_Force_Report_October_2013.pdf

[105] Nassauer, J.I., Santelmann, M.V., & Scavia, D. (2007). From the Corn Belt to the Gulf: Societal and environmental implications of alternative agricultural futures. Washington, D.C.: Resources for the Future.

[106] Fry, J.P., Love, D.C., MacDonald, G.K., West, P.C., Engstrom, P.M., Nachman, K.E., & Lawrence, R.S. (2016). Environmental health impacts of feeding crops to farmed fish. *Environment International, 91,* 201-214.

[107] Graham, J.P., Nachman, K.E. (2010). Managing waste from confined animal feeding operations in the United States: the need for sanitary reform. *Journal of Water Health, 8,* 646–670.

[108] Cooper, J., & Dobson, H. (2007). The benefits of pesticides to mankind and the environment. *Crop Protection, 26*(9), 1337-1348.

[109] Replace with update citation: "Fitch, C., Hricko, C., & Martin, B. (2017). *Public Health, Immigration Reform and Food System Change.* Baltimore, MD: Johns Hopkins Center for a Livable Future".

[110] Harrison, J.L. (2011). Pesticide drift and the pursuit of environmental justice. Cambridge, MA: MIT Press.

[111] Garry, V.F. (2004). Pesticides and children. *Toxicology and Applied Pharmacology, 198*(2), 152-163.

[112] Eskenazi, B., Bradman, A., & Castorina, R. (1999). Exposures of children to organophosphate pesticides and their potential adverse health effects. *Environmental Health Perspectives, 107*(Suppl 3), 409.

[113] Cooper, J., & Dobson, H. (2007). The benefits of pesticides to mankind and the environment. *Crop Protection, 26*(9), 1337-1348.

[114] Smith-Spangler, C., Brandeau, M.L., Hunter, G.E., Bavinger, J.C., Pearson, M., Eschbach, P.J., ... & Bravata, D.M. (2012). Are organic foods safer or healthier than conventional alternatives?: A systematic review. *Annals of Internal Medicine, 157*(5), 348-366.

115 Curl, C.L., Beresford, S.A., Fenske, R.A., Fitzpatrick, A.L., Lu, C., Nettleton, J.A. & Kaufman, J.D.

(2015). Estimating pesticide exposure from dietary intake and organic food choices: The multi-ethnic study of atherosclerosis (MESA). *Environmental Health Perspectives, 123*(5), 475-83.

[116] Horrigan, L., Lawrence, R.S., & Walker, P. (2002). How sustainable agriculture can address the environmental and human health harms of industrial agriculture. *Environmental Health Perspectives, 110*(5), 445.

[117] DeLorenzo, M. E., Scott, G. I., & Ross, P. E. (2001). Toxicity of pesticides to aquatic microorganisms: a review. *Environmental Toxicology and Chemistry, 20*(1), 84-98.

[118] Potts, S.G., Biesmeijer, J.C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W.E. (2010). Global pollinator declines: Trends, impacts and drivers. *Trends in Ecology & Evolution, 25*(6), 345-353.

[119] Desneux, N., Decourtye, A., & Delpuech, J.M. (2007). The sublethal effects of pesticides on beneficial arthropods. *Annual Review of Entomology, 52,* 81-106.

[120] Godfray, H.C.J., Blacquiere, T., Field, L.M., Hails, R.S., Petrokofsky, G., Potts, S.G., ... & McLean, A.R. (2014). A restatement of the natural science evidence base concerning neonicotinoid insecticides and insect pollinators. *Proceedings of the Royal Society B,* 281(1786), 20140558.

[121] Traynor, K.S., Pettis, J.S., Tarpy, D.R., Mullin, C.A., Frazier, J.L., & Frazier, M. (2016). In-hive pesticide exposome: Assessing risks to migratory honey bees from in-hive pesticide contamination in the Eastern United States. *Nature Scientific Reports, 6.*

[122] McKie, R. (2016). Millions at risk as deadly fungal infections acquire drug resistance. *Guardian* (August 27). Retrieved from https://www.theguardian.com/society/2016/aug/27/millions-at-risk-as-deadly-fungal-infections-acquire-drug-resistance

[123] US Food and Drug Administration (2015). *Summary report on antimicrobials sold or distributed for food-producing animals in 2014.* Silver Spring, MD: FDA. Retrieved from http://www.fda.gov/downloads/ForIndustry/UserFees/AnimalDrugUserFeeActADUFA/UCM476258.pdf

[124] Health Care Without Harm (2014). *Expanding Antibiotic Stewardship: The role of health care in eliminating antibiotic overuse in animal agriculture.* Retrieved from https://noharm-uscanada.org/sites/default/files/documents-files/2735/Expanding%20Antibiotic%20Stewardship.pdf

[125] Cabello, F.C. (2006). Heavy use of prophylactic antibiotics in aquaculture: A growing problem for human and animal health and for the environment. *Environmental Microbiology, 8,* 1137–1144.

[126] Rushton, J., Ferreira, J.P., & Stärk, K.D. (2014). Antimicrobial Resistance: The Use of Antimicrobials in the Livestock Sector. OECD Food, Agriculture and Fisheries Papers, No. 68, OECD Publishing. Retrieved from http://dx.doi.org/10.1787/5jxvl3dwk3f0-en

[127] Kolodziej, E.P., Harter, T., & Sedlak, D.L. (2004). Dairy wastewater, aquaculture, and spawning fish as sources of steroid hormones in the aquatic environment. *Environmental Science & Technology, 38*(23), 6377-6384.

[128] Jobling, S., Nolan, M., Tyler, C.R., Brighty, G., & Sumpter, J.P. (1998). Widespread sexual disruption in wild fish. *Environmental Science & Technology, 32*(17), 2498-2506.

[129] Thorpe, K.L., Cummings, R.I., Hutchinson, T.H., Scholze, M., Brighty, G., Sumpter, J.P., & Tyler, C.R. (2003). Relative potencies and combination effects of steroidal estrogens in fish. *Environmental Science & Technology, 37*(6), 1142-1149.

[130] Lange, I.G., Daxenberger, A., Schiffer, B., Witters, H., Ibarreta, D., & Meyer, H.H. (2002). Sex hormones originating from different livestock production systems: Fate and potential disrupting activity in the environment. *Analytica Chimica Acta, 473*(1), 27-37.

[131] Jackson, L.E., Pascual, U., & Hodgkin, T. (2007). Utilizing and conserving agrobiodiversity in agricultural landscapes. *Agriculture, Ecosystems & Environment, 121*(3), 196-210.

[132] Thrupp, L.A. (2000). Linking agricultural biodiversity and food security: The valuable role of sustainable agriculture. *International Affairs,* 265-281.

[133] Brussaard, L., De Ruiter, P.C., & Brown, G.G. (2007). Soil biodiversity for agricultural sustainability. *Agriculture, Ecosystems & Environment, 121*(3), 233-244.

[134] Myers, M.L. (2010). Review of occupational hazards associated with aquaculture. *Journal of Agromedicine, 15*(4) 412-426.

[135] Food Chain Workers Alliance and Solidarity Research Cooperative (2016). *No Piece of the Pie: U.S. Food Workers in 2016*. Los Angeles, CA: Food Chain Workers Alliance.

[136] Brown, S., & Getz, C. (2008). Towards domestic fair trade? Farm labor, food localism, and the 'family scale' farm. *GeoJournal, 73*(1), 11-22.

[137] Oxfam America (2015). *Lives on the Line: The Human Cost of Cheap Chicken*. Retrieved from https://www.oxfamamerica.org/static/media/files/Lives_on_the_Line_Full_Report_Final.pdf

[138] Donham, K.J., Wing, S., Osterberg, D., Flora, J.L., Hodne, C., Thu, K.M., & Thome, P.S. (2007). Community health and socioeconomic issues surrounding concentrated animal feeding operations. *Environmental Health Perspectives,* 317-320.

[139] World Wide Fund for Nature (WWF) (2014). *The Growth of Soy: Impacts and Solutions*. Gland, Switzerland: WWF International. Retrieved from http://wwf.panda.org/what_we_do/footprint/agriculture/soy/soyreport/index.cfm

[140] Parker-Gibson, N. (2015). Quinoa: Catalyst or catastrophe?. *Journal of Agricultural & Food Information, 16*(2), 113-122.

[141] Garnett, T., Mathewson, S., Angelides, P., & Borthwick, F. (2015). *Policies and actions to shift eating patterns: What works*? Oxford, UK: Food Climate Research Network and Chatham House. Retrieved from http://www.fcrn.org.uk/sites/default/files/fcrn_chatham_house_0.pdf

[142] Thornton, P.K. (2010). Livestock production: Recent trends, future prospects. *Philosophical Transactions of the Royal Society of London B: Biological Sciences, 365*(1554), 2853-2867.

[143] Miele, M. (2011). The taste of happiness: Free-range chicken. *Environment and Planning A, 43,* 2076–2090.

[144] Young, V.R., & Pellett, P.L. (1994). Plant proteins in relation to human protein and amino acid nutrition. *The American Journal of Clinical Nutrition, 59*(5), 1203S-1212S.

[145] USDA ARS (2016). Food Composition Databases: Nutrient Lists. Retrieved September 25, 2016 from https://ndb.nal.usda.gov/ndb/nutrients

[146] Scarborough, P., Appleby, P.N., Mizdrak, A., Briggs, A.D., Travis, R.C., Bradbury, K.E., & Key, T.J. (2014). Dietary greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK. *Climatic Change, 125*(2), 179-192.

[147] Nadathur, S., Wanasundara, J., & Scanlin, L. (eds.)(2016). *Sustainable Protein Sources.* London, UK: Elsevier.

[148] Post, M.J. (2012). Cultured meat from stem cells: Challenges and prospects. *Meat Science, 92*(3), 297–301.

[149] Spiegel, V.D.M., Noordam, M.Y., & Fels- Klerx, H.J. (2013). Safety of novel protein sources (insects, microalgae, seaweed, duckweed, and rapeseed) and legislative aspects for their application in food and feed production. *Comprehensive Reviews in Food Science and Food Safety, 12*(6), 662-678.

[150] Tom, M.S., Fischbeck, P.S., & Hendrickson, C.T. (2016). Energy use, blue water footprint, and greenhouse gas emissions for current food consumption patterns and dietary recommendations in the US. *Environment Systems and Decisions, 36*(1), 92-103.

[151] Kim, B.F., Nachman, K.E., Neff, R.A., Spiker, M.L., & Santo, R.E. (2016). Concerns re: interpretation and translation of findings in Energy use, blue water footprint, and greenhouse gas emissions for current food consumption patterns and dietary recommendations in the US. *Environment Systems and Decisions, 36*(1), 104-105.

[152] Carlsson-Kanyama, A. (1998). Climate change and dietary choices—how can emissions of greenhouse gases from food consumption be reduced? *Food Policy, 23*(3/4), 277-293.

[153] Van Kernebeek, H.R.J., Oosting, S.J., Feskens, E.J.M., Gerber, P.J., & De Boer, I.J.M. (2014). The effect of nutritional quality on comparing environmental impacts of human diets. *Journal of Cleaner Production, 73,* 88-99.

[154] Pernollet, F., Coelho, C.R., & van der Werf, H.M. (2016). Methods to simplify diet and food life cycle inventories: Accuracy versus data-collection resources. *Journal of Cleaner Production,* in press.

[155] Fusi, A., Bacenetti, J., González-García, S., Vercesi, A., Bocchi, S., & Fiala, M. (2014). Environmental profile of paddy rice cultivation with different straw management. *Science of the Total Environment, 494,* 119-128.

[156] Kendall, A., Marvinney, E., Brodt, S., Zhu, W., & Yuan, J. (2012). Greenhouse gas and energy footprint (Life Cycle Assessment) of California almond production. *Almond Board of California.* Retrieved from http://almondboard.com/PR/A.2011.11-AIR8-Kendall.Kendall.Greenhouse%20Gas%20and%20Energy%20Footprint.pdf

[157] Gattinger, A., Muller, A., Haeni, M., Skinner, C., Fliessbach, A., Buchmann, N., ... & Niggli, U. (2012). Enhanced top soil carbon stocks under organic farming. *Proceedings of the National Academy of Sciences, 109*(44), 18226-18231.

[158] Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science, 304*(5677), 1623-1627.

[159] He, Y., Trumbore, S.E., Torn, M.S., Harden, J.W., Vaughn, L.J.S., Allison, S.D., Randerson, J.T. (2016). Radiocarbon constraints imply reduced carbon uptake by soils during the 21st century. *Science, 353*(6306), 1419-1424.

[160] Pulse Canada (n.d.). What is a pulse? Retrieved September 20, 2016 from http://www.pulsecanada.com/food-health/what-is-a-pulse

[161] UN Food and Agriculture Organization (FAO)(2016). Pulses and biodiversity. Retrieved from http://www.fao.org/fileadmin/user_upload/pulses-2016/docs/factsheets/Biodiversity_EN_PRINT.pdf

162 Rose, T. J., Hardiputra, B., & Rengel, Z. (2010). Wheat, canola and grain legume access to soil phosphorus fractions differs in soils with contrasting phosphorus dynamics. *Plant and Soil, 326*(1-2), 159-170.

[163] Sinclair, T.R., & Vadez, V. (2012). The future of grain legumes in cropping systems. *Crop and Pasture Science, 63*(6), 501-512.

[164] Crews, T.E., & Peoples, M.B. (2004). Legume versus fertilizer sources of nitrogen: Ecological tradeoffs and human needs. *Agriculture, Ecosystems & Environment, 102*(3), 279-297.

[165] Williams, M., Stout, J., Roth, B., Cass, S., Pappa, V., & Rees, B. (2014). *Environmental implications of legume cropping.* Legume Futures Report 3.7. Retrieved from http://www.legumefutures.de/images/Legume_Futures_Report_3.7.pdf

[166] UN Food and Agriculture Organization (FAO)((2016). What are pulses? Retrieved from http://www.fao.org/pulses-2016/news/news-detail/en/c/337107/

[167] US Department of Agriculture (2016). Dry Beans. Retrieved October 16, 2016 from http://www.ers.usda.gov/topics/crops/vegetables-pulses/dry-beans/

[168] US Department of Agriculture, National Agricultural Statistics Service (2016). Acreage. Retrieved from http://usda.mannlib.cornell.edu/usda/current/Acre/Acre-06-30-2016.pdf

[169] UN Food and Agriculture Organization (FAO)(2016). FAOSTAT: Detailed Trade Matrix 2011 data, United States. Retrieved April 2016 from http://faostat3.fao.org/download/T/TM/E

[170] UN Food and Agriculture Organization (FAO)(2015). FAOSTAT: Production. Retrieved September 20, 2016 from http://faostat3.fao.org/browse/Q/QC/E

[171] McBride, W., & Greene, C. (2015). Despite profit potential, organic field crop acreage remains low. *Amber Waves* (November 2). US Department of Agriculture, Economic Research Service. Retrieved from http://www.ers.usda.gov/amber-waves/2015/november/despite-profit-potential-organic-field-crop-acreage-remains-low/

[172] US Department of Agriculture (2016). Soybeans & Oil Crops Background. Retrieved September 20, 2016 from http://www.ers.usda.gov/topics/crops/soybeans-oil-crops/background.aspx

[173] López, S. L., Aiassa, D., Benitez-Leite, S., Lajmanovich, R., Manas, F., Poletta, G., ... & Carrasco, A. E. (2012). Pesticides used in South American GMO-based agriculture: A review of their effects on humans and animal models. *Advances in Molecular Toxicology, 6,* 41-75.

[174] Leguizamón, A. (2016). Environmental injustice in Argentina: Struggles against genetically modified soy. *Journal of Agrarian Change.*

[175] Motta, R., & Arancibia, F. (2015). Health experts challenge the safety of pesticides in Argentina and Brazil. In Chamberlain, J.M. (e.d.), *Medicine, Risk, Discourse and Power,*164-179.

[176] UN Food and Agriculture Organization (FAO)(2008). Meat products with high levels of extenders and fillers. FAO Corporate Document Repository. Retrieved from http://www.fao.org/docrep/010/ai407e/AI407E16.htm

[177] UN Food and Agriculture Organization (FAO)(2016). Health benefits of pulses. Retrieved from http://www.fao.org/fileadmin/user_upload/pulses-2016/docs/factsheets/Health_EN_PRINT.pdf

[178] Mudryi, A., Yu, N., & Aukema, H. (2014). Nutritional and health benefits of pulses. *Applied Physiology, Nutrition, and Metabolism, 39*(11), 1197-1204.

[179] Rebello, C., Greenway, F., & Finley, J. (2014). A review of the nutritional value of legumes and their effects on obesity and its related co-morbidities. *Obesity Reviews, 15*(5), 392-407.

[180] Souza, R., Gomes, A., Naves, M., & Mota, J. (2015). Nuts and legume seeds for cardiovascular risk reduction: Scientific evidence and mechanisms of action. *Nutrition Reviews, 73*(6), 335-347.

[181] Rebello, C., Greenway, F., & Finley, J. (2014). Whole grains and pulses: A comparison of the nutritional and health benefits. *Journal of Agricultural and Food Chemistry, 62*(29), 7029-7049.

[182] Farvid, M., Cho, E., Chen, W., Eliassen, A., & Willett, W. (2014). Dietary protein sources in early adulthood and breast cancer incidence: Prospective cohort study. *BMJ, 348*, g3437.

[183] Wolever, T.M., Jenkins, D.J., Thompson, L.U., Wong, G.S., & Josse, R.G. (1987). Effect of canning on the blood glucose response to beans in patients with type 2 diabetes. *Human nutrition. Clinical nutrition, 41*(2), 135-140.

[184] Duranti, M. (2006). Grain legume proteins and nutraceutical properties. *Fitoterapia, 77*, 67–82.

[185] Khandelwal, S., Udipi, S. A., & Ghugre, P. (2010). Polyphenols and tannins in Indian pulses: Effect of soaking, germination and pressure cooking. *Food Research International, 43*(2), 526-530.

[186] Henkel, J. (2000). Soy: Health claims for soy protein, questions about other components. *FDA Consumer, 34*(3), 13-15, 18-20.

[187] Omoni, A.O., & Aluko, R.E. (2005). Soybean foods and their benefits: Potential mechanisms of action. *Nutrition Reviews, 63*(8), 272-283.

[188] Rietjens, I. M., Louisse, J., & Beekmann, K. (2016). The potential health effects of dietary phytoestrogens. *British Journal of Pharmacology*.

[189] Anderson, J.W., Johnstone, B.M., & Cook-Newell, M.E. (1995). Meta-analysis of the effects of soy protein intake on serum lipids. *New England Journal of Medicine, 333*(5), 276-282.

[190] Reynolds, K., Chin, A., Lees, K.A., Nguyen, A., Bujnowski, D., & He, J. (2006). A meta-analysis of the effect of soy protein supplementation on serum lipids. *The American Journal of Cardiology, 98*(5), 633-640.

[191] Clarkson, T.B. (2002). Soy, soy phytoestrogens and cardiovascular disease. *The Journal of nutrition, 132*(3), 566S-569S.

[192] Bawa, S. (2010). The significance of soy protein and soy bioactive compounds in the prophylaxis and treatment of osteoporosis. *Journal of Osteoporosis*, 891058.

[193] Zhang, X., Shu, X.O., Li, H., Yang, G., Li, Q., Gao, Y.T., & Zheng, W. (2005). Prospective cohort study of soy food consumption and risk of bone fracture among postmenopausal women. *Archives of Internal Medicine, 165*(16), 1890-1895.

[194] Hotz, C., & Gibson, R.S. (2007). Traditional food-processing and preparation practices to enhance the bioavailability of micronutrients in plant-based diets. *Journal of Nutrition, 137*(4), 1097-100.

[195] Macfarlane, B.J., van der Riet, W.B., Bothwell, T.H., Baynes, R.D., Siegenberg, D., Schmidt, U., ... & Mayet, F. (1990). Effect of traditional oriental soy products on iron absorption. *American Journal of Clinical Nutrition, 1*(5), 873-80.

[196] Franco, O. H., Chowdhury, R., Troup, J., Voortman, T., Kunutsor, S., Kavousi, M., ... & Muka, T. (2016). Use of plant-based therapies and menopausal symptoms: A systematic review and meta-analysis. *JAMA, 315*(23), 2554-2563.

[197] Oseni, T., Patel, R., Pyle, J., & Jordan, V.C. (2008). Selective estrogen receptor modulators and phytoestrogens. *Planta Medica, 74*, 1656-65.

[198] Schettler, T. (2014). *The Ecology of Breast Cancer: The Promise of Prevention and Hope for Healing*. Science & Environmental Health Network & Collaborative on Health and the Environment. Chapter 3. Retrieved from http://sehn.org/new-release-the-ecology-of-breast-cancer-the-promise-of-prevention-and-the-hope-for-healing

[199] McCullough, M. (2012). The bottom line on soy and breast cancer (blog). American Cancer Society. Retrieved from http://blogs.cancer.org/expertvoices/2012/08/02/the-bottom-line-on-soy-and-breast-cancer-risk/?_ga=1.177795873.541656139.1456368351

[200] Magnuson, B., Munro, I., Abbot, P., Baldwin, N., Lopez-Garcia, R., Ly, K., ... & Socolovsky, S. (2013). Review of the regulation and safety assessment of food substances in various countries and jurisdictions. *Food Additives & Contaminants: Part A, 30*(7), 1147-1220.

[201] Center for Science in the Public Interest (n.d.). Chemical cuisine. Retrieved from https://cspinet.org/eating-healthy/chemical-cuisine

[202] Davis, J., Sonesson, U., Baumgartner, D., & Nemecek, T. (2010). Environmental impact of four meals with different protein sources: Case studies in Spain and Sweden. *Food Research International, 43,* 1874–1884.

[203] Reijnders, L., & Soret, S. (2003). Quantification of the environmental impact of different dietary protein choices. *American Journal of Clinical Nutrition, 78*(3 Suppl), 664S–668S.

[204] Peters, C. J., Wilkins, J. L., & Fick, G. W. (2007). Testing a complete-diet model for estimating the land resource requirements of food consumption and agricultural carrying capacity: The New York State example. *Renewable Agriculture and Food Systems, 22*(02), 145-153.

[205] Gan, Y., McConkey, B.G., Clayton, G.W., Lafond, G., Johnston, A., & Walley, F. (2004). Management of fertility in the pulse-based cropping systems of Western Canada. Retrieved from http://www.usask.ca/soilsncrops/conference-proceedings/previous_years/Files/2004/2004docs/028.pdf

[206] Leach, A. M., Emery, K. A., Gephart, J., Davis, K. F., Erisman, J. W., Leip, A., ... & Castner, E. (2016). Environmental impact food labels combining carbon, nitrogen, and water footprints. *Food Policy, 61,* 213-223.

[207] Zhu, X., & Van Ierland, E.C. (2004). Protein chains and environmental pressures: A comparison of pork and novel protein foods. *Environmental Sciences, 1*(3), 254-276.

[208] U.S.A. Dry Pea & Lentil Council, & Pulse Canada (2002). Pest Management Strategic Plan for Pulse Crops (Chickpeas, Lentils, and Dry Peas) in the United States and Canada. Retrieved from www.ipmcenters.org/pmsp/pdf/USCAPulsePMSP.pdf

[209] Beyond Pesticides (2016). Eating with a conscience: Beans and peas. Retrieved November 23, 2016 from http://beyondpesticides.org/resources/eating-with-a-conscience/choose-a-crop?foodid=63

[210] US Department of Agriculture, Economic Research Service (2013). Certified organic beans. Acres of soybeans, dry beans, dry peas/lentils by State, 1997 and 2000-11. Retrieved from http://www.ers.usda.gov/data-products/organic-production.aspx

[211] US Department of Agriculture, National Agricultural Statistics (2011). Acreage. Retrieved from http://usda.mannlib.cornell.edu/usda/nass/Acre//2010s/2011/Acre-06-30-2011.pdf

[212] US Department of Agriculture, National Agricultural Statistics (2016). Agricultural Chemical Use. Retrieved August 27, 2016 from https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use/index.php

[213] Beyond Pesticides (2016). Eating with a conscience: Soybeans. Retrieved November 23, 2016 from http://beyondpesticides.org/resources/eating-with-a-conscience/choose-a-crop?foodid=62

[214] US Department of Agriculture, Economic Research Service (2016). Recent Trends in GE Adoption. Retrieved September 26, 2016 from http://www.ers.usda.gov/data-products/adoption-of-genetically-engineered-crops-in-the-us/recent-trends-in-ge-adoption.aspx

[215] National Research Council (2010). *The Impact of Genetically Engineered Crops on Farm Sustainability in the United States*. Washington, DC: The National Academies Press. Retrieved from https://www.nap.edu/catalog/12804/the-impact-of-genetically-engineered-crops-on-farm-sustainability-in-the-united-states

[216] James, C. (2015). *Global Status of Commercialized Biotech/GM Crops: 2014*. ISAAA brief No. 49. Ithaca, NY: International Service for the Acquisition of Agri-biotech Applications (ISAAA).

[217] Canadian Biotechnology Action Network (2015). *GMO Inquiry 2015: Where in the world are GM crops and foods?* Retrieved from http://gmoinquiry.ca/wp-content/uploads/2015/03/where-in-the-world-gm-crops-foods.pdf

[218] Benbrook, C.M. (2012). Impacts of genetically engineered crops on pesticide use in the U.S. - the first sixteen years. *Environmental Sciences Europe, 24*(l), 24.

[219] Goodman, J. (2014). New seeds, old pesticides -2,4-D and 'next generation' GMOs. *The Ecologist* (Oct 27). Retrieved from http://www.theecologist.org/blogs_and_comments/commentators/2597864/new_seeds_old_pesticides_24d_and_next_generation_gmos.html

[220] Fritschi, L., McLaughlin, J., Sergi, C.M., Calaf, G.M., Le Curieux, F., Forastiere, F., ... & Martin, M.T. (2015). Carcinogenicity of tetrachlorvinphos, parathion, malathion, diazinon, and glyphosate. *The Lancet Oncology, 16*(5), 490-491.

[221] Loomis, D., Guyton, K., Grosse, Y., El Ghissasi, F., Bouvard, V., Benbrahim-Tallaa, L., ... & Monograph Working Group. (2015). Carcinogenicity of lindane, DDT, and 2, 4-dichlorophenoxyacetic acid. *The Lancet Oncology, 16*(8), 891.

[222] Williams, G.M., Berry, C., Burns, M., de Camargo, J.L.V., & Greim, H. (2016). Glyphosate rodent carcinogenicity bioassay expert panel review. *Critical Reviews in Toxicology, 46*(sup1), 44-55.

[223] Kurenbach, B., Marjoshi, D., Amábile-Cuevas, C.F., Ferguson, G.C., Godsoe, W., Gibson, P., & Heinemann, J.A. (2015). Sublethal exposure to commercial formulations of the herbicides Dicamba, 2, 4-Dichlorophenoxyacetic acid, and Glyphosate cause changes in antibiotic susceptibility in Escherichia coli and Salmonella enterica serovar Typhimurium. *MBio, 6*(2), e00009-15.

[224] Brussaard, L., De Ruiter, P.C., & Brown, G.G. (2007). Soil biodiversity for agricultural sustainability. *Agriculture, Ecosystems & Environment, 121*(3), 233-244.

[225] Vallaeys, C., Kastel, M., Fantle, W., & Buske, L. (2010). Banned in organics but common in "natural" food production: Soy protein and chemical solvents in nutrition bars and meat alternatives. Cornucopia, WI: The Cornucopia Institute. Retrieved from http://www.cornucopia.org/hexane-guides/nvo_hexane_report.pdf

[226] Gaetke, L., Willett, E., Hofe, C., & Finnie, M. (2010). *Environmental Pollutants and Nutrition: Nuts and Seeds.* University of Kentucky Cooperative Extension Service. Retrieved July 22, 2016 from http://www2.ca.uky.edu/agcomm/pubs/fcs3/fcs3545/fcs3545.pdf

[227] King, J.C., Blumberg, J., Ingwersen, L., Jenab, M., & Tucker, K.L. (2008). Tree nuts and peanuts as components of a healthy diet. *The Journal of Nutrition, 138*(9), 1736S-1740S.

[228] Ros, E. (2010). Health benefits of nut consumption. *Nutrients, 2*(7), 652-682.

[229] US Department of Agriculture (2016). California Drought: Crop Sectors. Retrieved July 08, 2016 from http://www.ers.usda.gov/topics/in-the-news/california-drought-farm-and-food-impacts/california-drought-crop-sectors.aspx#.U-TUyYBdU_E

[230] National Peanut Board (n.d.). Peanut Country, U.S.A. Retrieved July 21, 2016 from http://nationalpeanutboard.org/peanut-info/peanut-country-usa.htm

[231] University of Georgia Extension (n.d.). Pecans. Retrieved July 26, 2016, from http://extension.uga.edu/agriculture/ag-fruits-vegetables/pecans/

[232] Perez, A. (2016). Fruit and Tree Nuts: Trade. Retrieved July 21, 2016, from http://www.ers.usda.gov/topics/crops/fruit-tree-nuts/trade.aspx

[233] US Department of Agriculture (2016). Sunflowerseed. Accessed November 14, 2016 from http://www.ers.usda.gov/topics/crops/soybeans-oil-crops/sunflowerseed.aspx

[234] Cherney, J.H., & Small, E. (2016). Industrial hemp in North America: Production, politics and potential. Agronomy, 6(58).

[235] Daniells, S. (2013). Chia boom: With 239% growth, chia category set to hit $1 bn by 2020. Food Navigator USA. Retrieved from http://www.foodnavigator-usa.com/Markets/Chia-boom-With-239-growth-chia-category-set-to-hit-1-bn-by-2020

[236] Schneider, G. (2014). Kentucky firm first to grow Chia seeds in U.S. USA Today (October 22). Retrieved from http://www.usatoday.com/story/news/nation/2014/10/22/kentucky-firm-first-to-grow-chia-seeds-in-us/17750971/

[237] US Department of Agriculture (2016). Food Availability (Per Capita) Data System, Nuts (2014 data). Retrieved November, 2016 from http://www.ers.usda.gov/data-products/food-availability-per-capita-data-system/

[238] Geisseler, D., & Horwath, W.R. (2016). Almond production in California. UC Davis. Retrieved November 22, 2016 from https://apps1.cdfa.ca.gov/FertilizerResearch/docs/Almond_Production_CA.pdf

[239] California Department of Food and Agriculture (2015). California Agricultural Statistics Review, 2014-2015. Retrieved November 23, 2016 from https://www.cdfa.ca.gov/statistics/PDFs/2015Report.pdf

[240] Kris-Etherton, P.M., Hu, F.B., & Sabate, J. (2008). The role of tree nuts and peanuts in the prevention of coronary heart disease: Multiple potential mechanisms. *The Journal of Nutrition, 138*(9), 1746S-1751S.

[241] Vannice, G., & Rasmussen, H. (2014). Position of the academy of nutrition and dietetics: Dietary fatty acids for healthy adults. *Journal of the Academy of Nutrition and Dietetics, 114*(1), 136-153.

[242] Bao, Y., Han, J., Hu, F.B., Giovannucci, E.L., Stampfer, M.J., Willett, W.C., & Fuchs, C.S. (2013). Association of nut consumption with total and cause-specific mortality. *New England Journal of Medicine, 369*, 2001-2011.

[243] Sicherer, S.H., Muñoz-Furlong, A., Godbold, J.H., & Sampson, H.A. (2010). US prevalence of self-reported peanut, tree nut, and sesame allergy: 11-year follow-up. *Journal of Allergy and Clinical Immunology, 125*(6), 1322-1326.

[244] Thomas, R. & Gebhardt, S. (n.d.) Sunflower seed butter and almond butter as nutrient-rich alternatives to peanut butter. Beltsville, MD: Beltsville Human Nutrition Research Center, ARS/USDA. Retrieved September 23, 2016 from https://www.ars.usda.gov/ARSUserFiles/80400525/Articles/ADA10_SunflowerAlmondButter.pdf

[245] Akbulut, M. & Çoklar, H. (2008). Physicochemical and rheological properties of sesame paste (Tahin) processed from hulled and unhulled roasted sesame seeds and their blends at various levels. *Journal of Food Process Engineering, 31*, 488-502.

[246] Sylla, A., Diallo, M. S., Castegnaro, J. J., & Wild, C. P. (1999). Interactions between hepatitis B virus infection and exposure to aflatoxins in the development of hepatocellular carcinoma: a molecular epidemiological approach. *Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis, 428*(1), 187-196.

[247] Wild, C. P., & Turner, P. C. (2002). The toxicology of aflatoxins as a basis for public health decisions. *Mutagenesis, 17*(6), 471-481.

[248] Finkel, A.M. (1995). Toward less misleading comparisons of uncertain risks: The example of aflatoxin and alar. *Environmental Health Perspectives, 103*(4), 376.

[249] Krampner, J. (2014). Creamy and crunchy: An informal history of peanut butter, the all-American food. New York, NY: Columbia University Press.

[250] Tosun, H., & Arslan, R. (2013). Determination of aflatoxin B1 levels in organic spices and herbs. *The Scientific World Journal, 2013*.

[251] Luedeling, E., Zhang, M., & Girvetz, E.H. (2009). Climatic changes lead to declining winter chill for fruit and nut trees in California during 1950–2099. *PLoS ONE, 4*(7).

[252] Ames, G.K., & Dufour, R. (2014). *Climate Change and Perennial Fruit and Nut Production: Investing in Resilience in Uncertain Times.* National Center for Appropriate Technology. Retrieved July 15, 2016 from http://asdevelop.org/wp-content/uploads/2015/10/Fruit-Nut-Product-for-Climate-Change.pdf

[253] Sabaté, J., Sranacharoenpong, K., Harwatt, H., Wien, M., & Soret, S. (2014). The environmental cost of protein food choices. *Public Health Nutrition, 18*(11), 2067-2073.

[254] Philpott, T. (2014). Lay off the almond milk, you ignorant hipsters. Mother Jones (July 16). Retrieved from http://www.motherjones.com/tom-philpott/2014/07/lay-off-almond-milk-ignorant-hipsters

[255] Hamblin, J. (2014). The dark side of almond use. *The Atlantic* (August 28). Retrieved from http://www.theatlantic.com/health/archive/2014/08/almonds-demon-nuts/379244/

[256] Hanak, E., Escriva-Bou, A., Howitt, R., Lund, J., Burt, C., Harter, T., ... & Zoldoske, D. (2016). California's Water: Water for Farms. Public Policy Institute of California. Retrieved from www.ppic.org/main/publication.asp?i=1140

[257] Downs, S.M., & Fanzo, J. (2015). Is a cardio-protective diet sustainable? A review of the synergies and tensions between foods that promote the health of the heart and the planet. *Current Nutrition Reports, 4*(4), 313-322.

[258] Almond Board of California (2015). More almonds does not equal more water for agriculture. (2015). Retrieved July 26, 2016 from http://www.almonds.com/blog/water/more-almonds-does-not-equal-more-water-agriculture#_ftnref2

[259] US Environmental Protection Agency (n.d.). Water-Saving Technologies. Retrieved July 26, 2016 from https://www3.epa.gov/watersense/outdoor/tech.html

[260] US Department of Agriculture (2016). 2015 California Almond Acreage Report. Retrieved July 26, 2016 from https://www.nass.usda.gov/Statistics_by_State/California/Publications/Fruits_and_Nuts/201605almac.pdf

[261] Holthaus, E. (2014). The thirsty West: 10 percent of California's water goes to almond farming. The Atlantic (May 14). Retrieved from http://www.slate.com/articles/technology/future_tense/2014/05/_10_percent_of_california_s_water_goes_to_almond_farming.html

[262] Leach, A. M., Emery, K. A., Gephart, J., Davis, K. F., Erisman, J. W., Leip, A., ... & Castner, E. (2016). Environmental impact food labels combining carbon, nitrogen, and water footprints. *Food Policy, 61*, 213-223.

[263] Metson, G. S., Bennett, E. M., & Elser, J. J. (2012). The role of diet in phosphorus demand. *Environmental Research Letters, 7*(4), 044043.

[264] Mahapatro, G. K., & Panigrahi, M. (2014). Endosulfan issue: science verses conscience. *Current Science, 106*(2), 152-155.

[265] Brown, E.G., Rodriquez, M., & Leahy, B. (2016). *Summary of Pesticide Use Report Data, 2014: Indexed by Commodity.* California Environmental Protection Agency, Department of Pesticide Regulation. Retrieved from http://www.cdpr.ca.gov/docs/pur/pur14rep/comrpt14.pdf

[266] Eskenazi, B., Bradman, A., & Castorina, R. (1999). Exposures of children to organophosphate pesticides and their potential adverse health effects. *Environmental Health Perspectives, 107*(Suppl 3), 409.

267 Lee, W. J., Blair, A., Hoppin, J. A., Lubin, J. H., Rusiecki, J. A., Sandler, D. P., ... & Alavanja, M. C. (2004). Cancer incidence among pesticide applicators exposed to chlorpyrifos in the Agricultural Health Study. *Journal of the National Cancer Institute, 96*(23), 1781-1789.

268 Beyond Pesticides (2016). Eating with a conscience: Choose a crop. Retrieved November 23, 2016 from http://beyondpesticides.org/resources/eating-with-a-conscience/choose-a-crop

269 Andersen, P.C., Athearn, K.R., Olmstead, M.A., & Williamson, J.G. (2000). Sustainability Assessment of Fruit and Nut Crops in North Florida and North Central Florida. *IFAS Extension University of Florida*. Retrieved from http://edis.ifas.ufl.edu/pdffiles/MG/MG36700.pdf

270 The White House, Office of the Press Secretary (2014). Fact sheet: The economic challenge posed by declining pollinator populations. Retrieved from https://www.whitehouse.gov/the-press-office/2014/06/20/fact-sheet-economic-challenge-posed-declining-pollinator-populations

271 Colopy, M. (2014). 80,000+ beehives damaged or dead; Beekeepers meet with EPA (blog). Pollinator Stewardship Council. Retrieved September 23, 2016 from http://pollinatorstewardship.org/?p=2192

272 Lamble, L., Hirsch, A., Harris, R., & Chambers, I. (2013). The true cost of cashews. *Guardian* (November 25). Retrieved from https://www.theguardian.com/global-development/ng-interactive/2013/nov/cashew-nut-industry-true-cost

273 Rainey, C. (2015). The high demand for cashews Is crippling harvesters in India and Vietnam. *Grub Street*. Retrieved August 03, 2016, from http://www.grubstreet.com/2015/05/cashew-demand.html

274 Amon, J. (2011). National Cashew Day more than nuts. *Human Rights Watch*. Retrieved August 03, 2016, from https://www.hrw.org/news/2011/10/03/national-cashew-day-more-nuts

275 Human Rights Watch (2011). The rehab archipelago: Forced labor and other abuses in drug detention centers in Southern Vietnam. Retrieved August 03, 2016, from https://www.hrw.org/report/2011/09/07/rehab-archipelago/forced-labor-and-other-abuses-drug-detention-centers-southern

276 Tomich, T.P., Brodt, S.B., Dahlgren, R.A., & Scow, K.M. (n.d.) *The California Nitrogen Assessment: Challenges and Solutions for People, Agriculture, and the Environment*. UC Davis Agricultural Sustainability Institute, University of California Agriculture and Natural Resources. Retrieved from http://asi.ucdavis.edu/programs/sarep/research-initiatives/are/nutrient-mgmt/california-nitrogen-assessment/ExecutiveSummaryLayout_FINAL_reduced.pdf

277 Balazs, C., Morello-Frosch, R., Hubbard, A., & Ray, I. (2011). Social disparities in nitrate- contaminated drinking water in California's San Joaquin Valley. *Environmental Health Perspectives, 119*(9), 1272.

278 Moore, E., & Matalon, E. (2011). *The Human Costs of Nitrate-contaminated Drinking Water in the San Joaquin Valley*. Oakland, CA: Pacific Institute. Retrieved from http://pacinst.org/app/uploads/2013/02/nitrate_contamination3.pdf

279 Laux, M. (2013). Eggs profile. Agricultural marketing resource center. Retrieved September 14, 2016 from http://www.agmrc.org/commodities-products/livestock/poultry/eggs-profile/

280 US Department of Agriculture (1940). Farm production and income: Chickens and eggs, 1938-1939. Retrieved from http://usda.mannlib.cornell.edu/usda/nass/ChicEggs//1940s/1940/ChicEggs-05-00-1940.pdf

281 US Department of Agriculture, National Agricultural Statistics Service (2014). Poultry Inventory and Number Sold: 2012 and 2007. Retrieved from https://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_US/st99_1_032_033.pdf

282 Mench, J.A., Sumner, D.A., & Rosen-Molina, J.T. (2011). Sustainability of egg production in the United States—The policy and market context. *Poultry science, 90*(1), 229-240.

283 USDA, National Agricultural Statistics Service. Chickens and Eggs (September 2016). Retrieved from http://usda.mannlib.cornell.edu/usda/current/ChicEggs/ChicEggs-09-23-2016.pdf

284 Ponte, P.I.P., Prates, J.A.M., Crespo, J.P., Crespo, D.G., Mourão, J.L., Alves, S.P., ... & Fontes, C.M.G.A. (2008). Restricting the intake of a cereal-based feed in free-range-pastured poultry: Effects on performance and meat quality. *Poultry Science, 87*(10), 2032-2042.

285 United Egg Producers (2015). United Egg Producers Animal Husbandry Guidelines for U.S. Egg Laying Flocks: 2016 edition. Retreived from http://uepcertified.com/wp-content/uploads/2015/08/UEP-Animal-Welfare-Guidelines-20141.pdf

286 Coalition for Sustainable Egg Supply (2016). Final Research Results Report. Retrieved from http://www2.sustainableeggcoalition.org/final-results

287 Hilimire, K. (2012). The grass is greener: Farmers' experiences with pastured poultry. *Renewable Agriculture and Food Systems, 27*(03), 173-179.

[288] Ploch, H., Hepworth, M., Laboy, B., Wallace, S., & Morris, S. (n.d.). Hampton Creek Foods Beyond Eggs egg replacer: LCA. Stanford Civil & Environmental Engineering, CEE Class 226. Retrieved from https://cee.stanford.edu/programs/sustainable-design-construction-programs/class-websites/cee-class-226

[289] Zeisel, S.H., & Da Costa, K.A. (2009). Choline: an essential nutrient for public health. *Nutrition Reviews, 67*(11), 615-623.

[290] Shin, J.Y., Xun, P., Nakamura, Y., & He, K. (2013). Egg consumption in relation to risk of cardiovascular disease and diabetes: A systematic review and meta-analysis. *The American Journal of Clinical Nutrition,* ajcn-051318.

[291] Williams, K.A., Krause, A.J., Shearer, S., & Devries, S. (2015). The 2015 Dietary Guidelines Advisory Committee report concerning dietary cholesterol. *The American Journal of Cardiology, 116*(9), 1479-1480.

[292] Nestle, M. (2015). Does eating eggs raise blood cholesterol levels? (Blog). *Food Politics*. Retrieved September 9, 2016 from http://www.foodpolitics.com/2015/11/does-eating-eggs-raise-blood-cholesterol-levels/

[293] Fraeye, I., Bruneel, C., Lemahieu, C., Buyse, J., Muylaert, K., & Foubert, I. (2012). Dietary enrichment of eggs with omega-3 fatty acids: A review. *Food Research International, 48*(2), 961-969.

[294] Harris, W.S., Mozaffarian, D., Lefevre, M., Toner, C.D., Colombo, J., Cunnane, S.C., ... & Whelan, J. (2009). Towards establishing dietary reference intakes for eicosapentaenoic and docosahexaenoic acids. *The Journal of Nutrition, 139*(4), 804S-819S.

[295] Karsten, H.D., Patterson, P.H., Stout, R., & Crews, G. (2010). Vitamins A, E and fatty acid composition of the eggs of caged hens and pastured hens. *Renewable Agriculture and Food Systems, 25*(01), 45-54.

[296] Lopez-Bote, C.J., Arias, R.S., Rey, A.I., Castano, A., Isabel, B., & Thos, J. (1998). Effect of free-range feeding on n− 3 fatty acid and -tocopherol content and oxidative stability of eggs. *Animal Feed Science and Technology,72*(1), 33-40.

[297] Mollenhorst, H., Berentsen, P.B.M., & De Boer, I.J.M. (2006). On-farm quantification of sustainability indicators: an application to egg production systems. *British Poultry Science, 47,* 405–417.

[298] Williams, A.G., Audsley, E. and Sandars, D.L. (2006). *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra. Retrieved from http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=11442

[299] Peters, C. J., Picardy, J. A., Darrouzet-Nardi, A., & Griffin, T. S. (2014). Feed conversions, ration compositions, and land use efficiencies of major livestock products in US agricultural systems. *Agricultural Systems, 130,* 35-43.

[300] Xin, H., Gates, R. S., Green, A. R., Mitloehner, F. M., Moore, P. A., & Wathes, C. M. (2011). Environmental impacts and sustainability of egg production systems. *Poultry Science, 90*(1), 263-277.

[301] Schiere, H., & Kater, L. (2001). *Mixed crop-livestock farming: A review of traditional technologies based on literature and field experiences.* Rome: FAO.

[302] US Food and Drug Administration (FDA). Animal Drugs @ FDA: FDA Approved Animal Drug Products. Retrieved June, 2015 from https://animaldrugsatfda.fda.gov/adafda/views/#/search

[303] Hilimire, K. (2011). Integrated crop/livestock agriculture in the United States: A review. *Journal of Sustainable Agriculture, 35*(4), 376-393.

[304] Whyte, R.T. (2002). Occupational exposure of poultry stockmen in current barn systems for egg production in the United Kingdom. *British Poultry Science, 43,* 364–373.

[305] The Humane League (2016). United Egg Producers announces elimination of chick culling by 2020 [press release]. Retrieved from http://www.thehumaneleague.com/press_releases/uep/

[306] Fleurence, J., Morançais, M., Dumay, J., Decottignies, P., Turpin, V., Munier, M., ... & Jaouen, P. (2012). What are the prospects for using seaweed in human nutrition and for marine animals raised through aquaculture?. *Trends in Food Science & Technology, 27*(1), 57-61.

[307] UN Food and Agriculture Organization (FAO) (2014). The state of world fisheries and aquaculture. Opportunities and challenges. Rome, Italy: FAO.

[308] Larsen, J., & Roney, J. M. (2013). Farmed fish production overtakes beef. Washington, DC: Earth Policy Institute.

[309] National Marine Fisheries Service (2016). Fisheries of the United States, 2015. U.S. Department of Commerce, NOAA Current Fishery Statistics No.2015. Retrieved from http://www.st.nmfs.noaa.gov/Assets/commercial/fus/fus15/documents/FUS2015.pdf

[310] Greenberg, P. (2015). *American catch: The fight for our local seafood.* New York, NY: Penguin.

[311] Health Care Without Harm (2015). Choosing Seafood for Health Care. Retrived from https://noharm-uscanada.org/documents/choosing-seafood-health-care

[312] Sea Grant Delaware (n.d.). Omega-3 content of frequently consumed seafood products. Retrieved September 12, 2016 from http://www.seafoodhealthfacts.org/seafood-nutrition/healthcare-professionals/omega-3-content-frequently-consumed-seafood-products

[313] Nesheim, M.C., Oria, M., & Tsai Yih, P. (eds.) (2015). A framework for assessing effects of the food system. Institute of Medicine and National Research Council. Washington, D.C.: National Academies Press. Chapter 15. Retrieved September 10, 2016 from https://www.nap.edu/read/18846/chapter/15#291

[314] Sydenham, E.D.A. & Lim, W.S. (2012). Fish oils for the prevention of dementia in older people. *The Cochrane Collaboration*. Retrieved from http://www.cochrane.org/CD005379/DEMENTIA_fish-oils-for-the-preventionof-dementia-in-older-people

[315] Lund, E.K. (2013). Health benefits of seafood: Is it just the fatty acids?. *Food chemistry, 140*(3), 413-420.

[316] Gormaz, J.G., Fry, J.P., Erazo, M., & Love, D.C. (2014). Public health perspectives on aquaculture. *Current Environmental Health Reports, 1*(3), 227-238.

[317] Foran, J.A., Carpenter, D.O., Hamilton, M.C., Knuth, B.A., & Schwager, S.J. (2005). Risk-based consumption advice for farmed Atlantic and wild Pacific salmon contaminated with dioxins and dioxin-like compounds.
Environmental Health Perspectives, 552-556.

[318] Mozaffarian, D., & Rimm, E. B. (2006). Fish intake, contaminants, and human health: Evaluating the risks and the benefits. *JAMA, 296*(15), 1885-1899.

[319] Dórea, J.G. (2008). Persistent, bioaccumulative and toxic substances in fish: Human health considerations. *Science of the Total Environment, 400*(1), 93-114.

[320] US Food and Drug Administration (2014). New advice: Pregnant women and young children should eat more fish. Retrieved September 24, 2016 from http://www.fda.gov/ForConsumers/ConsumerUpdates/ucm397443.htm

[321] Dietary Guidelines Advisory Committee. (2015). Scientific Report of the 2015 Dietary Guidelines Advisory Committee. *Washington, D.C.: USDA and US Department of Health and Human Services*. Part D, Chapter 5: Food Sustainability and Safety. Retrieved from https://health.gov/dietaryguidelines/2015-scientific-report/10-chapter-5/

[322] Jenkins, D.J., Sievenpiper, J.L., Pauly, D., Sumaila, U.R., Kendall, C.W., & Mowat, F.M. (2009). Are dietary recommendations for the use of fish oils sustainable?. *Canadian Medical Association Journal, 180*(6), 633-637.

[323] Thurstan, R.H. & Roberts, C.M. (2014) The past and future of fish consumption: Can supplies meet

healthy eating recommendations? Marine Pollution Bulletin, 89(1-2), 5—11.

[324] Tacon, A.G.J., Hasan, M.R., & Metian, M. (2011). *Demand and supply of feed ingredients for farmed fish and crustaceans: trends and prospects*. FAO Fisheries and Aquaculture Technical Paper, No. 639.51 TAC. Retrieved from http://www.fao.org/docrep/015/ba0002e/ba0002e.pdf

[325] Klinger, D., & Naylor, R. (2012). Searching for solutions in aquaculture: Charting a sustainable course. *Annual Review of Environment and Resources, 37,* 247-276.

[326] Tyedmers, P. (2004). Fisheries and energy use. *Encyclopedia of energy, 2,* 683-693.

[327] Smith, M. D., Roheim, C. A., Crowder, L. B., Halpern, B. S., Turnipseed, M., Anderson, J. L., ... & Liguori, L. A. (2010). Sustainability and global seafood. *Science, 327*(5967), 784-786.

[328] Sonesson, U., Davis, J., & Ziegler, F. (2010). *Food production and emissions of greenhouse gases: An overview of the climate impact of different product groups*. SIK-Report No 802 2010. The Swedish Institute for Food and Biotechnology.

[329] Rice, J.C., & Garcia, S.M. (2011). Fisheries, food security, climate change, and biodiversity: Characteristics of the sector and perspectives on emerging issues. *ICES Journal of Marine Science, 68,* 1343-1353.

[330] Laffoley, D. & Baxter, J.M. (eds.)(2016). *Explaining ocean warming: Causes, scale, effects and consequences*. Full report. Gland, Switzerland: IUCN. Retrieved from https://portals.iucn.org/library/sites/library/files/documents/2016-046_0.pdf

[331] Holmyard, N. (2014). Climate Change: Implications for Fisheries & Aquaculture. Key findings from the Intergovernmental Panel on Climate Change Fifth Assessment Report. Cambridge, UK: University of Cambridge and Sustainable Fisheries Partnership. Retrieved from http://cmsdevelopment.sustainablefish.org.s3.amazonaws.com/2014/05/27/IPCC_AR5_Fisheries_Summary_FINAL_Web-1001a188.pdf

[332] Troell, M., Naylor, R.L., Metian, M., Beveridge, M., Tyedmers, P.H., Folke, C., ... & Gren, Å. (2014). Does aquaculture add resilience to the global food system?. *Proceedings of the National Academy of Sciences, 111*(37), 13257-13263.

[333] Ellingsen, H., & Aanondsen, S.A. (2006). Environmental impacts of wild caught cod and farmed Salmon—A comparison with chicken. *The International Journal of Life Cycle Assessment, 11*(1), 60-65.

[334] Verdegem, M.C.J., Bosma, R.H., & Verreth, J.A.J. (2006). Reducing water use for animal production through aquaculture. *International Journal of Water Resource Development, 22,* 101–13.

[335] Love, D.C., Uhl, M.S., & Genello, L. (2015). Energy and water use of a small-scale raft aquaponics system in Baltimore, Maryland, United States. *Aquacultural Engineering, 68,* 19-27.

[336] Pahlow, M., Van Oel, P.R., Mekonnen, M.M., & Hoekstra, A.Y. (2015). Increasing pressure on freshwater resources due to terrestrial feed ingredients for aquaculture production. *Science of the Total Environment, 536,* 847-857.

[337] Burridge, L., Weis, J.S., Cabello, F., Pizarro, J., & Bostick, K. (2010). Chemical use in salmon aquaculture: A review of current practices and possible environmental effects. *Aquaculture, 306*(1), 7-23.

[338] Food & Water Watch (2008). *Suspicious Shrimp: The Health Risks of Industrialized Shrimp Production*. Washington, D.C.: FWW. Retrieved from http://www.foodandwaterwatch.org/sites/default/files/suspicious_shrimp_report_nov_2009.pdf

[339] Islam, M.S. (2005). Nitrogen and phosphorus budget in coastal and marine cage aquaculture and impacts of effluent loading on ecosystem: Review and analysis towards model development. *Marine Pollution Bulletin, 50*(1), 48-61.

[340] Done, H.Y., & Halden, R.U. (2015). Reconnaissance of 47 Antibiotics and Associated Microbial Risks in Seafood Sold in the United States. *Journal of Hazardous Materials, 282,* 10-7.

[341] Thrush, S.F., & Dayton, P.K. (2002). Disturbance to marine benthic habitats by trawling and dredging: Implications for marine biodiversity. *Annual Review of Ecology and Systematics*, 449-473.

[342] Valiela, I., Bowen, J. L., & York, J. K. (2001). Mangrove forests: One of the world's threatened major tropical environments. *Bioscience, 51*(10), 807-815.

[343] Trujilo, P. (2008). Using a mariculture sustainability index to rank countries performances. In: Pauly, D.J.A. (ed.), *A Comparative Assessment of Biodiversity, Fisheries and Aquaculture in 53 Countries' Exclusive Economic Zones*. Vancouver, British Columbia: The Fisheries Centre, University of British Colombia, 28–56. Retrieved from: https://open.library.ubc.ca/cIRcle/collections/ubccommunityandpartnerspublicati/37052/items/1.0074742

[344] Shumway, S.E., Davis, C., Downey, R., Karney, R., Kraeuter, J., Parsons, J., ... & Wikfors, G. (2003). Shellfish aquaculture–in praise of sustainable economies and environments. *World Aquaculture, 34*(4), 8-10.

[345] Parsons, G.J., Shumway, S.E., Kuenstner, S., & Gryska, A. (2002). Polyculture of sea scallops (Placopecten magellanicus) suspended from salmon cages. *Aquaculture International, 10*(1), 65-77.

[346] Mendoza, M., McDowell, R., Mason, M., Htusan, E., & The Associated Press (2016). *Fishermen Slaves: Human Trafficking and the Seafood We Eat*. Associated Press. http://www.ap.org/books/fishermen-slaves/index.html

[347] The Guardian (n.d.). Modern-day slavery in focus + Thailand. Retrieved August 28, 2016 from https://www.theguardian.com/global-development/series/modern-day-slavery-in-focus+world/thailand

[348] Myers, M.L. (2010). Review of occupational hazards associated with aquaculture. *Journal of Agromedicine, 15*(4), 412-426.

[349] Hossain, M.S., Uddin, M.J., & Fakhruddin, A.N.M. (2013). Impacts of shrimp farming on the coastal environment of Bangladesh and approach for management. *Reviews in Environmental Science and Bio/Technology, 12*(3), 313-332.

[350] Lebel, L., Mungkung, R., Gheewala, S.H., & Lebel, P. (2010). Innovation cycles, niches and sustainability in the shrimp aquaculture industry in Thailand. *Environmental Science & Policy, 13*(4), 291-302.

[351] The Humane Society of the United States (2008). *An HSUS Report: The Welfare of Animals in the Aquaculture Industry*. Retrieved from http://www.humanesociety.org/assets/pdfs/farm/hsus-the-welfare-of-animals-in-the-aquaculture-industry-1.pdf

[352] Yue, S (2008). *An HSUS Report: The Welfare of Farmed Fish at Slaughter.* The Humane Society of the United States. Retrieved from http://www.humanesociety.org/assets/pdfs/farm/hsus-the-welfare-of-farmed-fish-at-slaughter.pdf

[353] UN Food and Agriculture Organization (FAO)(n.d.). Dairy production and products: Milk composition. Retrieved September 12, 2016 from http://www.fao.org/agriculture/dairy-gateway/milk-and-milk-products/milk-composition/en/#.V-t8-ZMrL6Y

[354] US Department of Agriculture, National Agricultural Statistics Service (2016). Milk Production. Retrieved September 26, 2016 from http://usda.mannlib.cornell.edu/usda/current/MilkProd/MilkProd-09-20-2016.pdf

[355] US Department of Agriculture, National Agricultural Statistics Service (2016). Sheep and Goats. Retrieved September 26, 2016 from http://usda.mannlib.cornell.edu/usda/current/SheeGoat/SheeGoat-01-29-2016.pdf

[356] US Department of Agriculture, National Agricultural Statistics Service (2016). Dairy Products: 2015 Summary. Retrieved September 26, 2016 from http://usda.mannlib.cornell.edu/usda/current/DairProdSu/DairProdSu-04-28-2016.pdf

[357] US Department of Agriculture, National Agricultural Statistics Service (2014). *2012 Census of Agriculture Highlights: Dairy Cattle and Milk Productio*n. Retrieved September 26, 2016 from https://agcensus.usda.gov/Publications/2012/Online_Resources/Highlights/Dairy_Cattle_Milk_Prod/Dairy_Cattle_and_Milk_Production_Highlights.pdf

[358] Barkema, H. W., von Keyserlingk, M. A. G., Kastelic, J. P., Lam, T. J. G. M., Luby, C., Roy, J. P., … & Kelton, D. F. (2015). Invited review: Changes in the dairy industry affecting dairy cattle health and welfare. *Journal of Dairy Science, 98*(11), 7426-7445.

359 MacDonald, J.M. & Newton, D. (2014). Milk production continues shifting to large-scale farms. *Amber Waves*. US Department of Agriculture, Economic Research Service. Retrieved September 26 from http://www.ers.usda.gov/amber-waves/2014/december/milk-production-continues-shifting-to-large-scale-farms/

[360] US Department of Agriculture, Economic Research Service (2016). Dairy products: Per capita consumption, United States (Annual)[data file]. Retrieved September 27, 2016 from http://www.ers.usda.gov/data-products/dairy-data.aspx

[361] US Department of Agriculture, Economic Research Service (2014). Trends in US Per Capita Consumption of Dairy Products 1970-2012. Retrieved September 27, 2016 from http://www.ers.usda.gov/amber-waves/2014-june/trends-in-us-per-capita-consumption-of-dairy-products,-1970-2012.aspx#.V-usRJMrL6Y

[362] Beverage Marketing Corporation (2016). *U.S. Dairy Alternative Beverages Through 2020*. Retrieved from http://www.beveragemarketing.com/shop/US-Dairy-Alternative-Beverages.aspx

[363] Mäkinen, O.E., Wanhalinna, V., Zannini, E., & Arendt, E.K. (2016). Foods for special dietary needs: Non-dairy plant-based milk substitutes and fermented dairy-type products. *Critical Reviews in Food Science and Nutrition, 56*(3), 339-349.

[364] Van Allen, J. (2014). Got milk? From a cow or a plant? *Washington Post* (June 10). Retrieved from https://www.washingtonpost.com/news/to-your-health/wp/2014/06/10/got-milk-from-a-cow-or-a-plant/

[365] Markets and Markets (2015). Dairy Alternatives Market - Global Forecast to 2020. Retrieved from http://www.marketsandmarkets.com/Market-Reports/dairy-alternative-plant-milk-beverages-market-677.html

[366] Levitt, T. (2016). Animal-free dairy products move a step closer to market. *Guardian* (September 13). Retrieved from https://www.theguardian.com/environment/2016/sep/13/animal-free-dairy-products-move-a-step-closer-to-market

[367] Steer, M. (2015). A comparison of land, water, and energy use between conventional and yeast-derived dairy products: An initial analysis. Retrieved from http://www.animalfreemilk.com/files/PD-LCA.pdf

[368] Chowdhury, R., Warnakula, S., Kunutsor, S., Crowe, F., Ward, H.A., Johnson, L., … & Khaw, K.T. (2014). Association of dietary, circulating, and supplement fatty acids with coronary risk: A systematic review and meta-analysis. *Annals of Internal Medicine, 160*(6), 398-406.

[369] Ravnskov, U., DiNicolantonio, J.J., Harcombe, Z., Kummerow, F.A., Okuyama, H., & Worm, N. (2014). The questionable benefits of exchanging saturated fat with polyunsaturated fat. *Mayo Clinic Proceedings, 89*(4), 451-453.

[370] German, J.B., Gibson, R.A., Krauss, R.M., Nestel, P., Lamarche, B., Van Staveren, W.A., … & Destaillats, F. (2009). A reappraisal of the impact of dairy foods and milk fat on cardiovascular disease risk. *European Journal of Nutrition, 48*(4), 191-203.

[371] Ludwig, D.S., & Willett, W.C. (2013). Three daily servings of reduced-fat milk: An evidence-based recommendation?. *JAMA Pediatrics, 167*(9), 788-789.

[372] Dawczynski, C., Kleber, M. E., März, W., Jahreis, G., & Lorkowski, S. (2015). Saturated fatty acids are not off the hook. *Nutrition, Metabolism and Cardiovascular Diseases, 25*(12), 1071-1078.

[373] Benbrook, C.M., Butler, G., Latif, M.A., Leifert, C., & Davis, D.R. (2013). Organic production enhances milk nutritional quality by shifting fatty acid composition: A United States–wide, 18-month study. *PLoS One, 8*(12), e82429.

[374] Alvarez-León, E.E., Román-Viñas, B., & Serra-Majem, L. (2006). Dairy products and health: A review of the epidemiological evidence. British Journal of Nutrition, 96(Suppl 1), S94-S99.

[375] Bischoff-Ferrari, H.A., Dawson-Hughes, B., Baron, J.A., Burckhardt, P., Li, R., Spiegelman, D., ... & O'Reilly, E. (2007). Calcium intake and hip fracture risk in men and women: a meta-analysis of prospective cohort studies and randomized controlled trials. *The American Journal of Clinical Nutrition, 86*(6), 1780-1790.

[376] Feskanich, D., Bischoff-Ferrari, H.A., Frazier, A.L., & Willett, W.C. (2014). Milk consumption during teenage years and risk of hip fractures in older adults. *JAMA Pediatrics, 168*(1), 54-60.

[377] Michaëlsson, K., Wolk, A., Langenskiöld, S., Basu, S., Lemming, E. W., Melhus, H., & Byberg, L. (2014). Milk intake and risk of mortality and fractures in women and men: cohort studies. *BMJ,* 349.

[378] Physicians Committee for Responsible Medicine (n.d.). What is lactose intolerance? Retrieved October 2, 2016 from http://www.pcrm.org/health/diets/vegdiets/what-is-lactose-intolerance

[379] Kerstetter, J.E., Kenny, A.M., & Insogna, K.L. (2011). Dietary protein and skeletal health: A review of recent human research. *Current Opinion in Lipidology, 22*(1), 16.

[380] Darling, A.L., Millward, D.J., Torgerson, D.J., Hewitt, C.E., & Lanham-New, S.A. (2009). Dietary protein and bone health: A systematic review and meta-analysis. *The American Journal of Clinical Nutrition,* ajcn-27799.

[381] Harvard T.H. Chan School of Public Health (n.d.). Calcium: What's best for your bones and health. Retrieved October 2, 2016 from https://www.hsph.harvard.edu/nutritionsource/calcium-full-story

[382] Swagerty, D.L., Walling, A.D., & Klein, R.M. (2002). Lactose intolerance. *American Family Physician, 65*(9), 1845-1860.

[383] Bloom, G., & Sherman, P. W. (2005). Dairying barriers affect the distribution of lactose malabsorption. *Evolution and Human Behavior, 26*(4), 301-312.

[384] Hilliard, C.B. (2016). High osteoporosis risk among East Africans linked to lactase persistence genotype. *BoneKEy Reports, 5.*

[385] Freeman, A. (2014). The Unbearable whiteness of milk: Food oppression and the USDA. *UC Irvine Law Review, 3*(4), 1251-1277.

[386] Aune, D., Lau, R., Chan, D.S.M., Vieira, R., Greenwood, D.C., Kampman, E., & Norat, T. (2012). Dairy products and colorectal cancer risk: A systematic review and meta-analysis of cohort studies. *Annals of Oncology, 23*(1), 37-45.

[387] Lampe, J.W. (2011). Dairy products and cancer. *Journal of the American College of Nutrition, 30*(sup5), 464S-470S.

[388] Ralston, R A., Lee, J.H., Truby, H., Palermo, C.E., & Walker, K.Z. (2012). A systematic review and metaanalysis of elevated blood pressure and consumption of dairy foods. *Journal of Human Hypertension, 26,* 3–13.

[389] Weaver, C.M., Proulx, W.R., & Heaney, R. (1999). Choices for achieving adequate dietary calcium with a vegetarian diet. *The American Journal of Clinical Nutrition, 70*(3), 543s-548s.

[390] Maruyama, K., Oshima, T., & Ohyama, K. (2010). Exposure to exogenous estrogen through intake of commercial milk produced from pregnant cows. *Pediatrics International, 52*(1), 33-38.

[391] Ganmaa, D., Wang, P.Y., Qin, L.Q., Hoshi, K., & Sato, A. (2001). Is milk responsible for male reproductive disorders? *Medical Hypotheses, 57,* 510–514.

[392] Ganmaa, D., & Sato, A. (2005). The possible role of female sex hormones in milk from pregnant cows in the development of breast, ovarian and corpus uteri cancers. *Medical Hypotheses, 65*(6), 1028-1037.

[393] Pape-Zambito, D.A., Roberts, R.F., & Kensinger, R.S. (2010). Estrone and 17- -estradiol concentrations in pasteurized-homogenized milk and commercial dairy products. *Journal of Dairy Science, 93*(6), 2533-2540.

[394] Schettler, T. (2013). Chapter 3: Diet, nutrition and breast cancer, p.44. *In The Etiology of Breast Cancer: The Promise of Prevention and the Hope for Healing.* Science & Environmental Health Network and Collaborative on Health and the Environment. Retrieved from http://sehn.org/wp-content/uploads/2014/03/EcolOfBC_Chap3.pdf

[395] Alvarez-León, E.E., Román-Viñas, B., & Serra-Majem, L. (2006). Dairy products and health: A review of the epidemiological evidence. *British Journal of Nutrition, 96*(Suppl 1), S94-S99.

[396] Parodi, P.W. (2012). Impact of cows' milk estrogen on cancer risk. *International Dairy Journal, 22*(1), 3-14.

[397] World Cancer Research Fund, American Institute for Cancer Research (2007). *Food, nutrition, physical activity, and the prevention of cancer: A global perspective.* Washington DC: AICR.

[398] Giovannucci, E., Rimm, E.B., Wolk, A., Ascherio, A., Stampfer, M.J., Colditz, G.A., & Willett, W.C. (1998). Calcium and fructose intake in relation to risk of prostate cancer. *Cancer Research, 58*(3), 442-447.

[399] Giovannucci, E., Liu, Y., Platz, E.A., Stampfer, M.J., & Willett, W.C. (2007). Risk factors for prostate cancer incidence and progression in the Health Professionals Follow-up Study. *International Journal of Cancer, 121*, 1571–78.

[400] Woods, V.B., & Fearon, A.M. (2009). Dietary sources of unsaturated fatty acids for animals and their transfer into meat, milk and eggs: A review. *Livestock Science, 126*(1), 1-20.

[401] Zhao, Y., Martin, B.R., & Weaver, C.M. (2005). Calcium bioavailability of calcium carbonate fortified soymilk is equivalent to cow's milk in young women. *The Journal of Nutrition, 135*(10), 2379-2382.

[402] Heaney, R.P., Rafferty, K., & Bierman, J. (2005). Not all calcium-fortified beverages are equal. *Nutrition Today*, 40, 39–44.

[403] World Health Organization (2015). *Sugars intake for adults and children guideline*. Retrieved from http://www.who.int/nutrition/publications/guidelines/sugars_intake/en/

[404] Cornucopia Institute (2016). *Carrageenan: New studies reinforce link to inflammation, cancer and diabetes*. Retrieved from http://www.cornucopia.org/wp-content/uploads/2016/04/CarageenanReport-2016.pdf

[405] Shannon, R., & Rodriguez, J. M. (2014). Total arsenic in rice milk. *Food Additives & Contaminants: Part B, 7*(1), 54-56.

[406] Gerber, P., Vellinga, T., Opio, C., Henderson, B., & Steinfeld, H. (2010). *Greenhouse Gas Emissions from the Dairy Sector: A Life Cycle Assessment*. Rome, Italy: UN Food and Agriculture Organization. Retrieved from http://www.fao.org/docrep/012/k7930e/k7930e00.pdf

[407] Pelletier, N., Pirog, R., & Rasmussen, R. (2010). Comparative life cycle environmental impacts of three beef production strategies in the Upper Midwestern United States. *Agricultural Systems, 103*(6), 380-389.

[408] Beauchemin, K.A., Kreuzer, M., O'mara, F., & McAllister, T.A. (2008). Nutritional management for enteric methane abatement: a review. *Animal Production Science, 48*(2), 21-27.

[409] Capper, J.L. (2012). Is the grass always greener? Comparing the environmental impact of conventional, natural and grass-fed beef production systems. *Animals, 2*(2), 127-143.

[410] Lupo, C.D., Clay, D.E., Benning, J.L., & Stone, J.J. (2013). Life-cycle assessment of the beef cattle production system for the Northern Great Plains, USA. *Journal of Environmental Quality, 42*(5), 1386-1394.

[411] Liebig, M.A., Gross, J.R., Kronberg, S.L., & Phillips, R.L. (2010). Grazing management contributions to net global warming potential: A long-term evaluation in the Northern Great Plains. *Journal of Environmental Quality, 39*(3), 799-809.

[412] Allard, V., Soussana, J. F., Falcimagne, R., Berbigier, P., Bonnefond, J. M., Ceschia, E., ... & Pinares-Patino, C. (2007). The role of grazing management for the net biome productivity and greenhouse gas budget (CO2, N2O and CH4) of semi-natural grassland. *Agriculture, Ecosystems & Environment, 121*(1), 47-58.

[413] Gill, M., Smith, P., & Wilkinson, J. M. (2010). Mitigating climate change: The role of domestic livestock. *Animal, 4*(03), 323-333.

[414] Hoffmann, I. (2010). Climate change and the characterization, breeding and conservation of animal genetic resources. *Animal Genetics, 41*(s1), 32-46.

[415] West, J.W. (2003). Effects of heat-stress on production in dairy cattle. *Journal of Dairy Science, 86*(6), 2131-2144.

[416] Klinedinst, P.L., Wilhite, D.A., Hahn, G.L., & Hubbard, K.G. (1993). The potential effects of climate change on summer season dairy cattle milk production and reproduction. *Climatic Change, 23*(1), 21-36.

[417] Wolfe, D.W., Ziska, L., Petzoldt, C., Seaman, A., Chase, L., & Hayhoe, K. (2008). Projected change in climate thresholds in the Northeastern US: Implications for crops, pests, livestock, and farmers. *Mitigation and Adaptation Strategies for Global Change, 13*(5-6), 555-575.

[418] Feraldi, R., Huff, M., Molen, A.M., & New, H. (2012). Life cycle assessment of coconut milk and two non-dairy milk beverage alternatives. LCA XII. Tacoma, American Center for Life Cycle Assessment. Retrieved from http://lcacenter.org/lcaxii/final-presentations/719.pdf

[419] Röös, E., Patel, M., & Spångberg, J. (2016). Producing oat drink or cow's milk on a Swedish farm—Environmental impacts considering the service of grazing, the opportunity cost of land and the demand for beef and protein. *Agricultural Systems, 142*, 23-32.

[420] van Zanten, H. H., Mollenhorst, H., Klootwijk, C. W., van Middelaar, C. E., & de Boer, I. J. (2016). Global food supply: Land use efficiency of livestock systems. *The International Journal of Life Cycle Assessment, 21*(5), 747-758.

[421] This value was derived by dividing the global average WF of soybean ingredients in soymilk as reported in reference 73 (3763 L/kg) by 10, since soymilk consists of 90% water (as discussed in Ercin, A. E., Aldaya, M. M., & Hoekstra, A. Y. (2012). The water footprint of soy milk and soy burger and equivalent animal products. *Ecological indicators, 18,* 392-402).

[422] US Department of Agriculture (1995). Animal Manure Management, RCA Issue Brief #7. Retrieved September 21, 2016 from http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/?&cid=nrcs143_014211

[423] Roche, J.R., Ledgard, S.F., Sprosen, M.S., Lindsey, S.B., Penno, J.W., Horan, B., & Macdonald, K.A. (2016). Increased stocking rate and associated strategic dry-off decision rules reduced the amount of nitrate-N leached under grazing. *Journal of Dairy Science, 99(7), 5916-5925.*

[424] Rushton, J., Pinto Ferreira, J., & Stärk, K.D. (2014). Antimicrobial resistance: The use of antimicrobials in the livestock sector. OECD Food, Agriculture and Fisheries Papers, No. 68. OECD Publishing. Retrieved from http://dx.doi.org/10.1787/5jxvl3dwk3f0-en

[425] US Department of Agriculture, Animal and Plant Health Inspection Service (2008). Dairy 2007; Part III: Reference of dairy cattle health and management practices in the United States, 2007. Fort Collins, CO: USDA-APHIS- VS, CEAH. Retrieved from: http://www.aphis.usda.gov/animal_health/nahms/dairy/downloads/dairy07/Dairy07_dr_PartIII_rev.pdf

[426] US Department of Agriculture, Animal and Plant Health Inspection Service. (2009). Highlights of Dairy 2007 Part iv: Reference of dairy cattle health and management practices in the United States, 2007. Retrieved from https://www.aphis.usda.gov/animal_health/nahms/dairy/downloads/dairy07/Dairy07_is_PartIV_Highlights.pdf

[427] US Food and Drug Administration (2009). Report on the Food and Drug Administration's Review of the Safety of Recombinant Bovine Somatotropin. Retrieved October 4, 2016 from http://www.fda.gov/AnimalVeterinary/SafetyHealth/ProductSafetyInformation/ucm130321.htm

[428] Dohoo, I.R., Leslie, K., DesCôteaux, L., Fredeen, A., Dowling, P., Preston, A., & Shewfelt, W. (2003). A meta-analysis review of the effects of recombinant bovine somatotropin: 1. Methodology and effects on production. *Canadian Journal of Veterinary Research, 67*(4), 241.

[429] Kronfeld, D. S. (2000). Recombinant bovine somatotropin and animal welfare. *Journal of the American Veterinary Medical Association, 216*(11), 1719-1722.

[430] American Cancer Society (2014). Recombinant Bovie Growth Hormone. Retrieved October 4, 2016 from http://www.cancer.org/cancer/cancercauses/othercarcinogens/athome/recombinant-bovine-growth-hormone

[431] Health Care Without Harm (n.d.). Position Statemnt on rBGH. Retrieved October 4, 2016 from https://noharm.org/sites/default/files/lib/downloads/food/HCWH_Position_on_rBGH.pdf

[432] American Public Health Association (2009). Opposition to the use of hormone growth promoters in beef and dairy cattle production. Retrieved October 4, 2016 from http://www.apha.org/policies-and-advocacy/public-health-policy-statements/policy-database/2014/07/09/13/42/opposition-to-the-use-of-hormone-growth-promoters-in-beef-and-dairy-cattle-production

[433] Lange, I.G., Daxenberger, A., Schiffer, B., Witters, H., Ibarreta, D., & Meyer, H.H. (2002). Sex hormones originating from different livestock production systems: Fate and potential disrupting activity in the environment. *Analytica Chimica Acta, 473*(1), 27-37.

[434] Raman, D.R., Williams, E.L., Layton, A.C., Burns, R.T., Easter, J.P., Daugherty, A.S., ... & Sayler, G.S. (2004). Estrogen content of dairy and swine wastes. *Environmental Science & Technology, 38*(13), 3567-3573.

[435] Rook, A. J., & Tallowin, J. R. (2003). Grazing and pasture management for biodiversity benefit. *Animal Research, 52*(2), 181-189.

[436] Kleijn, D., Kohler, F., Báldi, A., Batáry, P., Concepción, E. D., Clough, Y., ... & Kovács, A. (2009). On the relationship between farmland biodiversity and land-use intensity in Europe. *Proceedings of the Royal Society of London B: Biological Sciences, 276*(1658), 903-909.

[437] Migrant Justice (2015). Farmworkers document abuse and propose solution: Milk with Dignity! Retrieved October 3, 2016 from http://migrantjustice.net/sites/default/files/FinalSurveyMay2015.pdf

[438] Migrant Justice (2015). Summary of Milk with Dignity Code of Conduct. Retrieved October 3, 2016 from http://migrantjustice.net/sites/default/files/MilkWDignityStandardsMay2015%20.pdf

[439] Hinze, S., Bergmann, K.C., Løwenstein, H., & Hansen, G.N. (1997). Cow hair allergen (Bos d 2) content in house dust: Correlation with sensitization in farmers with cow hair asthma. *International Archives of Allergy and Immunology, 112*(3), 231-237.

[440] Kullman, G.J., Thorne, P.S., Waldron, P.F., Marx, J.J., Ault, B., Lewis, D.M., ... & Merchant, J.A. (1998). Organic dust exposures from work in dairy barns. *American Industrial Hygiene Association, 59*(6), 403-413.

[441] D'Ann, L.W., McCormack, M.C., Matsui, E.C., Diette, G.B., McKenzie, S.E., Geyh, A.S., & Breysse, P.N. (2016). Cow allergen (Bos d2) and endotoxin concentrations are higher in the settled dust of homes proximate to industrial-scale dairy operations. *Journal of Exposure Science and Environmental Epidemiology, 26,* 42-47.

[442] US Department of Agriculture, Animal and Plant Health Inspection Service (2008). Dairy 2007, Part I: Reference of dairy cattle health and management practices in the United States, 2007. Fort Collins, CO: USDA-APHIS- VS, CEAH. Retrieved from http://www.aphis.usda.gov/animal_health/nahms/dairy/downloads/dairy07/Dairy07_dr_PartI.pdf

[443] Barclay, E. (2015). What's funny about the business of monkeys picking coconuts? *NPR The Salt* (October 19). Retrieved October 4, 2016 from http://www.npr.org/sections/thesalt/2015/10/19/448960760/monkeys-pick-coconuts-in-thailand-are-they-abused-or-working-animals

[444] Moyer, J.W. (2015). The murky ethics of making monkeys pick our coconuts. *The Washington Post* (October 20). Retrieved October 4, 2016 from https://www.washingtonpost.com/news/morning-mix/wp/2015/10/20/the-murky-ethics-of-making-monkeys-pick-our-coconuts/

[445] Center for a Livable Future (in progress). Impact on Climate and Freshwater Footprints from Adopting Plant-Centric Diets in Selected Countries.

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This report was produced by Health Care Without Harm's national Healthy Food in Health Care program, which harnesses the purchasing power and expertise of the health care sector to advance the development of a sustainable food system.

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ACKNOWLEDGMENTS

Content written and coordinated by Raychel Santo and Stacia Clinton. Contributions from Ted Schettler and Madeline Stein. The authors would like to thank Claire Fitch, Jillian Fry, Jim Galloway, Kerry Hughes, Allison Leach, Bob Martin, Colleen Matts, Kristie Middleton, Lucia Sayre, and Allysan Scatterday for the time, effort, and invaluable feedback they contributed in reviewing drafts of this report. We also want to thank Brent Kim for assistance with additional in-house calculations and April Galarza for editorial support and Kevin Conway for design and layout.

Please cite the report as: Health Care Without Harm. (2017). Redefining Protein: *Adjusting Diets to Protect Public Health and Conserve Resources.*

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