U.S. Beef Supply Chain

Opportunities in Fresh Water, Wildlife Habitat, and Greenhouse Gas Reduction

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EXECUTIVE SUMMARY

Background

Walmart and The Nature Conservancy developed this project to gain a better understanding of the key environmental impacts across the U.S. beef supply chain (i.e., cattle raised for beef within the United States) as well as the significant opportunities to reduce these impacts. The hope is that this information will allow stakeholders to take more informed positions within influential multi-stakeholder initiatives (e.g., Global and U.S. Roundtables for Sustainable Beef) as well as to improve the design of supply chain engagement programs.

The report was produced from a combination of a thorough literature review (of almost 200 primary sources), new analysis to produce high level summaries where insufficient data existed, and a review of the U.S. beef supply chain. The Conservancy assessed the main impacts of the U.S. beef supply chain, reviewing the relative impacts of key production phases (ranch and farm grazing, feed production, feedlots, and harvest facilities) on three types of environmental impacts: fresh water (both water supply and water quality issues), wildlife habitat and greenhouse gases (GHGs). The choice of the three specific impact categories was driven by the need to focus on the current beef production system and to make recommendations that could be implemented immediately and scaled up across the U.S. beef supply chain.

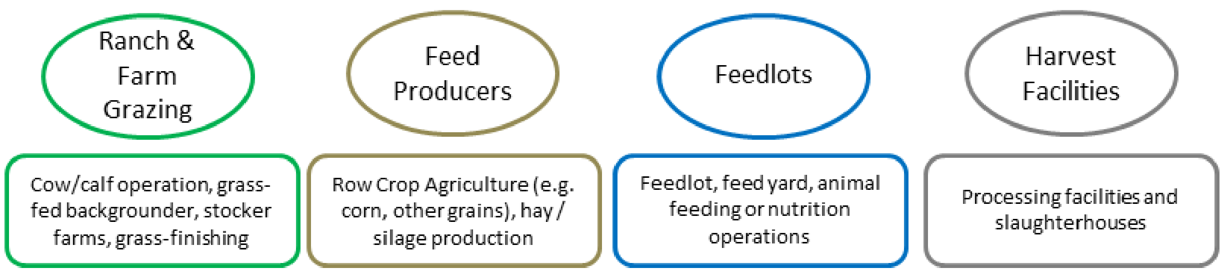

Figure 1. Beef production phases used in this report.

While the report highlights a number of improvement opportunities, it is not our intent to recommend a prescriptive approach that demands all suppliers make the same changes. We recognize that there are many social and economic factors that affect the ability and willingness of producers to change their practices. Moreover, from a conservation perspective, there is no substitute to having adaptive management plans for each site developed in consultation with trained ecologists and land management specialists, especially when seeking biodiversity outcomes. Determining how to scale up the adaptive management plan approach in a way that is practical, efficient, and effective is an important area for future research and collaboration. Finally, while we estimate impacts and discuss recommendations, we have not calculated the financial costs of each recommendation to determine where the most impact can be achieved per dollar spent.

Major Impacts of Beef Production

Fresh Water

All segments of the beef supply chain have an impact on both water quality and water consumption, although harvest facilities have a significantly smaller impact than the other phases. Water consumption is greatest in the feed production and ranch and farm grazing phases (up to 99% of total water consumed), whereas water quality impacts are most significant in the ranch and farm grazing and feedlot phases, which together contribute to 93% of the impaired stream miles and 84% of impaired lake acres attributable to beef production. Our review found the most significant impacts are (higher impacts at top):

- Water consumption by irrigated pasture and feed crop production, which is of particular concern in regions of the U.S. vulnerable to water scarcity from competing demands and non-renewable supplies of groundwater (High impact, limited extent to mostly western rangelands and central corn producing regions).
- Runoff of sediment, nutrients and pathogens from grazed lands into lakes and streams (the dominant source of water quality impacts, although pesticides, hormones, and pharmaceuticals are also of concern) (High impact, large extent).
- Leaching and runoff of nutrients and pathogens from feedlots into lakes and streams. (moderate impact, moderate extent)
- Runoff of sediment and nutrients from cropland into lakes and streams (moderate impact, large extent).

Wildlife Habitat

Roughly 41% of the land area of the lower 48 states of the U.S. is grazed; of this approximately 15% is intensely managed pasture and 85% is rangeland or grazed forest land. The impact of this grazing on terrestrial wildlife habitats, however, varies substantially by region (fresh water impacts are covered in that section). Our review found the most significant impacts that could potentially be improved are (higher impacts at top):

- Degradation (reduced quality) of regularly grazed native habitats from introduction of non-native grasses and over-grazing (moderate impact but large magnitude, primarily in western rangelands)
- Degradation (reduced quality) of pasture in terms of a variety of ecological services (moderate impact and moderate extent).
- Loss of habitat by conversion of native ecosystems to production agriculture used to supply cattle feed (high impact but limited in extent).
- Mortality of animals (and / or destruction of their nests) in supplemental feed production (moderate impact and moderate extent).

Greenhouse Gas Emissions

The U.S. agriculture system as a whole is responsible for approximately 9% of the total greenhouse gas emissions in the U.S., of which the U.S. beef supply chain is a major contributor. Greenhouse gas emissions come from every phase of the beef supply chain, but most come from the ranch and farm grazing phase. This phase also has the greatest opportunity to both reduce emissions and sequester carbon. Note that carbon dioxide (CO_2) only represents 12% of U.S. beef GHGs, as nitrous oxide (52%)

and methane (36%) have a much larger impact on climate change per unit of emissions. Our review found the most significant impacts are (higher impacts at top):

- Release of enteric methane (flatulence and belching) from cattle during the ranch and farm grazing phase.
- Nitrous oxide emissions on fertilized pasture from the breakdown of manure and inorganic fertilizer.
- Emissions of methane and nitrous oxide from manure on feedlots.
- Nitrous oxide emissions on feed sourcing cropland from the breakdown of manure and inorganic fertilizer.

Top Recommendations

To make the improvement opportunities easier to compare and evaluate, we created a Table of Recommendations in the appendix of this report (see attached). The table of recommendations organizes the potential opportunities for improvement by production phase, and evaluates their relative potential impact, investment required, estimate of current uptake, and the scientific certainty of efficacy. Further context and details on each of these recommendations is contained within the main report. The improvement opportunities identified for harvest facilities and listed in the table were relatively minor compared to those available for other phases of production. Some of the top recommendations in terms of being both high-impact and practical to implement are:

- **Ranch & Farm Grazing**
    - Encourage grazing operations to adopt water quality best management practices that reduce nutrient, sediment and pathogen runoff, i.e. riparian buffers, riparian fencing and alternative watering points.
    - Encourage producers to pay special attention to conserving riparian areas and wetlands on their ranchlands and to follow recommended grazing management practices in these areas.
    - Investigate how to scale up the preparation, implementation, and use of adaptive management grazing plans. Consider supporting efforts by the Natural Resources Conservation Service (NRCS) and conservation partners across the country to cost-share Farm Bill Biologist positions to work with landowners to implement priority conservation practices on their lands.
- **Feedlot**
    - Install aerobic digesters at feedlots to reduce GHG emissions, add revenue to the operation via energy production, cut waste management costs, reduce odor, and reduce water quality issues. This will require changes to manure management in most cases.
    - Encourage suppliers for feedlots geographically located in those areas of the country with moderate or higher departure from reference conditions for one or more rangeland health indicators to implement better rangeland management practices.
    - Encourage feedlots to adopt sound manure management practices, including safe manure storage to prevent runoff, and applying manure to fields following the "4R

philosophy" (the right fertilizer, at the right rate, at the right time, in the right place; TFI 2016).

- **Feed Producers**
  - Encourage farmers and ranchers to reduce water consumption via improved irrigation efficiency methods; optimizing the timing and amount of water application (e.g., drip irrigation) in partnership with irrigation districts where relevant, and using early maturing corn varieties.
  - Source cattle from feedlots and suppliers that in turn only source feed from croplands which have not "recently" been converted from natural habitat (within the last 10 years); avoid sourcing feed from regions of the country experiencing high conversion rates or requiring significant irrigation.
  - Encourage feed grain and pasture farmers to adopt water quality best management practices that reduce nutrient and sediment runoff, i.e., riparian buffers and vegetative treatment systems.
  - Encourage suppliers for feedlots geographically located in those areas of the country with moderate or higher departure from reference conditions for one or more rangeland health indicators to implement better rangeland management practices.
  - Encourage hayland operators to follow wildlife-friendly harvesting procedures, such as delaying first harvest of hay or hay-crop silage to encourage success of ground-nesting birds and raising the cutting height of hay to improve survival of turtles and other small animals.

Part 1: Introduction

1.1 Background

Walmart and The Nature Conservancy developed this project to assess the key environmental impacts across the U.S. beef supply chain (i.e., cattle raised for beef within the United States) as well as the significant opportunities to reduce these impacts. The intent is to enable stakeholders to take more informed positions within influential multi-stakeholder initiatives (e.g., Global and U.S. Roundtables for Sustainable Beef) as well as to improve the design of supply chain engagement programs.

The Conservancy assessed the key impacts of the U.S. beef supply chain, reviewing the relative impacts of key production phases (ranch and farm grazing, feedlots, feed production, and harvest facilities) on three types of environmental impacts: fresh water (both water supply and water quality issues), wildlife habitat, and greenhouse gases (GHGs). The choice of the three specific impact categories was driven by the need to focus on the current beef production system and to make recommendations that could be implemented immediately and scaled up across the U.S. beef supply chain. The report was developed from a combination of a thorough literature review (of almost 200 primary sources), new analysis to produce high-level summaries of the overall impacts of beef by production phase where insufficient data existed, and a review of the U.S. beef supply chain. We then identified and evaluated potential interventions to mitigate and monitor impacts.

1.2 Beef Production Phases

This analysis is framed around four key components of the supply chain: ranch and farm grazing, feed producers, feedlots, and harvest facilities.

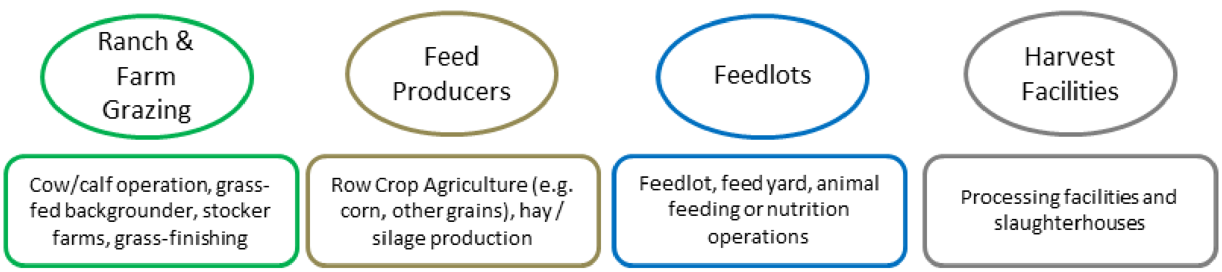

Figure 1. Beef production phases used in this report.

The "**ranch and farm grazing**" phase includes any operations where cattle are grazing forage produced onsite, on either rangelands (natural grasslands, shrublands, or woodlands where management is generally limited, see section 3.2.2 for a full definition) or pasture (also known as "pasturelands," more intensively managed or man-made grasslands, see section 3.2.3 for a full definition). This includes cow-calf operations (where young calves up to four-seven months old are drinking their mothers' milk and grazing), stockers and backgrounders (where weaned calves graze on a variety of kinds of pasture and rangeland, including young wheat fields, until they are 12-18 months old), and the finishing phase for the three percent of U.S. cattle that finish their growth prior to slaughter on rangeland or pasture rather than a feedlot (Mathews and Johnson 2013).

The "**feed producers**" phase analyzes the impacts and opportunities associated with the *production of the feed* that cattle eat while at feedlots (whether grains like corn, or hay and other forms of silage).

While feedlots can choose what they feed their cattle, practices related to *how* that feed is produced are largely up to the farmers supplying the feed. Given the different approach needed to implement improvements to feed production and feedlot operation, these processes have been split. The "**feedlots**" phase is the *onsite operation* of these facilities, which are also known as feedyards. At feedlots, cattle typically spend four to six months living in pens and eating primarily grain for rapid weight gain. Most feedlots are classified as "animal feeding operations" (AFOs), meaning that the animals are confined for more than 45 days in a season, and the area does not produce vegetation on-site (meaning the feed is imported). The term "concentrated animal feeding operation" (CAFO) applies to AFOs over a certain size threshold (which varies somewhat by specific federal agency definition).

Finally, "**harvest facilities**" are the slaughterhouses (or processing facilities) where cattle are killed and initial processing (known as dressing) takes place. Dressing typically includes removing the head, hide, and internal organs (offal) to produce the beef carcass.

1.3 Overview of Beef Industry in the U.S.

The U.S. has the largest fed-cattle industry in the world, supplying a domestic market of 25.5 billion pounds of beef annually as well as a smaller export market (NCBA 2015).

Beef makes up roughly 5% of the U.S. diet by calories per capita (calculations based on USDA ERS 2010 and Davis and Lin 2005), a proportion that has been declining since the 1970s as U.S. consumers have increasingly switched to other options (EPI 2012). At least some of this is also due to the rise in retail price of beef, which has gone from $3.32/lb in 2002 to $5.97/lb in 2014 (USDA ERS 2015a). However, an increasing U.S. population has made total beef consumption relatively stable over this time period (USDA ERS 2015b).

The national herd is estimated to be roughly 90 million head of cattle, of which approximately 31.9 million head were slaughtered commercially in 2014 (NCBA 2015). The size of the herd has dropped by a third since 1975 as the supply chain became more efficient (USDA NASS 2015). However, as shown in Figure 2, total beef production has gone up in the same period, as increased weight per head of cattle has offset the declining herd size. The data also show a more recent dip in production over the past few years that is tentatively attributed to weakening consumer demand, drought, and higher prices. There has also been a shift in the structure of the cow-calf and ranching production phase as the number of beef cow operations has declined and a smaller share of operators has taken a larger share of the overall herd in more commercial scale operations (USDA NASS 2013).

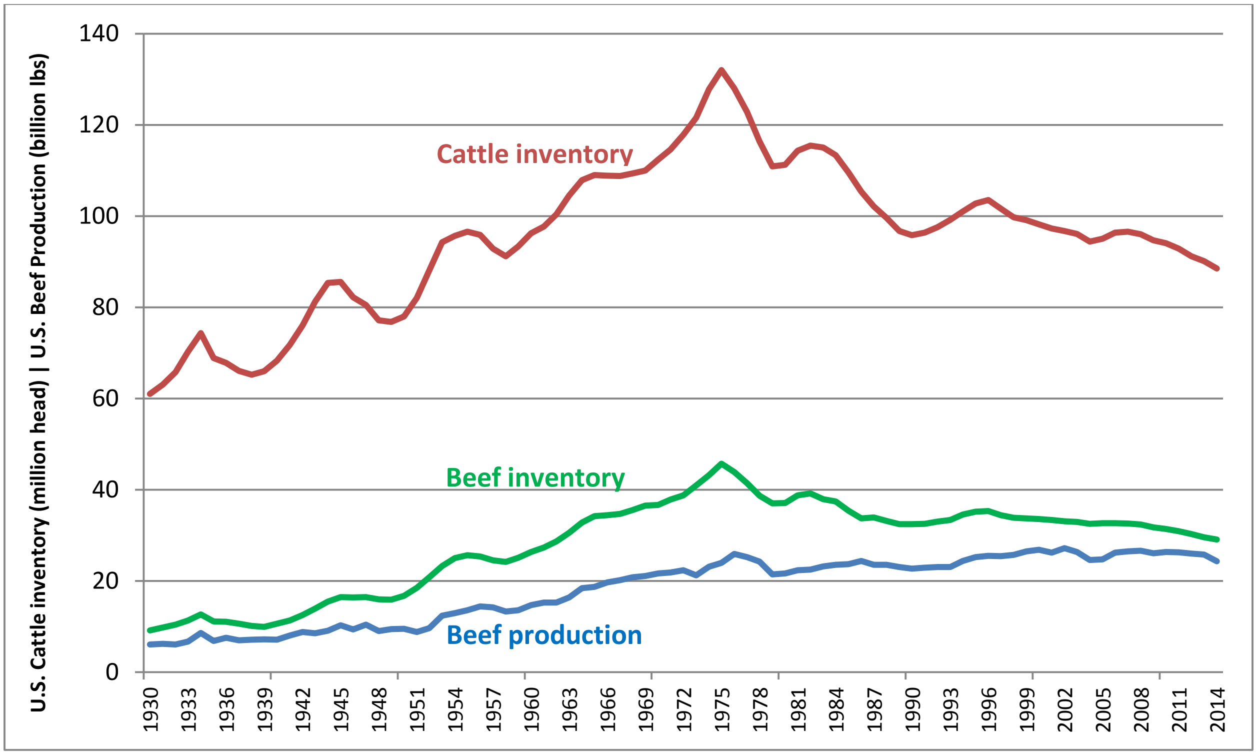

Figure 2. U.S. total cattle inventory, beef cattle inventory and beef production from 1930 – 2014 (USDA NASS 2015).

In terms of geography, cattle production today is also fairly concentrated. Ten states (TX, NE, KS, OK, MO, IA, SD, CA, MT, CO) account for 59% of the total non-dairy cattle inventory, and cattle in feedlots are even more concentrated, with 55.4% in the top three states (NE, TX, KS) and 85.1% in the top ten states.

1.4 Interpreting this Report

This report makes a number of recommendations about practices that could be implemented to improve the sustainability of the beef supply chain. It is not our intent to recommend a prescriptive approach that demands all suppliers make the same changes, and we recognize that there are many factors that affect the ability and willingness of producers to change their practices.

On the other hand, we do think it is important to consider the impact that different practices can have, and to communicate that to producers. Some voluntary programs have emphasized that all improvements represent a step forward, but have made it challenging for producers to understand the resulting impact. To address this concern, we have labeled each of our recommendations with an estimate of both expected impact and required investment to assist in selecting practices that make sense locally but also show a relatively high return on investment.

Furthermore, in most cases the best outcomes for any potential intervention will only be achieved through coordinating or changing the practices of many producers in a broader region. For example, decisions of neighboring ranches to improve the habitat quality of their lands can add up to meet thresholds of habitat size and connectivity (i.e., the degree to which the landscape facilitates the movement of wild animals and other ecological processes) so that the benefits to wildlife are substantially increased. Similarly, improvements to water quality by a single ranch or farm or feedlot are good, but if producers in a watershed work together to make improvements, they are more likely to achieve targets for freshwater biodiversity and water quality in streams and lakes than a single operator would (the whole is greater than the sum of the parts).

1.5 Areas of Emphasis and Further Research Needed

In framing this paper, we have deliberately chosen to focus on a large subset of the impacts and opportunities for improved sustainability in the U.S. beef supply chain. That focus is driven primarily by the types of change for which large retailers should realistically be able to advocate and monitor in the next several years. We highlight where there is clear scientific consensus on particular issues and areas where further research is needed. For example, from a conservation perspective, there is no substitute to having adaptive management plans for each site developed in consultation with trained ecologists and range conservationists, especially when seeking biodiversity outcomes. However, further work is needed to identify how this approach can be scaled up to meet the supply needs of large retailers.

This report was intended as a rapid assessment of the beef supply chain, so we focused on the large majority of the beef supply that is raised specifically for meat, and exclude dairy cattle sold as beef when their milk production declines. Since dairy cattle are raised differently than beef cattle, a separate analysis focusing on dairy would be most appropriate to identify key impacts and opportunities for that segment.

As 97% of the current U.S. beef supply is grain-finished, our review did not assess the relative merits of grass-finished (aka "grass-fed") vs. grain-finished beef. More research would be needed to determine longer term opportunities, especially because the differences between the two systems are complex, and which one is preferable depends on the weighting of different factors. As noted above, our recommendations for improvements under ranch and farm grazing apply to the grass finishing phase where applicable, in addition to the phases that apply to younger calves.

We analyzed the beef *production* system rather than examining issues around consumption, such as whether or not beef can be considered truly "sustainable" given its considerably higher environmental impacts relative to other protein sources (e.g., Eshel et al. 2014). Along these lines, this report focuses on relative impacts and opportunities within the beef supply chain rather than attempting to compare this data to non-beef data. We limited this analysis strictly to environmental impacts due to limited time available; the incorporation of social, economic, public health, and animal welfare impacts of beef production (all of which are important, and worthy of careful consideration) is an important area for future research and would likely result in additional or modified recommendations for improvement. There are likely to be trade-offs in some cases (e.g., some practices may improve environmental outcomes while negatively impacting animal welfare), and these issues merit a more complete analysis than we would have been able to provide here. Finally, we also did not analyze how the beef supply chain could impact soil health (e.g., Robertson 1996), an increasingly important issue for the conservation community, though aspects of this topic are examined in some sections.

Finally, it should be noted that analyses of the environmental impacts of beef reveal a wide range of values, due to differing (but valid) choices in methodology, studies in different locations and contexts, and natural variation. We used credible, and, to the extent possible, peer-reviewed sources for the best available data, but also have highlighted areas where the data are limited or there is no scientific consensus on the "best" approach to take. As some of the sources we cite were funded by the beef industry, a group opposed to beef production, or a related group (which could influence their findings and objectivity), in the references section we have flagged these sources where possible.

1.6 How to Use this Report

This report is written to be used both as an in-depth overview of the environmental impacts related to the U.S. beef supply chain as well as a useful reference of potential improvement opportunities. To make the improvement opportunities easier to compare and evaluate, we created a Table of Recommendations in the appendix to this report. The table of recommendations organizes the potential opportunities for improvement by production phase, and evaluates their relative potential impact, investment required, estimate of current uptake, and the scientific certainty of efficacy.

For a holistic and deep view of the relative environmental impacts and improvement opportunities we suggest reading the report cover to cover with the table alongside each section for reference. However, if interested in a specific supply chain segment or type of impact, the table of contents makes it easy to dive into specific sections. The executive summary and table alone can also serve as a useful reference and guide to improvement opportunities and if more detail or background is required the body of this report can be used as reference.

Part 2: Fresh water Opportunities in the U.S. Beef Supply Chain

2.1 Water Consumption

Water scarcity is one of the greatest challenges of our time, driven by increasing demand, degrading quality of the water available, and changes in rainfall patterns. Already, 2.7 billion people live in areas that experience severe water scarcity at least one month out of each year (Hoekstra et al. 2012). Figure 3 separates out water-scarce areas into places that experience continual (annual) water scarcity, seasonal water scarcity, or scarcity in dry years.

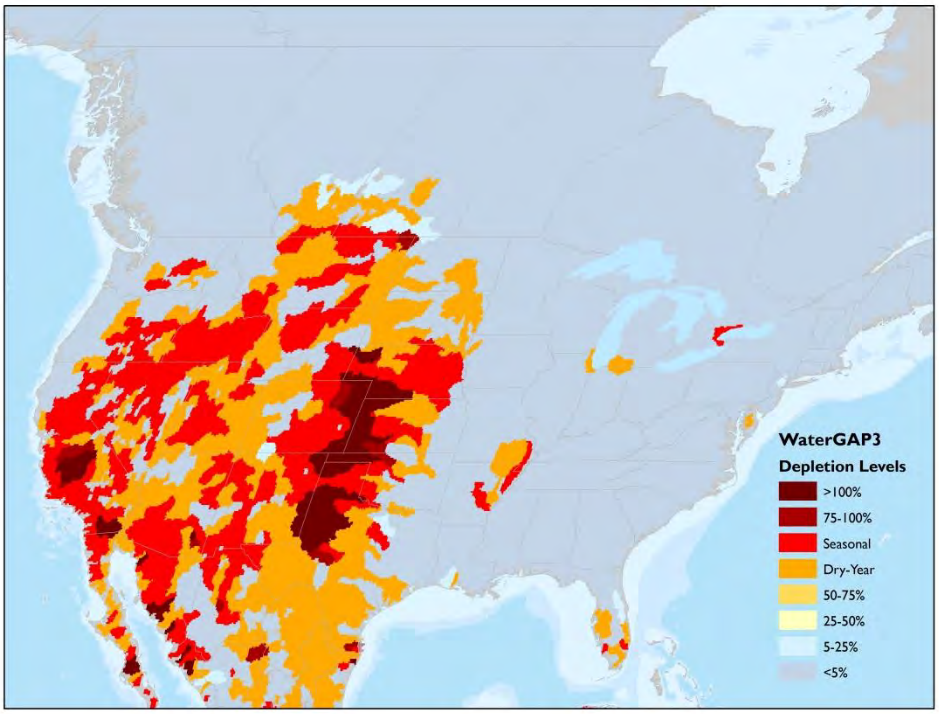

Figure 3: Water depletion in U.S. watersheds. (Adapted from Brauman et al. 2016). Water depletion, the fraction of renewable fresh surface and groundwater available in a watershed consumptively used by human activities on annual, seasonal, and inter-annual time scales, for U.S. watersheds delineated in WaterGAP3**.**

Globally, agriculture represents 70% of ground and surface water withdrawals (FAO 2014) and in the future water is expected to become the main limiting factor for agricultural production as competition for water with urban and industrial uses increases and groundwater resources are depleted (Postel 2000). While water consumption is an issue of global concern, water consumption patterns vary regionally and thus need to be addressed with specific approaches. In this report we focus on the consumption of “blue water” which includes withdrawals from groundwater and surface water (streams & lakes) but excludes precipitation, as blue water withdrawals offer greater opportunity for improvement especially in water-scarce areas (Chapagain et al. 2006). Note that not all water withdrawn is “consumed,” as typically some water returns to ground and surface water rather than evaporating or being transpired by plants.

Irrigated feeds for all livestock (not just beef) are estimated at approximately 9% of total fresh water withdrawals in the U.S. (CAST 2012), with direct water consumption in feedlots and extensive livestock farms comprising roughly another 1% (Maupin et al. 2014), and livestock processing (meat and egg processing) industries accounting for 0.1% of total fresh water withdrawals based on 2005 estimates (CAST 2012). The bulk of the direct water withdrawals occur in Texas, California, Iowa, Nebraska and

Kansas, accounting for 41% (Maupin et al. 2014) of all livestock water withdrawals from feedlots. However, these data do not separate cattle from all other livestock types, and incorrectly assumes that all water withdrawn is consumed. In addition, few studies distinguish water by consumption by production phase at a national level for U.S. beef. Given this, Beckett and Oltjen (1993) remains one of the most complete assessments of actual water consumed (from ranch and farm grazing to harvest facilities) at a national level as they identify water consumption by beef cattle rather than water withdrawals for all livestock. They found that ranch and farm grazing on irrigated pasture accounted for almost half of total beef water consumption, with feed production (both grain and hay) combined representing just over half, and feedlots and harvest facilities together accounting for less than 1% (Table 1).

Since we lack a more current estimate with the same level of detail as Beckett and Oltjen, we estimate the total water consumption of U.S. beef has increased roughly 12% from 1993 to 2014. This is due to growth in beef production that offsets improvements in animal and crop productivity (NCBA 2015, Capper 2011a). 25.8 billion pounds of beef carcasses were produced in 2014 (NCBA 2015), of which roughly 70% is boneless beef (Holland et al. 2015). At 441 gallons per pound this works out to 7,968 billion gallons of water per year. However, since Capper (2011a) found a 12% total improvement in beef water use from 1977 to 2007, if we annualize that and assume constant improvement (0.28% per year for 21 years), the current U.S. beef water consumption is 7,507 billion gallons. An estimated 355 billion gallons / day of water were used in the U.S. in 2010, 86% of which was freshwater (Maupin et al. 2014). On an annual basis, beef water consumption is about 6.7% of total U.S. fresh water use.

Table 1: Beef Cattle Water Consumption. Source: [1]Beckett and Oltjen 1993, [2]Rotz et al. 2015

	U.S. Water Consumption[1]			Kansas, Oklahoma, Texas Water Consumption[2]	
	billion gal/yr	*gal/lb boneless beef*	*%*	*gal/lb boneless beef*	*%*
Ranch and Farm Grazing [a]	3,130	206.0	46.8%	153.5	45.0%
Feed production [b]	3,499	230.2	52.3%	185.4	54.3%
Feedlots[c]	40	2.7	0.6%	2.5	0.7%
Harvest Facilities	21	1.4	0.3%	-	-
Total	6,690	440.1	100.0%	341.4	100%

[a] includes water used for drinking and irrigated pasture (for the final two columns it includes hay produced at the ranch).
[b] includes water used for producing irrigated grain feed and hay.
[c] includes drinking water only.

2.1.1 Water consumption in the beef supply chain

Water is consumed in all phases of the beef supply chain, with feed production (irrigated grains and hay) closely followed by ranch and farm grazing consuming the most water (Table 1). Cattle in the U.S. are fed large amounts of grains, primarily irrigated corn (Gerbens-Leenes et al. 2013). However, fresh water consumption per pound of beef is likely greater for grass-finished beef than in intensive feedlot systems (Capper 2012). This is largely due to the water consumed by plants in evapotranspiration over the large land areas used in extensive production, and as such these estimates change dramatically with changing assumptions about how much pasture is irrigated. In contrast, drinking consumes relatively little water, approximately 1-4 % of total water consumed; of this water most (70%) is consumed at the ranch and farm grazing phase (Rotz et al. 2015).

Although Beckett and Oltjen (1993) reported that 405 gallons of water per animal (approximately 0.6 gallons per pound of beef carcass weight) were used in processing, few studies go beyond the feedlot to include water consumed for processing. Similarly, estimates for Midwestern meat processors are reported to range from 450 to 1,500 gallons per animal (NC DENR 2010). Based on water usage rates and processing facility production rates for 2000, water consumption during the processing phase is estimated at between 0.4-1.5 gallon per pound of live weight killed for cattle and calves (U.S. EPA 2002). Overall, beef processing accounts for less than 1% of water consumed in the supply chain (Beckett and Oltjen 1993) and as such represents only a minor opportunity for improvement.

Measures for the water consumption in the beef supply chain vary greatly due to both the differences in climate across regions as well as the ways water consumption metrics are calculated (Doreau et al. 2012). There are two main approaches to measuring environmental impacts of water consumption: (i) the water footprint (AKA virtual water content or VWC, Hoekstra and Chapagain 2007) which separates water consumption into blue water (surface and groundwater), green water (soil water consumed in evapotranspiration) and gray water (water used to dilute pollutants) and (ii) the Life Cycle Inventory (LCI) approach (which typically focuses only on blue water inputs). For this analysis we focus on the LCI approach limited to blue water, but report both types of estimates here for comparison.

Estimates for water consumed per pound of beef range from 7.1 to 52,834.4 gallons (Table 2). The large spread is largely due to differences in water consumption accounting methods. Water footprint estimates include precipitation (green water) and tend to be much higher than LCI estimates. In addition, for the same method, results depend on which types of water use are included or excluded, and the aridity of the region (Ridoutt et al. 2012). At the lower end, the 3.2 – 64.7 gallon per pound values from Peters et al. (2010) are based on estimates that exclude water used by farm dams, thus they likely underestimate total water consumption. The upper bound estimates of 10,000-20,000 from Pimentel (1997) and Thomas (1987) were based on extensive rangeland systems, including evapotranspiration from rain-fed pastures and rangeland consumed by livestock, and are believed to be unrealistically high (Doreau et al. 2014).

Table 2: Summary of Beef Water Consumption Assessments. Source: Adapted from Ridoutt et al. 2012, Capper 2011a, Mekonnen and Hoekstra 2012, Rotz et al. 2015.

Value	*Assessment*	*Reference*
3.2 - 64.7 gal/lb., HSCW[a]	LCI result[e]	Peters et al. 2010
441.2 gal/lb., cuts boneless	LCI result	Beckett and Oltjen 1993
211.2 gal/lb., beef	LCI result	Capper 2011a
229.2 gal/lb., carcass	LCI result	Rotz et al. 2015
6.6 – 13.3 gal/lb., steak	Drinking Water	Costa 2007
1,617.8 gal/lb., beef	VWC[f]	Barthelemy, in Renault and Wallender 2000
2,422.8 gal/lb., beef [b]	VWC	Mekonnen and Hoekstra 2012
1,682.5 gal/lb., beef[c]	VWC	Mekonnen and Hoekstra 2012
402.1 gal/lb., beef[d]	VWC	Mekonnen and Hoekstra 2012
1,857.1 gal/lb., beef	VWC[g]	Hoekstra and Chapagain 2007
11,984.1 gal/lb., beef	VWC	Pimentel et al. 1997
23,968.2 gal/lb., beef	VWC	Thomas 1987, in Pimentel et al. 1997
1,739.6 gal/lb., carcass	VWC[h]	Pimentel et al. 2004

1,748.7 gal/lb., cuts bone in	VWC[h]	Chapagain and Hoekstra 2003
2,838.4 gal/lb., cuts boneless	VWC[h]	Chapagain and Hoekstra 2003
4,853.5 gal/lb., beef	VWC[i]	Deutsch et al. 2010
1,438 gal/lb., beef	Modified VWC[j]	Deutsch et al. 2010

[a] HSCW, hot standard carcass weight.
[b] Grazing system, U.S.
[c] Mixed system, U.S.
[d] Industrial system, U.S.
[e] Life Cycle Inventory (LCI) approach
[f] Water footprint, AKA virtual water content or VWC
[g] This figure is the reported global average. The range was 1320.5 gal/lb. (Japan) to 4525.4 gal/lb. (Mexico).
[h] Figures in the table are the reported global average.
[i] Range from 3631.1 gal/lb. to 6375.5 gal/lb. depending on the production system.
[j] Modified VWC (Virtual Water Content) excludes pasture evapotranspiration but includes evapotranspiration for crop and fodder production.

2.1.1.1 Regional impacts

Beef production in the U.S. is concentrated in regions where there is growing competition for water between agricultural, municipal and industrial users (Barton and Clark 2014), and where groundwater is increasingly overdrawn. The High Plains (also known as Ogallala) aquifer underlies roughly 225,000 square miles across eight states in the central U.S., which includes parts of the top beef producing states (Texas, Nebraska, Kansas, Oklahoma, South Dakota and Colorado). Of all of the groundwater withdrawn for irrigation in 2005 in the eight states over the High Plains aquifer, 78% was in Nebraska, Kansas and Texas. Nebraska, Kansas, California, Colorado and Texas are expected to be especially vulnerable to water shortages becoming more severe due to climate change (Barton and Clark 2014). Figure 4 shows the areas where the water level has dropped the most within the High Plains aquifer.

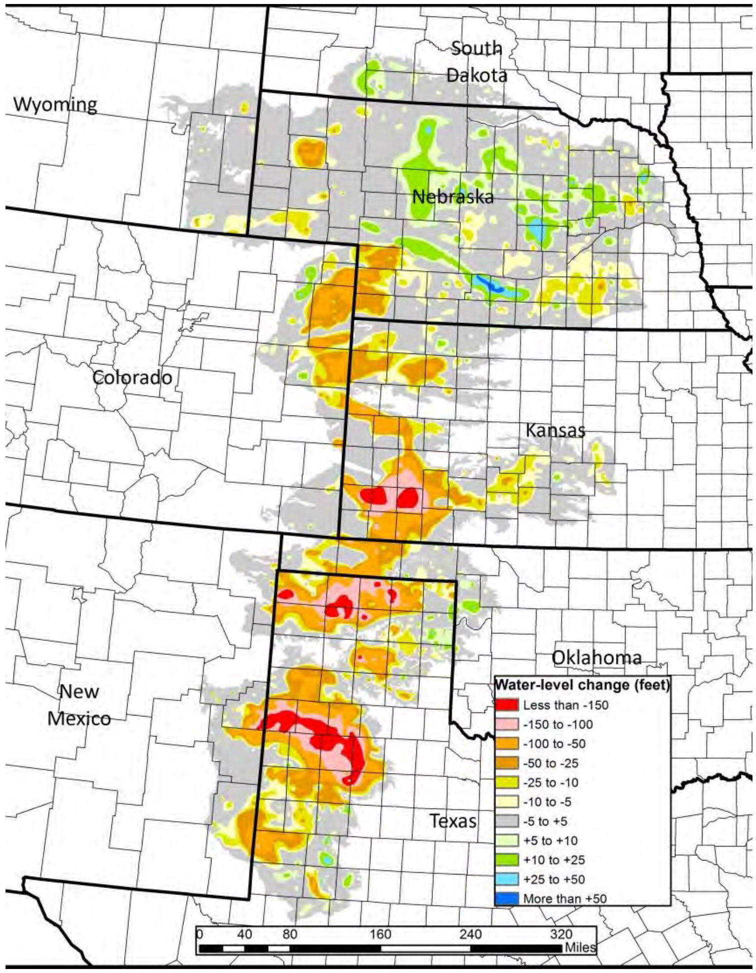

Figure 4. Water-level changes in the High Plains aquifer, predevelopment (~1950) to 2013. Source: McGuire (2014).

Similarly, studies of water consumption specifically for beef show similar regional variations. Beckett and Oltjen (1993) found that among U.S. cattle producing states, the Kansas-Nebraska region consumed the most water, primarily through drinking water and water from irrigated feed, closely followed by the New Mexico-Texas-Oklahoma production region. A partial life cycle assessment ("cradle-to-gate," meaning the life cycle prior to shipment to the consumer) by Rotz et al. (2015) found that 43% of the water consumed in beef production within Texas, Oklahoma and Kansas is used by the ranch and farm grazing phase, with 57% used in feedlots and feed production. Across all production phases, 95% of the water consumed is used for some form of feed production (whether forage for ranch and farm grazing, or hay and grain feed production for feedlots). This high proportion reflects a high use of irrigation for pasture and other forms of feed production in Texas. Production systems may vary by region (Rotz et al. 2015) which can make broad generalizations about water use unreliable in a specific region (Ridoutt et al. 2012, Rotz et al. 2013). Recommendations to reduce water consumption should also take into account regional differences in both water scarcity and production systems.

2.1.2 Approaches to reduce water consumption

The opportunities to mitigate water consumption in the supply chain include: decreasing water consumed from irrigated grains, hay, and pasture; reducing water intake by cattle; and conserving and re-using water in harvest facilities (in that order). It's generally acknowledged that reducing direct use of drinking water for cattle can only amount to relatively low gains as it accounts for no more than 1-4%

(Beckett and Oltjen 1993, Rotz et al. 2015) of total water consumption in the supply chain at most, with use in harvest facilities even lower. Sensitivity analyses show total water consumption is relatively more sensitive to changes in irrigated feeds than changes in other factors like drinking water consumed by cattle (Capper 2012, Beckett and Oltjen 1993, Rotz et al. 2015) or water used in cattle processing (Beckett and Oltjen 1993). This suggests that greater potential for impact and water saving lies in reducing water consumed in producing feed. This applies to both forage in the ranch and farm grazing phase (in particular on irrigated pastures) and hay and grain crops grown in the feed production phase.

2.1.2.1 Reducing water consumed in feed production

The largest opportunities may lie in minimizing irrigated water used for feed grown in areas where low rainfall leads to seasonal fresh water depletion. While data do not exist yet that specifically highlight areas where there is water scarcity during the *growing* season for crops and pasture, Figure 3 is from a new analysis (currently in peer review) that highlights areas with regular water scarcity, seasonal water scarcity, and scarcity in dry years. This map highlights areas that should be avoided for feed production, including irrigated pasture.

Irrigation efficiency can be improved by optimizing the timing and amount of water applied, or shifting to different types of irrigation (such as conversion from flood to drip irrigation). Other options include using early maturing corn varieties, buying corn from regions that don't require irrigation, or replacing corn with more water efficient cereals such as sorghum. Roughly one-fifth of irrigated corn acres in the U.S. still use inefficient flood or furrow irrigation, and the use of highly efficient drip irrigation remains rare (USDA NASS 2008). The main reasons for this low uptake of efficient irrigation cited by farmers are costs of installation, uncertainty about the timing of water delivery, and perceived risks to crop yields (Schaible and Aillery 2012). Efforts to increase adoption would need to address these perceived (and real) barriers. However, irrigation efficiency does not always result in reduced water consumption; when farmers are not irrigating as much as they would like to, increased efficiency can lead to higher total water consumption (Foster and Perry 2010). Essentially since more of the water applied is generally consumed (evaporated or transpired) and less runs back into surface and groundwater, unless farmers *apply* less water the total water consumption can increase. At the same time, more efficient irrigation technologies can potentially reduce energy and pumping costs for farmers, as well as reduce runoff from fields which can carry sediment and nutrients into lakes and streams (Pfeiffer and Lin 2014). Reducing the energy used to pump and move water can reduce costs for farmers significantly. For example, in western Kansas, these energy costs represent 6-8% of the total costs for growing corn, compared to 8-15% of costs going to land rent (Ibendahl at al. 2015).

In addition to practices that enhance irrigation efficiency, water consumption can be reduced by conserving groundwater and surface water with cropping and management practices that increase water infiltration into the lower layers of the soil, increase water recycling, and decrease runoff. Improvements in livestock management can include crop-livestock integration where cattle can graze on crop by-products. These practices would be relevant for ranch and farm grazing operations as well as feed producers.

2.1.2.2 Reducing direct water consumed by animals in drinking and service use.

Feed with higher water content reduces the amount of water that cattle need, so for example a higher proportion of fresh grass / silage in the diet reduces water intake. Other options for reducing direct water consumption include using animal breeds adapted to drought, using shelters to reduce heat stress, improving animal productivity to reduce the amount of feed needed, and reducing time to harvest.

In addition to reducing direct consumption by animals, in feedlots water conservation practices can be applied to reduce wastage and increase recycling. More efficient water troughs can be installed, including reducing leakage and recycling overflow water from troughs (Parker et al. 2000). The overflow water can be used for several purposes, including being re-used for drinking, applied to crops via irrigation, using it for dust and temperature control, or using it in feed mills. However, improvements to direct water consumption are only expected to decrease water consumption slightly as noted above.

2.1.2.3 Harvest Facilities (Packing and Processing)

While packing and processing represent less than 1% of overall water consumption in the supply chain (Table 1), there are still opportunities to minimize water consumed in this phase (especially in locations where water is especially scarce). Recommended industry measures as listed in (World Bank 1999) include:

- "*Limiting water loss using taps with automatic shutoff, using high water pressure, and improving the process layout."*
- *"Eliminate wet transport (pumping) of wastes (for example, intestines and feathers) to minimize water consumption."*
- *"Separating cooling water from process water and wastewaters, and recirculate cooling water."*
- *"Implementing dry precleaning of equipment and production areas prior to wet cleaning*."

2.1.3 Recommendations

- Interventions to reduce impacts on water supply should focus on improving irrigated pasture and feed crop management to reduce water consumption. Areas of high water scarcity (as identified in Figure 3) should be a priority in which to reduce water consumption by both improving water efficiency and shifting feed production to regions where water is less scarce. Regional studies on water consumption in TX, OK, KS, NE and NM show that water consumption in these regions is among the highest nationally, most of it used for irrigated feed. High water consumption in these regions also potentially impacts groundwater through rates of extraction that exceed recharge rates.
- In planning interventions, it is important to look beyond "water use efficiency" and instead consider how much water being withdrawn is currently consumed vs. how much flows back to the surface or groundwater, and whether the intervention will lead to an increase or decrease in water consumption (Foster and Perry 2010).
- Feed should be sourced from farms that use efficient irrigation techniques such as drip irrigation where water budgeting indicates it is appropriate. Producers should be encouraged and incentivized to adopt more efficient techniques (in partnership with irrigation districts where relevant) where current irrigation techniques are leading to avoidable evaporative losses.
- Reduce the amount of corn used for feeds where possible and encourage substitution of more water efficient feeds, and/or by-products such as distiller's grains.
- Encourage use of improved cattle breeds adapted to drought in areas of high aridity and breeds with high productivity that minimize time to slaughter.

2.2 Water Quality Impacts

Pollution of fresh water occurs at all stages of the beef supply chain in varying degrees. At the ranch and farm grazing level, pollution comes primarily from soil erosion that washes sediment into water bodies (some of which would occur even without livestock grazing) and from cattle manure that is either deposited directly into streams by cattle or washed into streams and rivers by rain. At feedlots the large volume of animal manure produced can leach nutrients below ground (where it can flow into both groundwater and surface water) or directly run off into streams, lakes, and groundwater. Meat processors and packers produce effluent high in organic matter (U.S. EPA 2004a). In addition, feed production is also a significant contribution to nutrient pollution with excess nutrients from fertilizer runoff ending up in streams, lakes, and groundwater supplies.

Agriculture is the largest source of pollutants to streams in the U.S. accounting for 130,976 miles of impaired streams and rivers (U.S. EPA 2013). Agricultural run-off damages lakes, streams and groundwater by degrading the quality of available water for aquatic life, drinking, recreation, and other beneficial uses. Livestock production in particular produces large amounts of wastes during the grazing, feedlots, and crop production phases; livestock are responsible for a majority of the waters impaired by agriculture (U.S. EPA 2013). Intensive cattle production practices are also associated with a higher demand for feed, leading to increased use of inorganic fertilizers and pesticides to produce grain. Water pollutants that originate from livestock production systems (including growing feed) include nutrients such as nitrogen (N), phosphorous (P), sediment, pathogens, and other organic matter; emerging contaminants of concern include antibiotics, hormones, and other veterinary medicines (Burkholder et al. 2007). Nutrients from manure account for about 25% and nearly 40%, respectively, of N and P inputs in agricultural watersheds (Figures 5 & 6, Dubrovsky et al. 2010).

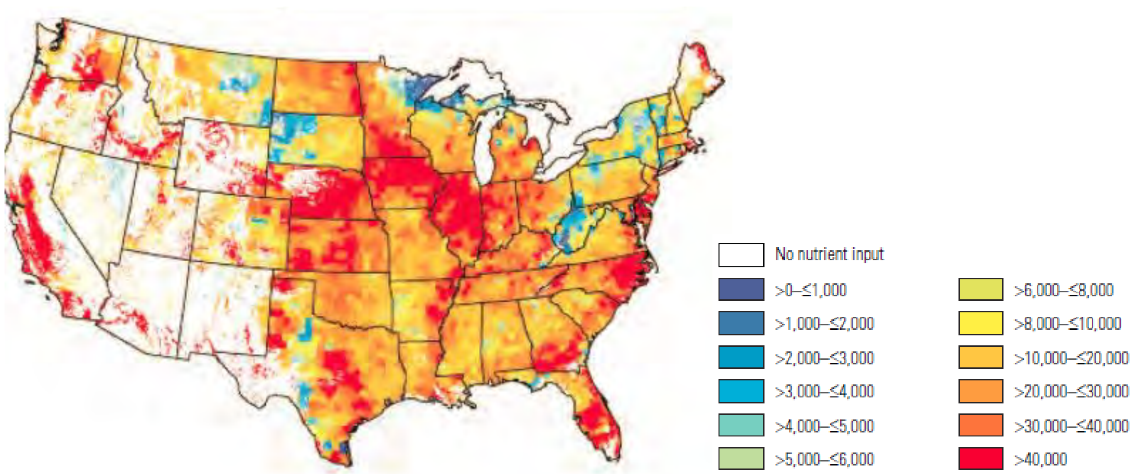

Figure 5: Nitrogen from Farm Fertilizer. Estimated 1997 input rate in pounds applied to fields per square mile. Source: Dubrovsky et al. (2010).

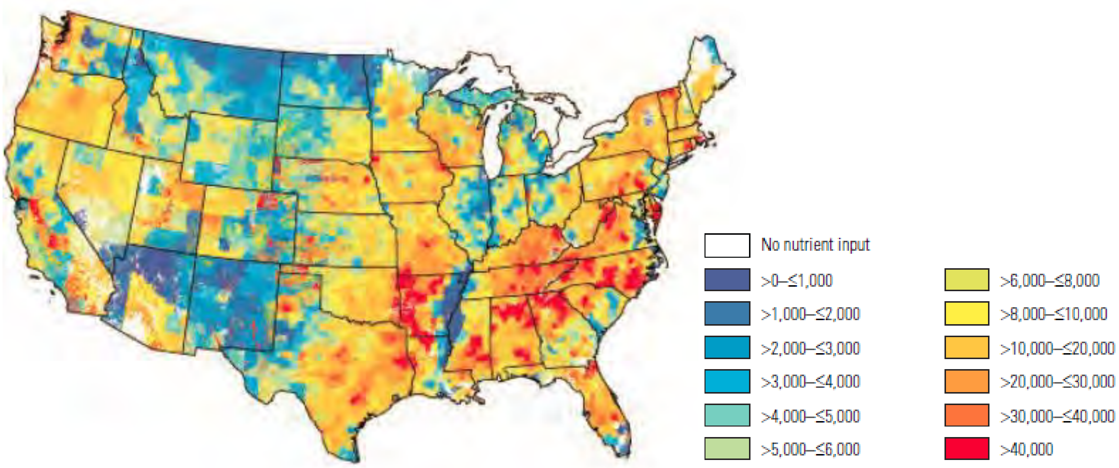

Figure 6: Nitrogen from Livestock Manure. Estimated 1997 input rate in pounds applied to fields per square mile Source: Dubrovsky et al. (2010).

Although most water pollution originates at the farm or ranch or feedlot site, the impacts may extend far beyond the farm by impacting water quality for downstream users. The Gulf of Mexico dead zone is an example of this; it is the result of years of nutrient runoff from upstream agriculture leading to hypoxia (Alexander et al. 2008). It is estimated that animal manure from pasture and rangelands contributes 37% of all P (and 5% of all N) that enters the Gulf of Mexico. Corn and soybean production contributes more than half (52%) of all N (Alexander et al. 2008), much of which is used as animal feed.

2.2.1 Sources and impacts of pollutants in the supply chain

2.2.1.1 Sources of pollution

There are many approaches to comparing different types of water pollution across production phases, from a "gray water footprint" that estimates the amount of water required to dilute pollutants, to biochemical oxygen demand (BOD) which focuses on the potential of pollution to cause oxygen depletion, to total mass of pollutants. Since our objective is to mitigate the *impact* from beef production, we have instead focused on sources of impaired waters as defined by the U.S. EPA, which identifies water bodies that do not meet local water quality standards under the Clean Water Act (U.S. EPA 2013). These standards are not arbitrary, and indicate that some of the intended uses of the river (such as human consumption of fish, recreation and providing suitable habitat) are negatively affected.

The U.S. EPA's Watershed Assessment, Tracking, & Environmental Results (WATERS) tool provides national summaries of the probable source of impaired waters, including breakdowns within the agriculture category. This data applies to *all* livestock, not just beef, and the row crop section applies to *all* row crops, not just the portion fed to animals.

Among waters impaired by agriculture, where a distinction is possible between impairment directly from animal production as opposed to growing crops, 73% of impaired stream miles and 53% of impaired lake acres can be directly attributed to livestock production (which does not include row crops or hay grown to feed livestock), of which grazing and feedlots together make up 78% of impaired stream miles and 95% of impaired lake acres (U.S. EPA 2013). See Table 3 for a breakdown of how much of this pollution is attributable to each production phase. Note that some of the categories in the data do not permit this distinction and are reported here as "ambiguous animal production," that "feedlots" includes both AFOs and CAFOs, and that in this table "Feed Production" includes all cropland rather than only crops grown for livestock.

Table 3: Breakdown of impaired waterways by production phase for *all agriculture* (including livestock other than cattle and all row crop production).

	Impaired stream miles due to agriculture		Impaired lake acres due to agriculture	
Ranch and Farm Grazing	59,702	39.0%	270,052	21.8%
Feed Production (**not just livestock**)	41,757	27.3%	586,313	47.3%
Feedlots	26,887	17.6%	349,381	28.2%
Ambiguous Animal Production	24,552	16.1%	34,172	2.8%
Total	152,898	100.0%	1,239,918	100.0%

Separating out agricultural impaired waters attributable to beef is challenging. In 2014, beef made up 51% of federally inspected red meat production in the U.S. (by weight), 26% of all meat/poultry production (USDA ERS 2015b), and 7% of total calories consumed in the U.S. (with poultry, pork, and eggs together providing another 11% of calories, Eshel et al. 2014). Corn is the dominant feed crop (excluding grass and hay) for cattle, accounting for over 95% of feed grains consumed in the U.S. (USDA RS 2015c). About 10% of corn produced in the U.S. is fed to cattle (Barton and Clark 2014) and about 11% of soybean meal used for livestock in the U.S. is used for beef (ASA 2016). Therefore, it is reasonable to assume that roughly 10% of the impaired waters from row crops are attributable to beef production. Ranch and farm grazing, on the other hand, is heavily dominated by cattle. In addition to the 92 million head of cattle (NCBA 2016), there are only 9 million horses (AHC 2015), 5 million sheep, and 2.6 million goats (USDA 2014) in the U.S. While goats and sheep eat less grass than cattle, without good data on stocking densities of each species in the U.S. we simply divide the total number of cattle minus the number of milk cows (9.32 million) by the total number of commercially grazed livestock to arrive at a rough estimate of 76% of pasture and rangeland being attributable to beef production. Without a better way to break down feedlot impact by species we assume 26% of the impact of feedlots is attributable to beef since beef is 26% of all meat production. Applying these estimates of what fraction of impaired waters may be attributable to beef (10% of row crops, 26% of feedlots and ambiguous animal production, 76% of ranch and farm grazing) results in a different emphasis of the impact of each production phase as shown in Table 4.

Table 4: Rough estimated breakdown of impaired waterways by production phase *for beef only*.

	Impaired stream miles due to beef		Impaired lake acres due to beef	
Ranch and Farm Grazing	45,374	72.1%	205,240	56.4%
Feed Production	4,176	6.6%	58,631	16.1%
Feedlots	6,991	11.1%	90,839	25.0%
Ambiguous Animal Production	6,384	10.1%	8,885	2.4%
Total	62,925	100.0%	363,595	100.0%

By comparing Table 3 to Table 4 you can see that beef accounts for roughly 41% of all impaired stream miles from agriculture, and 29% of impaired lake acres from agriculture, despite only providing 7% of the calories consumed in the U.S. It is also evident that the impacts of the ranch and farm grazing phase are far more pronounced compared to the other sectors for beef than compared to all agriculture. An estimate of the total reactive N produced by different types of animal products in the U.S. (as a proxy for overall water quality impact) found that beef contributed 65% of the total reactive N (even with manure excluded, Eshel et al. 2014). This finding is consistent with our results; the sum of miles and acres from Table 4 represents 55% and 57% of the stream miles and lake acres impaired due to livestock and if we were to attribute 25% of the ambiguous animal production to beef then beef would represent 61% and 59% of the impact due to livestock.

While this approach is imperfect, in the absence of consistent credible data reporting specifically on beef water quality impacts, we believe it appropriately identifies the most critical opportunities for improving water quality via changes in beef production. Specifically, it supports a focus on ranch and farm and feedlots rather than feed production to achieve the greatest impact. This approach does not give a measure of intensity of water quality impacts per unit of beef which would require further analysis beyond the scope of this paper. This also does not necessarily mean that focusing on ranch and farm grazing would result in the biggest environmental improvements per dollar spent. However, given that the US EPA's WATERS data is based on impaired waters we know that water quality declines are severe enough to restrict beneficial uses of the lakes and streams, making this an issue worth addressing.

While water quality issues predominately apply to surface water, it is possible for nutrients and pathogens to enter groundwater as well. However, the same best management practices (BMPs) that benefit surface water should also benefit groundwater. Special care should be taken in areas of karst topography (having underground drainage) (Desimone et al. 2014) to avoid groundwater contamination.

2.2.1.2 Bacteria and Pathogens

Pathogens are the single greatest cause of impaired streams and lakes in the U.S. (U.S. EPA 2013). Untreated manure, feces from grazing animals, and dead animal carcasses can all carry bacteria and pathogens such as *Escherichia coli, Cryptosporidium*, and *Giardia* (Sunohara et al. 2012) that when transported into surface waters can degrade water quality for drinking and recreation (Nicholson et al. 2005, Hooda et al. 2000). The impacts of pathogenic pollutants on aquatic life however, are largely unknown (Burkholder 2007). The risk of water contamination with bacteria and pathogens is higher in situations where rains follow spreading of contaminated manure, when there is flooding, or where infected cattle have direct access to rivers or other water bodies. While many of the bacteria in manure spread on fields are deactivated with exposure to bright sunlight (Mallin and Cahoon 2003), because of the large volumes of waste produced by feedlots pollution is still possible. In addition, pathogens tend to settle in stream sediments, surviving there for extended periods (Burkholder et al. 2007).

2.2.1.3 Sediment

High quantities of suspended or dissolved sediment in surface runoff from grazing lands and croplands negatively impact water quality in streams, lakes, and other water bodies. Suspended sediment increases turbidity which reduces the amount of light filtered through water, limiting the growth and distribution of aquatic plants, which in turn can reduce the level of dissolved oxygen available. Sediment pollution also directly impacts fish and aquatic invertebrates; increased turbidity reduces the feeding efficiency of fish, changes fish migration patterns, reduces the ability of fish to find food efficiently and can lead to fish mortality by clogging the gills and filtering mechanisms (Kjelland et al. 2015). In addition to directly degrading instream habitat, sediment also tends to deliver nutrients along with it, and accelerate erosion in streams (Allan 2004). Suspended sediments can also limit the recreational use of streams and lakes when fish populations and water visibility are reduced.

Erosion from overgrazing can directly contribute to heavy sediment loads in streams. Overgrazed pastures generally have poor forage cover and significant trampling – often as a result of overstocking (Hubbard et al. 2004) – which accelerates erosion. The role of overgrazing in increasing and accelerating erosion and sediment runoff and its negative impact on watersheds is well documented (Briske 2011). Similarly, croplands producing feed contribute to sediment loads through erosion from farming activities such as tillage and planting.

2.2.1.4 Nutrient pollution

Nutrient pollution is the third leading cause of water quality impairment (after pathogens and sediment) facing U.S. streams (and is second most significant for lakes after mercury) according to the EPA (U.S. EPA 2013). Excess nutrients from crops and livestock have increased sharply over the last 100 years to 304 billion pounds per year of N and 24 billion pounds per year of P, with further increases projected (Bouwman et al. 2013). Nutrient pollution has significant environmental and public health impacts. N and P are important nutrients as both can lead to aquatic eutrophication (Lewis et al. 2011), which involves increased algal growth and decreased oxygen levels that degrade water quality, restricting its use for drinking and other beneficial uses (U.S. EPA 1990), and impact aquatic species and habitat. Livestock manure (both on ranch and farm grazing, and during feed production) and inorganic fertilizers from feed production cause surface waters and groundwater to become contaminated with nutrients leached from soil and surface runoff (Sims et al. 1998). Nutrient pollution in drinking water can also pose significant public health concerns, especially where surface water is consumed without being treated first. For example, ingesting high levels of nitrates (exceeding the EPA standard of 10 mg/L, or 1 mg/L for nitrite, U.S. EPA 2009) can lead to oxygen deprivation, causing 'blue baby syndrome' in infants. Nitrates have also been linked to disrupted thyroid functions, reproductive problems, and various cancers (Kross et al. 1993, Follett and Hatfield 2001).

Manure and the associated nutrients are a concern at several stages: from cattle defecating in and near streams in ranch and farm grazing, runoff (from manure and other fertilizers) from row crops intended as cattle feed (and from fertilized pastures and hayfields), accumulation and runoff in open unpaved feedlots, and leakage or overflow from storage in holding ponds, lagoons, and uncovered stockpiles. Careful nutrient management including the use of manure can reduce and in some situations eliminate the need for inorganic fertilizer use. However, this does not necessarily ameliorate water quality issues arising from fertilization. Spreading manure on agricultural fields is a common practice for waste disposal in feedlots, and often decisions to apply manure are driven by the need to dispose of waste rather than considerations for crop nutrient needs (indicating that both feedlot managers and farmers should be engaged to make improvements). This view often leads to repeated application of manure at rates that far exceed crop needs, resulting in surplus nutrients that can be transported in surface and groundwater (Hooda et al. 2000, Mallin and Cahoon 2003). Regional concentration of cattle feedlots can drive the practice of excessive field application of manure due to the large imbalances between waste production and waste assimilation capacity of surrounding lands (Mallin and Cahoon 2003). In addition to agricultural management practices (including manure application timing and rates), nutrient loss through runoff where manure has been applied is determined by the physical characteristics of the site such as soil type and slope, and climate conditions such as rainfall amount and intensity. For example, studies have shown that generally P losses from leaching and runoff in livestock farming areas do not exceed 1.78 pounds Total P per acre per year, but may be considerably higher for a specific field or catchment, when there is rain or snowmelt following manure application (Hooda et al. 2000).

Feedlot runoff catchment basins and manure lagoons also pose significant spillage and leakage risks, caused by mismanagement or weather events than can contaminate surface and groundwater and cause massive fish kills (Mallin and Cahoon 2003). There is a long history of major pollution events from feedlots; some recent major incidents that have resulted in severe water contamination have been documented for feedlots in North Carolina, Iowa, Maryland and Missouri (Mallin and Cahoon 2003).

Feed production is a significant source of nutrient pollution in the beef supply chain via nutrient runoff and leaching. Corn is the leading feed grain used in beef production in the U.S. – 95% of all livestock feed grain production is from corn (USDA ERS 2015d) and 10%-13% of the total U.S. corn crop goes to cattle feed which is roughly equivalent to the amount (10%) of corn used for direct human consumption (Barton and Clark 2014, USDA ERS 2015c). Agricultural fields with artificial drainage systems (tile and mole drainage) that are common in the Midwest allow dissolved nutrients to be rapidly transported into streams and lakes without being filtered by surface features like grass strips and riparian buffers, requiring different conservation practices to ameliorate (Lemke et al. 2011). With tile drainage, nutrient loads in rivers and lakes can be raised even without a run-off event such as during or after rainfall or snowmelt (Hooda et al. 2000, Stoddard et al. 2005, Isensee and Sadeghi 1996).

2.2.1.5 Organic effluents
Effluents from meatpacking and processing plants contain substances such as blood and fat that have a high BOD, which causes the rapid growth of microorganisms that deplete oxygen levels in stream below levels needed to support aquatic life (Tewari et al. 1991). Direct discharge of untreated effluents can cause severe disruptions in aquatic ecosystems including fish kills (U.S. EPA 2004b).

2.2.1.6 Antibiotics, hormones and parasiticides
Antibiotics and hormones are used routinely in U.S. cattle production to treat and prevent disease and enhance growth (Montgomery et al. 2001, Gustafson and Bowen 1997). In the livestock sector veterinary medicines excreted in urine and feces and medicines washed off treated animals are the main path of entry for these into the environment. Regulatory research has shown that algae and plants are particularly sensitive to antibiotics, while Daphnids (water fleas) and fish are particularly sensitive to parasiticides. However, toxicity data alone is insufficient to establish the level of environmental risk (Boxall et al. 2004, Khan et al. 2008).

In animal agriculture, the use of antibiotics for reasons other than treating disease is widespread and a growing public health concern as it is believed to contribute to the emergence of drug resistant bacteria (Chee-Sanford et al. 2009). Though there is little research available on the level of antibiotic use in cattle production, a study by the Union of Concerned Scientists estimated that U.S. cattle producers use 3.7 million pounds a year of antibiotics for nontherapeutic purposes (approximately 10.3 million pounds are used in hog production and 24.6 million pounds for poultry, Mellon et al. 2001). A small proportion of the antibiotics consumed by an animal are absorbed; an estimated 75% of antibiotics consumed are excreted as waste (Chee-Sanford et al. 2009). Spreading manure on agricultural fields can thus potentially introduce significant amounts of antibiotics into the environment that can remain in the soil and be transported into groundwater and surface water. Antibiotics can be degraded to some extent by storing liquid manure prior to spreading on agricultural fields, anaerobic digestion and composting (Massé et al. 2014). Antibiotics originating from livestock agriculture have been detected in surface and groundwater at sites close to feedlots (Bartlett-Hunt 2011).

Hormones are often used to promote growth in cattle. Significant levels of steroidal hormones have been detected in feedlot retention ponds and downstream sites in the U.S. (Soto el al. 2004). A variety of natural hormones have been found in runoff, surface soil, and manure, both from feedlot cattle that have received hormonal growth stimulants and those that have not (Bartlett-Hunt 2012). Once in surface waters, steroid hormones act as endocrine disruptors and can cause hormonal abnormalities in a variety of species. Steroidal hormones from beef cattle have been shown to negatively impact the reproductive and endocrine systems of wild fish (Gray et al. 2006, Orlando et al. 2004). To date there is no evidence of hormones excreted by cattle leading to concentrations high enough to impact human health, but where surface water is consumed without treatment this could potentially be a concern.

2.2.2 Approaches to reduce water quality impacts

In the U.S. feedlots are subject to different water quality regulations depending on their size and whether or not they discharge pollutants into waterways via ditches or pipes. Feedlots classed as concentrated animal feeding operations (CAFOs) are regulated by the federal Clean Water Act (CWA) and are subject to water quality standards which are enforced via National Pollution Discharge Elimination System (NPDES) permits. Feedlots with over 1,000 head of beef cattle are considered "large CAFOs," "medium CAFOs" have 300-999 head and also "*a manmade ditch or pipe that carries manure or wastewater to surface water, or the animals come in contact with surface water that passes through the area where they are confined*," and small CAFOs have <300 head of cattle but has been designated as a significant source of pollution (U.S. EPA 2015a). Feedlots not classified as CAFOs (typically referred to as animal feeding operations or AFOs) are not subject to the same regulations. Even with these regulations, permitted runoff from CAFOs causes 3,855 miles of impaired rivers, and 14,162 acres of impaired lakes (U.S. EPA 2013), and CAFOs out of compliance may contribute additional pollution. Effluent discharges from meat packers and processors are also federally regulated but have not been identified as the primary source of any impaired waters.

Agricultural nonpoint sources such as cropland and ranches are not directly subject to the CWA, although amendments to the CWA do provide a framework for state-levels plans to address nonpoint sources where necessary to meet water quality goals. In the absence of CWA permitting requirements, the USDA and states have relied on voluntary programs to reduce nutrient runoff from nonpoint agricultural sources (Ribaudo 2005). Efforts rely primarily on voluntary adoption of agricultural BMPs or other incentive programs like payments for ecosystem service programs that can pay producers to reduce pollution run-off. Given the challenges in achieving water quality outcomes through changing agricultural practices (Lemke et al. 2011), it is critical to work with farmers across a watershed to ensure that field-level changes add up to meaningful improvements. For example, strategic targeting of conservation practices on fields and pastures was piloted with farmers in the Pecatonica River watershed in southwest Wisconsin and the results showed that farmers working with the project reduced their average erosion and P runoff almost in half one year after implementation (TNC 2014). More importantly, P loading in streams throughout the watershed was reduced by 37% during storm events when most runoff occurs after three years of implementation.

2.2.2.1 Measures to reduce water pollution on farms and feedlots

Reducing negative water quality impacts on farms and feedlots entails controlling surface runoff and leaching of fertilizers and livestock manure from farms and grazing lands; reducing and treating manure runoff from feedlots; and controlling bacteria, pathogens, and other emerging pollutants in runoff. Key recommendations for ranch and farm grazing involve improved fertilizer efficiency, manure management, riparian area protection, avoiding irrigation within 7-10 days of manure application, and vegetative buffers to trap and remove pollutants from runoff. Note that recommendations around the application of manure to farms apply to both feed producers (who use it as an input) and feedlot operators (who export it as waste). However, it will be easier to work with feedlot operators who generate the manure to improve their practices (and encourage them to work with farmers who apply the manure) than with farmers further up the supply chain. Outreach to the NRCS will also help producers find resources for making these improvements.

i. *Improving efficiency of fertilizer and livestock manure application* can control excessive nutrient accumulation in soils to reduce N and P leaching. Best practices include applying fertilizers (manure and inorganic fertilizer) based on soil testing and plant requirements, and timing fertilizer application to achieve higher plant uptake and minimize the amount of time nitrates are resident in the soil. This approach can be used for manure, ensuring manure application rate is determined by how much N and P are needed by crops to avoid an excess. Any additional fertilizers applied (whether inorganic or other organic fertilizers) should take into account nutrients supplied by manure. Nutrient management plans can incorporate much of these considerations and help guide decisions on nutrient application to avoid inputs in excess of crop requirements and to minimize loss to streams, groundwater, or the atmosphere. These plans should include desired outcomes (e.g. water quality of runoff) as well as practices to ensure that they are having the desired impact.

ii. *Timing of manure and slurry applications* should be made during spring and summer, and avoid winter application to avoid N being lost rather than used by crops. In general, producers should also avoid applying manure to soils that are frozen, saturated, or on steep slopes (Hooda et al. 2000) to limit chances of high N and P runoff. Feedlot operators can limit sales of manure to spring and summer months.

iii. *Manure application techniques* such as subsurface injection that minimize potential surface runoff of nutrients and organic matter should be encouraged to be used by feedlot operators. Diluting slurry with water before direct application can also help minimize runoff by helping the slurry seep into dry soil, although at a cost of increased water consumption.

iv. *Vegetative buffer strips* are effective for the reduction of pollutants from runoff in farms without tile drainage, especially suspended or dissolved particulate matter including sediment, organic matter, and particulate N and P. In pastures, mixed swards that combine a perennial legume with grass, for example clover and alfalfa, can also provide N from biological fixation as an alternative to inorganic N fertilizers. Vegetative strips especially those constructed with shrubs and trees, also have the advantage that they can provide wildlife and pollinator habitat, cool water temperatures and improve aesthetics (Briske 2011).

v. *Vegetative treatment systems / constructed wetlands* can be used to improve water quality by trapping sediment and breaking down nutrients on both farms (especially where tile drainage is present so they can intercept tile outflows) and feedlots. They can offer substantial improvement over other baseline systems, especially in areas with relatively high precipitation (e.g., central and eastern Corn Belt states; Koelsch et al. 2006). In irrigated pastures, vegetative wetlands in combination with irrigation management to reduce tail water run off rates reduce bacteria concentration in runoff (Knox et al. 2007). Vegetative treatment systems can be constructed to provide wildlife habitat and aesthetic benefits in addition to improving water quality.

vi. *Riparian Protection* from nutrient, pathogen pollution and erosion can be controlled by managing livestock distribution on the landscape to minimize time spent in and impact on riparian areas (Nader et al. 1998) and livestock's spatial distribution throughout the landscape to reduce time spent in one place. Management practices include placing salt, mineral or protein supplements away from riparian areas, installing alternative water sources in uplands, riparian fencing, and rotational grazing (Nader et al. 1998, Hubbard et al. 2004). In addition, reducing animal stocking densities so that they are not in excess of land carrying capacity can aid in reducing erosion (Hubbard et al. 2004).

vii. *Reducing or eliminating non-therapeutic uses of antibiotics and hormones* in feedlot cattle can minimize the amount of antibiotics and hormones that can enter the environment. While manure management practices such as storage, anaerobic digestion and composting can break down some antibiotics (Masse et al. 2014) the dangers posed by the degraded compounds are still poorly understood (Chee-Sanford et al. 2009). Reducing overall quantities used remains an opportunity for minimizing any potential environmental impacts.

viii. *Other* ways of controlling bacteria and pathogen runoff in addition to timing and techniques for manure application mentioned above, are maintaining farm buildings to prevent leakage; controlling rodents in vicinity of intensive animal resting facilities; spreading slurry and manure only after it has been stored long enough to destroy potential pathogens and when there is no likelihood of precipitation, and applying dirty water to fields with practices that reduce the chance of causing water pollution (Hooda et al. 2000). In irrigated pastures, resting pastures from grazing for at least one week before irrigation can reduce bacteria run-off (Knox et al. 2007). Manure management practices (storage and application) are likely to be the most impactful given that leakage and rodents are minor potential sources of pathogens.

The NRCS provides technical assistance to landowners (NRCS 2015) to implement prescribed practices and state specific guidance on which standard practices to use. For regulated entities some of these practices are built into conservation and nutrient management plans required for permits, but substantial opportunities for improvement likely remain in many cases.

Adopting improved nutrient management practices can incur additional costs for producers and processors. At the farm and ranch level certain BMPs like riparian fencing to keep cattle out of streams or planting riparian vegetation to trap sediment and nutrients have substantial costs associated with them. One economic analysis of conservation practices on rangelands in California found that installing conservation practices often results in a net financial loss to landowners in that state and would require at least a 50% cost share to break even (Kroeger et al. 2010). On the other hand, in some cases conservation practices can actually lead to increased profit; for example, moving cattle away from streams can mean even more forage consumption and thus increased weight gain (Stillings et al. 2003). Costs for implementing practices are likely to vary by state based on the level of incentives offered by federal conservation programs and the practices being implemented. The NRCS supports landowners with substantial technical and financial assistance to implement conservation programs such as the Agricultural Management Assistance (AMA), Conservation Stewardship Program (CSP) and the Environmental Quality Incentives Program (EQIP). Further review is needed to identify the subset of best management practices that are most cost-effective, and are most likely to be eligible for cost-sharing.

2.2.2.2 Harvest Facilities (Processing and Packing)

Practices that minimize the use of water to transport wastes, as well as reduce the amount waste produced can reduce the nutrient content and BOD values of effluent released into the environment. It is critical for processing plants to separate wastes from product at each stage of processing in order to avoid wasting meat and by-products, which then have to be disposed of. Some waste products can be put to use, such as sending hair and bones to a rendering plant. Processing plants can reduce the quantity and concentrations of wastes transported in water by applying best practices that focus on removing solid wastes without water, and screening out additional solid and concentrated wastes out of wastewater collection channels (World Bank 1999). In addition to practices to reduce water consumption listed in the previous section, standard industry practices as listed in World Bank (1999) include:

- "*Recover and process blood into useful byproducts and allowing enough time for blood draining.*
- *Process paunches and intestines and utilize fat and slime.*
- *Reduce the liquid waste load by preventing any solid wastes or concentrated liquids from entering the wastewater stream.*
- *Covering collection channels in the production area with grids to reduce the amount of solids entering the wastewater.*
- *Equip the outlets of wastewater channels with screens and fat traps to recover and reduce the concentration of coarse material and fat in the combined wastewater stream.*
- *Optimize the use of detergents and disinfectants in washing water, using no more than required.*
- *Remove manure (from the stockyard and from intestine processing) in solid form.*"

According to a 2001 EPA survey of meat processing plants (red meat and poultry), many meat processing plants already incorporate practices to reduce wastewater flow and waste loads as part of regular business operations to reduce costs and maximize profits to maintain competitiveness (U.S. EPA 2004c). However, there is large variation among processing plants in how widely and effectively practices are applied. The EPA survey findings (as well as the results presented in Table 3) suggest that opportunities for improvement remain to reduce both water use and water pollution by first cleaning facilities without water before washing them, as well as reuse of water (U.S. EPA 2004c).

2.2.3 Recommendations

- Interventions to address water quality should prioritize regions with high water quality risk. There are tools available to identify those areas with higher geographic risk such as Water Resources Institute's AQUEDUCT (WRI 2015).
  - The structure of the beef feedlot sector means that operations are concentrated in a few states and these can provide a starting point for focusing priority regions for interventions. Further information on specific locations of U.S. beef suppliers would allow finer targeting of priority regions.
  - For ranch and farm grazing operations that are more dispersed, additional information on key supply regions for major retailers and share of live animals supplied to large feedlots and processors would allow focused targeting of risk areas in this sector of the supply chain.
- Corn is the main feed grain in the beef sector and a key source of nutrient pollution; where feasible alternative grains with lower water quality impact potential and comparable nutritional value should be used to substitute for corn.
- Encourage grazing operations and feed producers to adopt water quality BMPs to reduce sediment, pathogen and nutrient runoff (i.e. riparian buffers, riparian fencing and alternative

watering points). Adoption of water quality BMPs is largely voluntary for farmers and ranchers and has associated costs. While they may receive some support (cost sharing and training) from government programs such as NRCS, this support often does not cover their full costs of implementation and landowners may lack sufficient resources to cover the remaining costs. They are likely to require some form of incentive (resources, technical assistance and performance guarantees) to encourage adoption of the necessary BMPs.

- Consider sourcing supply from producers supporting coordinated watershed management initiatives. Because the impacts of water pollution reach far beyond the point of initial discharge, efforts to implement BMPs benefit from coordination to ensure the greatest impact.
- Support water quality trading programs and integrated watershed management initiatives as these are often among the few tools available to incentivize and coordinate reductions in pollutant discharges among farmers and ranchers at a watershed scale. Payment for ecosystem services programs that seek to alleviate water pollution are emerging across the U.S. (e.g., Chesapeake Bay, Ohio River Basin, Oregon, Florida and Wisconsin; USDA 2015). Support independent third-party standards with verification mechanisms (including certification) to ensure outcomes are being met.
- Encourage packers and processors to adopt and meet water conservation measures that reduce the concentration of nutrients and other forms of BOD in waste discharges such as those recommended in by the EPA Industry effluent guidelines (U.S. EPA 2014).
- Improve manure management through the supply chain by sourcing cattle for feedlots from farm/grazing operations with nutrient management plans in place.
- Encourage feedlots to adopt sound manure management practices such as applying manure in the right time and place and amount, and proper storage prior to spreading to control pathogens.

Part 3: Wildlife Habitat Opportunities in the U.S. Beef Supply Chain

3.1 Beef Supply Chain impacts on Wildlife Habitat

A large amount of the land area of the U.S. is used for grazing. The 2010 Natural Resources Inventory (NRI; USDA 2013) estimated that there were 583.9 million acres of non-federal grazing land in the conterminous U.S., composed of 409.1 M acres of rangeland, 120.45 million acres of pasture, and 56.1 million acres grazed forest land (Figure 7).

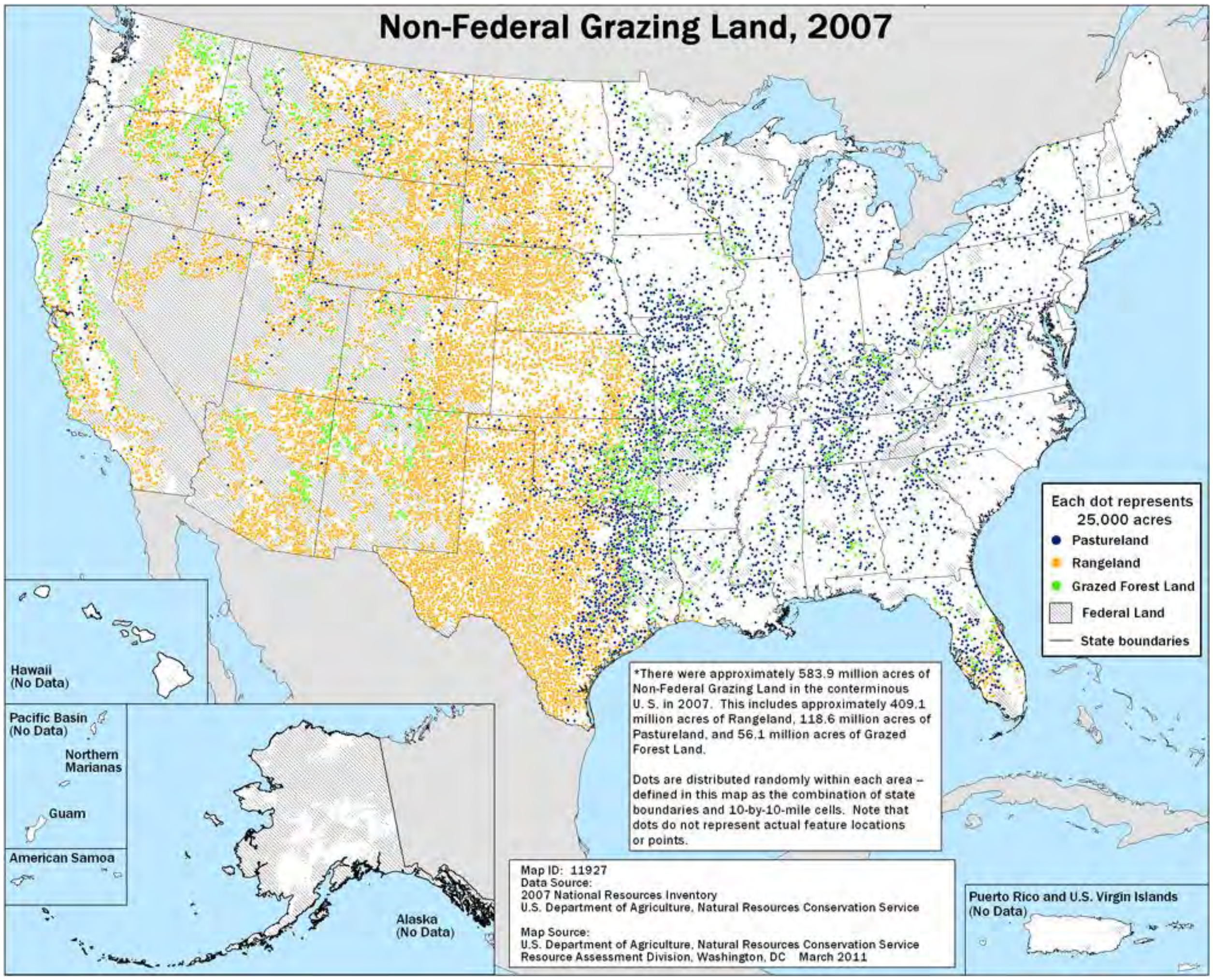

Figure 7: Non-Federal Grazing Land, 2007. Map of non-federal grazing land in conterminous United States. Source: USDA NRI 2011

For federal land, primarily owned by the Bureau of Land Management (BLM) and the U.S. Forest Service, an estimated 229 million acres are used for grazing by cattle and sheep (Glaser et al. 2015) and are almost all in eleven western states (AZ, CA, CO, ID, OR, MT, NM, NV, UT, WA, WY) which can be assumed to be predominantly rangeland or grazed forest land. The BLM alone manages grazing on 155 million acres of federal land (U.S. BLM 2015). Together, the federal and non-federal acres amount to about 812 million acres of land in the conterminous U.S. that are used for grazing, though this amount fluctuates over time. The area of the conterminous U.S. is about 1,996.7 million acres, so about 40.7% of the land area of the conterminous U.S. is grazed. Of grazed lands in the U.S., the above figures suggest that about 14.8% is managed pasture and 85.4% is rangeland or grazed forest land. As noted in section 2.2.1.1, roughly 76% of total livestock on grazing lands are cattle.

Land use of this geographic scale is certain to have a commensurate impact, but its severity varies by region, given the wide array of grazed lands, climate regimes, and alternative land uses in a country the size of the U.S. Our review of the impacts of grazing on wildlife habitat suggests four areas in which grazing has negative impacts on wildlife habitat as an ecosystem service:

- Loss of habitat by conversion of native ecosystems to production agriculture used to supply cattle feed.
- Degradation (loss of quality) of native habitats by grazing practices that are unfavorable to native plant and animal communities or by the introduction of non-native grasses (e.g., Lehman lovegrass, crested wheatgrass, old world bluestem, fescue, Bermuda grass; primarily in western rangelands that have few or no alternative productive uses).
- Degradation of pastures (lands that have been converted into some form of grass cover specifically for cattle production) in terms of ecological services such as wildlife habitat.
- Mortality of animals who are killed (or their nests destroyed) in supplemental feed production.

The first involves the outright loss of actual habitat for wildlife; the second and third involve the degradation of environmental benefits provided by habitats used for cattle grazing; and the fourth concerns the actual loss of individuals from various species' populations who presumably would otherwise have survived if not for the harvesting of cattle feed products. It is important to mention, however, that in many geographic areas of North America, ranching and grazing is an important contributor to local and regional economies that can incentivize the maintenance of these lands as natural habitat. In addition to providing forage for the beef industry, rangelands and pasture also provide socioeconomic benefits such as opportunities for hunting, fishing, hiking, and wildlife-watching which would be otherwise unavailable to the general public.

A recent life cycle assessment of the entire beef supply chain indicates that the vast majority of the land use impact (about 95%) of the supply chain comes from ranch and farm grazing operations (Figure 8; NCBA 2014).

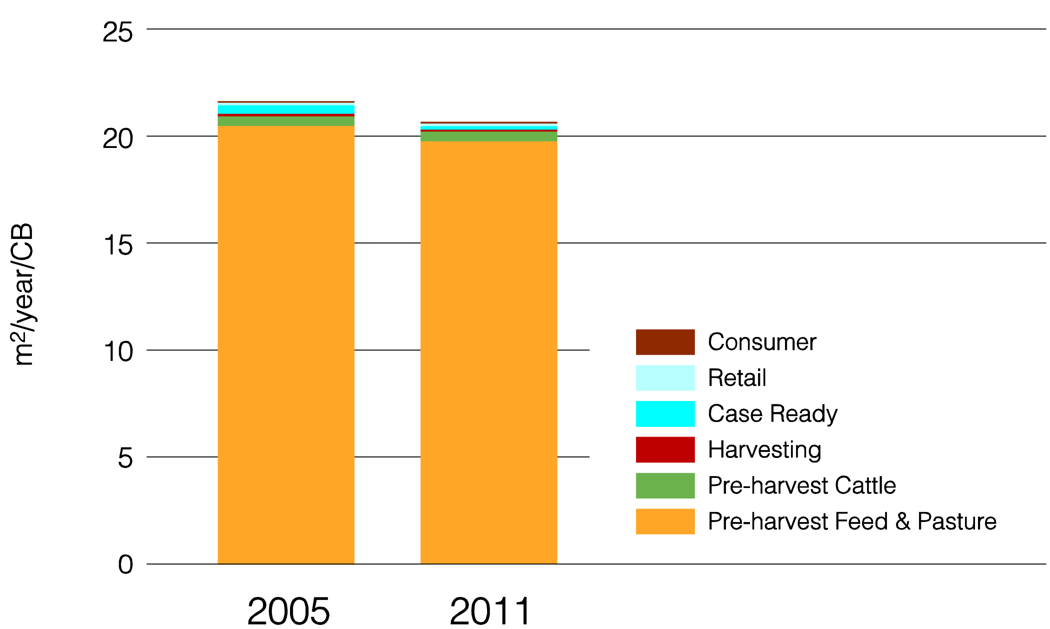

Figure 8: Land use required annually to produce one pound of boneless, edible, consumed beef (= one CB) for different components of the beef value chain. Source: NCBA 2014.

In particular, the later stages of the supply chain (harvest facilities, retail operations) have a minimal contribution to the land use impact of beef production. Interestingly, this analysis showed a 4% reduction in total land use impact between 2005 and 2011 in the beef supply chain, attributed to the following factors: increased crop yield, increased use of distiller's grains, lowered use of cardboard and packaging products, and energy efficiency improvements.

A 2010 study explored the pre-harvest phase of the supply chain (ranch and farm grazing, feedlots, and feed production) in greater detail to look at how different components affect the ecological footprint (Pelletier et al. 2010). The study split the ranch and farm grazing phase of the chain from the feedlot phase, primarily to compare three different beef production systems commonly used in the upper Midwest (Iowa and Minnesota). Pelletier et al. (2010) showed clearly that the largest footprint came from ranch and farm grazing (Figure 9), which was considerably larger than any of the three finishing systems modeled. For both the ranch and farm grazing phase and all of the three finishing systems, the feed production component of the system (made up of both grazing lands and farms producing feed such as corn) was the single largest contributor to footprint size (Figure 9).

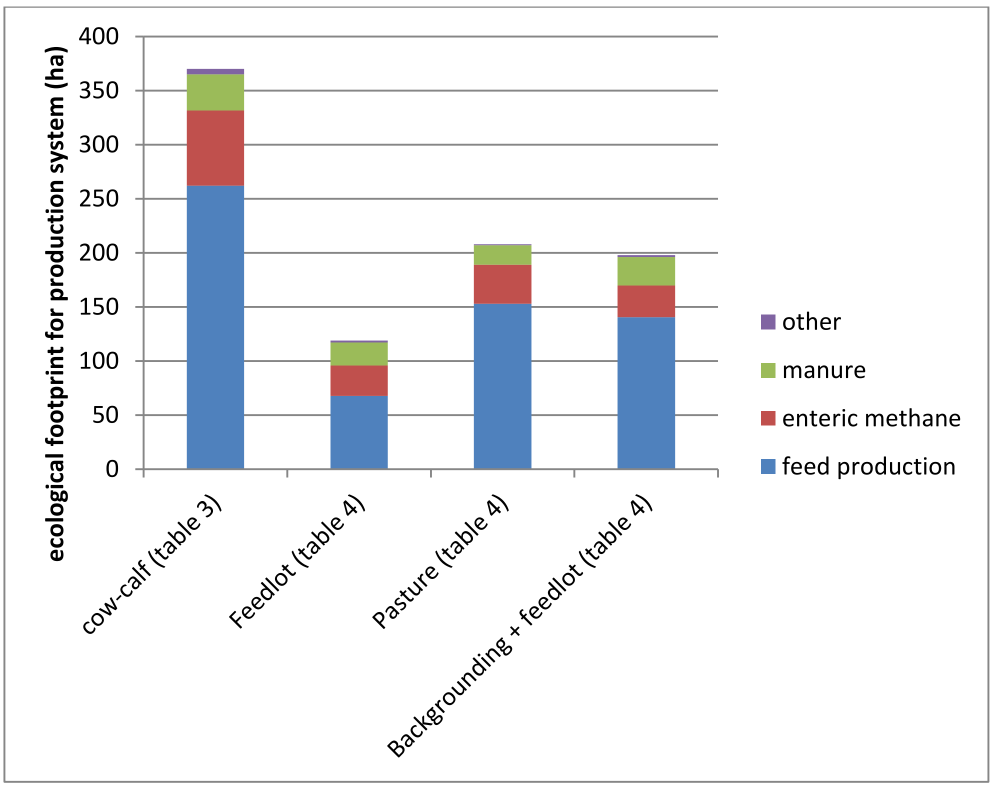

Figure 9: Ecological footprint (the "*area of productive ecosystem required to furnish specific economic goods and services*") for a modeled ranch and farm grazing system and three beef production systems in the upper Midwestern U.S. Data from Pelletier et al. (2010).

Unfortunately, Pelletier et al. (2010) did not separate out the relative contributions in the feed production component between pasture, hay, and grain crops. Plus, given the geographic location of the study, it is clear that rangeland was not considered a contributor to food production. The authors point out that hay production is more resource intensive than managed pasture and both are more resource intensive than rangeland. Therefore, it is difficult to extend these results to an area wider than the upper Midwestern U.S.

Two recent studies have attempted to model the amount of land required to produce beef consumed in the U.S.: Eshel et al. (2014) and Peters et al. (2014). Both studies use a qualitatively similar methodology to apportion the amount of land needed to produce a unit of beef consumed by the various feed classes used in producing beef: grains and concentrates; hay, silage, and other roughage; and pasture and rangeland. Although both studies were conducted to compare the production of beef with other sources of protein (e.g., chicken, pork, dairy), they do indicate that different feed classes are responsible for very different proportions of the total land required to produce a unit of beef for consumption (Figure 10), with rangeland using by far the most land area. Although not explored in any detail by either paper, this finding is presumably due to the relatively low level of calorie production or food value per unit of land of rangeland as compared to managed pasture or feed crops.

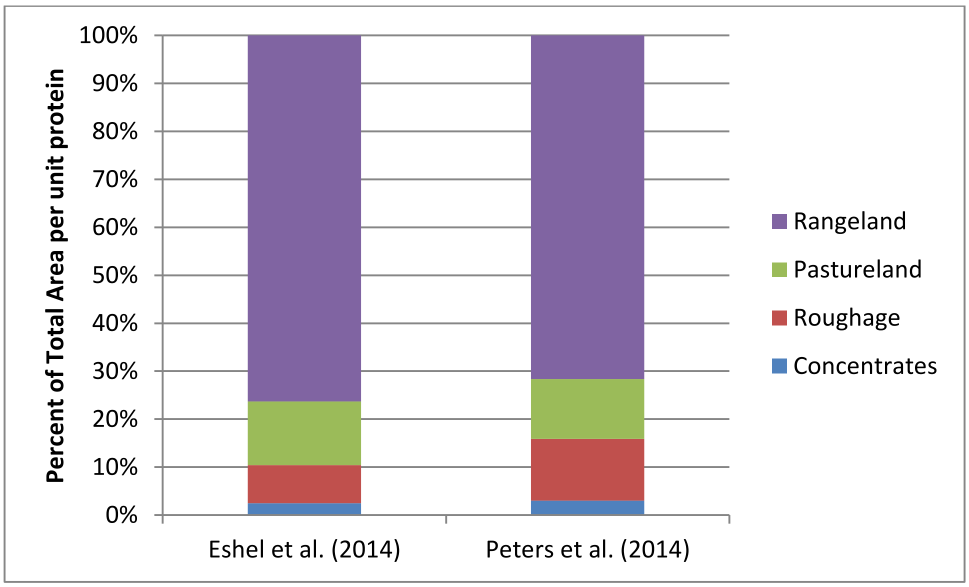

Figure 10: Comparison of results of Eshel et al. (2014) and Peters et al. (2014) In terms of percent of total area required by different feed classes to produce beef. In both cases, the proportions of rangeland and pasture have been calculated from the original source data based on the estimated proportion of pasture out of all grazed land in the U.S.

The two studies differ slightly in the relative proportions of land needed for pastures and roughage, though both are clearly less than rangeland in land use. Clearly, efficiency improvements in any or all of the different feed classes would reduce overall land needed to produce beef. However, additional research has to be conducted to determine the precise environmental impact of reducing the amount of land used for each feed class. Though it is very likely that using a given area of land to produce grain concentrate has more of an environmental impact than using the same area of rangeland, this could depend on what environmental variables are measured (e.g., biodiversity, water use, greenhouse gases).

Beef cattle are not distributed evenly across the U.S. Of the roughly 80 million cattle in the U.S. (excluding dairy cattle), the top 10 states (TX, NE, KS, OK, MO, IA, SD, CA, MT, CO) account for 59% (Figure 11). The estimated number of “beef cattle” (excluding calves, etc.) was 29,693,100 as of January 1, 2015.

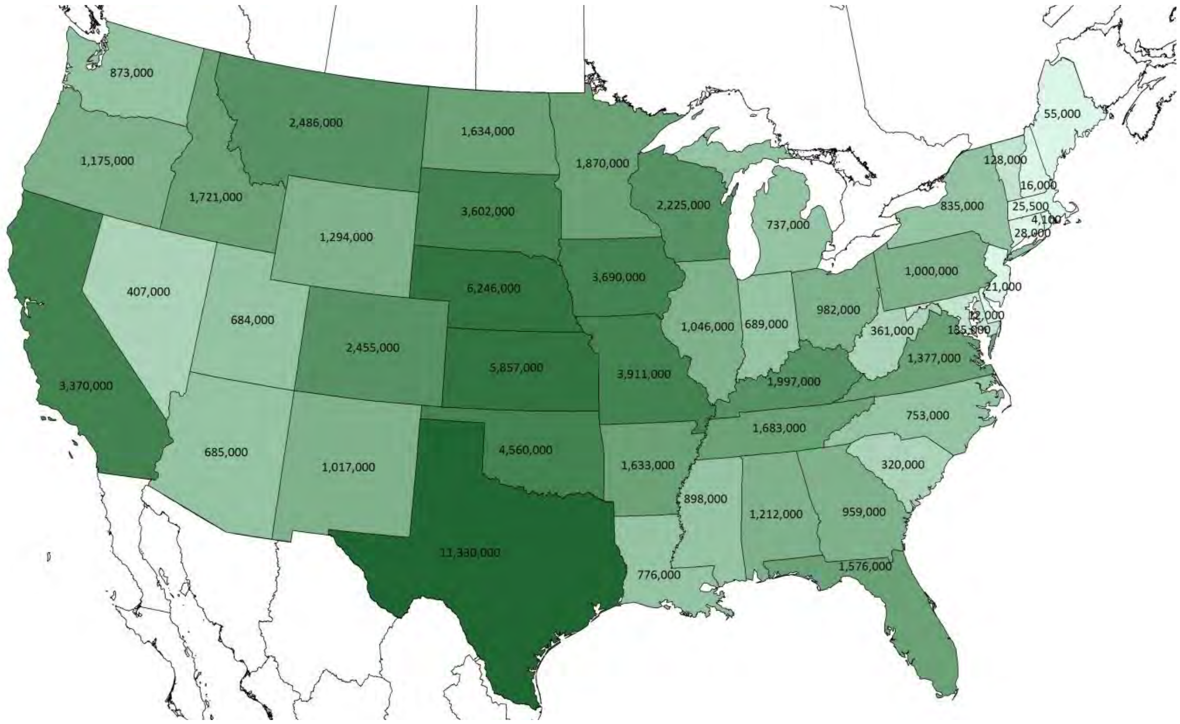

Figure 11: Number of non-dairy cattle by state as of January 1, 2015. Data from USDA National Agricultural Statistics Service (USDA NASS 2015). Darker states have higher numbers of cattle.

A key issue about the distribution of beef cattle in the U.S. with regards to wildlife and habitat impacts is the relative division in numbers of cattle between private and public lands (see section 3.2.2 on degradation of rangelands), the latter of which are primarily in the western U.S. NCBA estimates that "*about 40% of the beef cattle in the West spend some time on public lands*" (NCBA Federal Lands Ranching factsheet). The term "in the West" is ambiguous, but from this we can estimate that between 1,748,120 (if only western public lands states are included) and 7,130,040 (if all states from the Great Plains west are included) beef cattle spend some time on public lands, or between 5.9% and 24.0% of total beef cattle as of January 1, 2015. Cattle in feedlots are even more concentrated in the U.S. Out of an estimated 13,025,000 cattle on feed on January 1, 2015, 55.4% were in the top three states (NE, TX, and KS) and the top 10 states had 85.1% of these (Figure 12). The omission of calves from the figures above could bias the distribution towards states with large populations of cattle on feedlots.

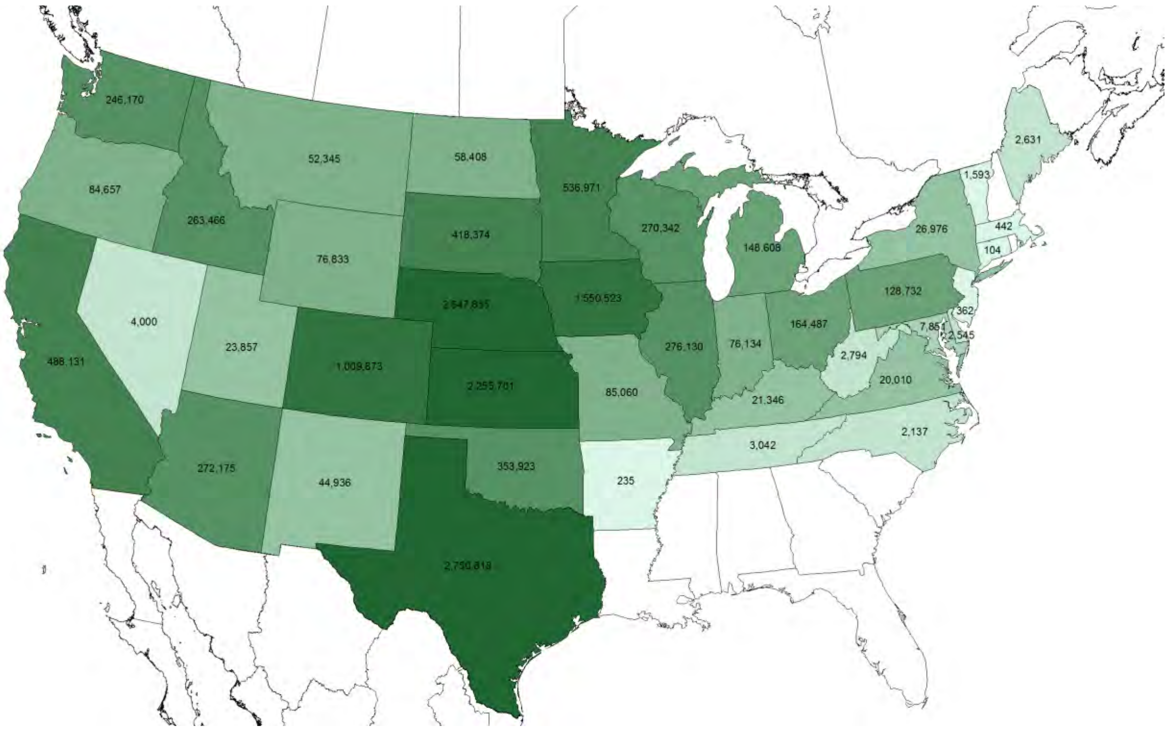

Figure 12: Number of cattle on feed by state as of January 1, 2015. Data from USDA National Agricultural Statistics Service (USDA NASS 2015). Numbers indicate quantity of cattle on feed in large feedlots with 1,000 head or more capacity for major States. Darker states have higher numbers of cattle, states in white had no data available.

Note that while we focus in this chapter on terrestrial habitat impacts, the beef supply chain also has significant impact on fresh water and marine systems (e.g., the Gulf hypoxia zone). However, these impacts are covered under the water use impacts section of this analysis, as water quality is a useful proxy for aquatic habitat degradation. Also, this analysis focuses on the production phases which have significant impact on wildlife and habitat, namely ranch and farm grazing, feedlot, and supplemental feed production. We omit phases with only minor impacts such as transport and harvest facilities. We also do not discuss any potential impacts of antibiotics, hormones, pesticides, and herbicides on terrestrial wildlife and habitat in this section since attributing these impacts to the beef supply chain is complex and requires further analysis.

The following sections describe the primary effects of the beef supply chain on wildlife and wildlife habitat, ranked in rough order of severity of impact.

3.2 Wildlife Habitat

3.2.1 Conversion of native habitats to cropland to produce cattle feed

Conversion between habitat types is of great interest and concern to the conservation community in the U.S., particularly conversion of grasslands to croplands and vice versa. The former is considered a major threat to wildlife and biodiversity, especially when native, intact, or previously unconverted grasslands are first converted, a process frequently termed “sod-busting.” Conversely, the latter is considered a beneficial transition that has great benefits for wildlife and biodiversity, either when croplands are fully restored to their original native vegetation type or when croplands are idled through enrollment in land retirement programs (e.g., Conservation Reserve Program, CRP). Transitions in either direction are driven by a complex mixture of market forces (commodity prices), land values, federal government incentives (e.g., Farm Bill programs), and landowner preferences. Unfortunately, accurately assessing the quantity and quality of conversion in either direction is difficult, since the remote sensing vegetation data used to measure these transitions at national scales cannot reliably distinguish between native grasslands, grazed rangeland, pasture, haylands, and idled CRP lands.

Nevertheless, recent studies of net habitat conversion (reflecting transitions in both directions) indicate that native habitats, primarily grasslands, are being converted to croplands more than vice versa (Lark et al. 2015). Conversion of native habitats produces an immediate loss of habitat and biodiversity for these areas. Numerous recent studies document increased conversion of grasslands and other native habitats into cropland over the past decade (EWG 2013, Lark et al. 2015, Wright and Wimberly 2013). The detailed analyses of Lark et al. (2015) show clearly that most of this expansion comes from grasslands (over 77%), with over 25% of this conversion coming from "long-term" grasslands (as opposed to from CRP or other restored grassland types). Much of this change is concentrated in the middle of the U.S. in the region known as the Great Plains (Figure 13), with additional hotspots of conversion in other predominately grassland parts of the country (Lark et al. 2015). Conversion also has many indirect effects that are difficult and/or expensive to reverse or restore. The effects of this conversion on native habitats and species are widespread; perhaps the best example is the long-term and well documented declines of North American grassland birds, which are one of the fastest declining groups of birds on the continent (NABCI 2009a, NABCI 2014).

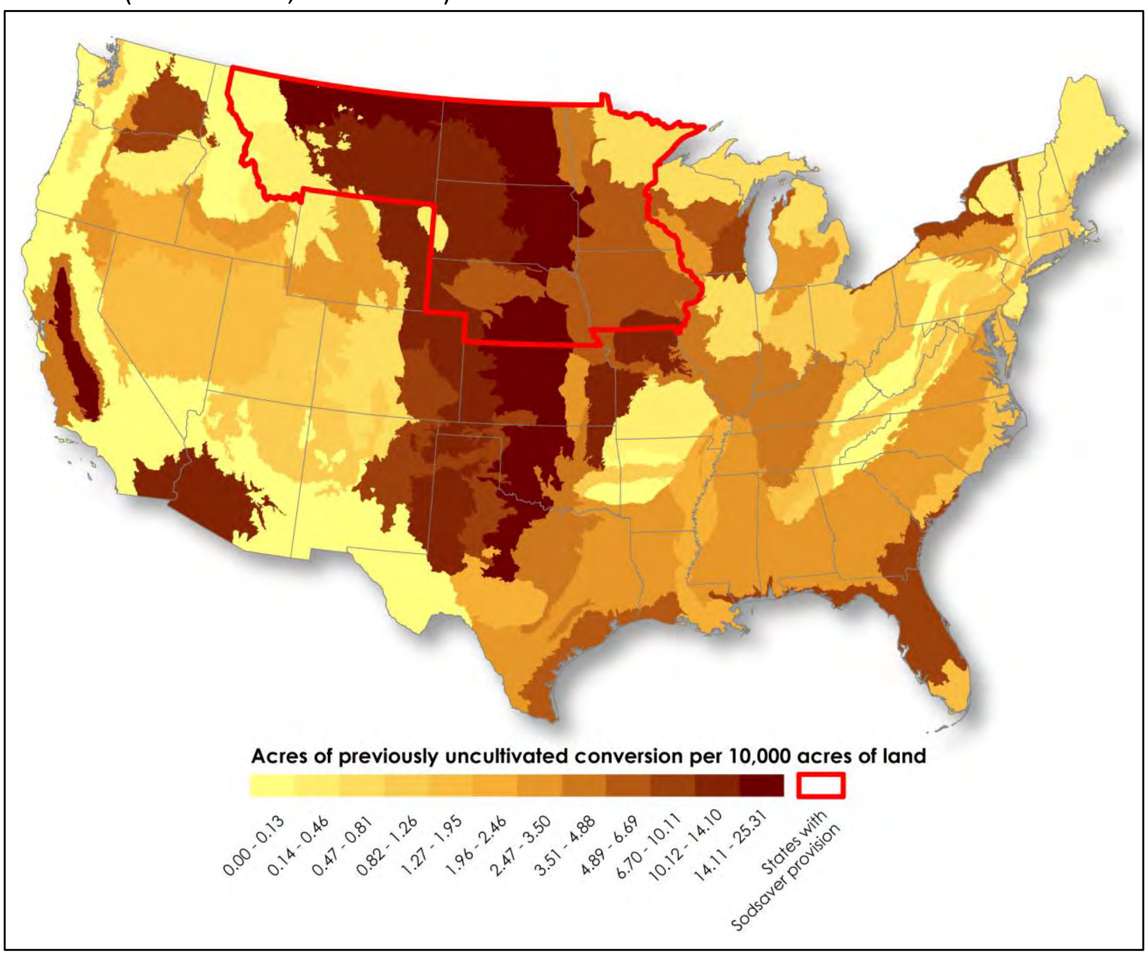

Figure 13: Ecoregions with high rates of conversion to cropland during the period 2008-2012. Shown is the average number of acres converted to cropland that had not been classified as planted or plowed since the 1970s. Source: Lark et al. 2015, Figure 4.

Lark et al. (2015) also found that corn and soybean were the first and third most common crops planted on this newly converted cropland, at 26% and 20%, respectively, of the newly converted acreage (with biofuels such as ethanol the main driver of this conversion). While dietary intake for cattle overall is over 80% composed of grass (forage and hay) throughout their life cycle, during the feedlot phase corn is the primary source of feed for beef cattle. Corn is also the major feed for other livestock in the U.S., with soybean meal playing an important role for species other than cattle (Peters et al. 2014).

In terms of loss of wildlife habitat from agricultural conversion, it is particularly important to highlight the importance of wetlands to wildlife and the high continental significance of the Prairie Pothole Region (PPR), which includes portions of Minnesota, Iowa, the Dakotas, Montana, Manitoba, Saskatchewan, and Alberta. The PPR is extremely important to North America as it is the heart of the breeding area for most species of waterfowl on the continent and for many other grassland- and wetland-associated birds and other wildlife (Dahl 2014). Although wetland loss in the U.S. as a whole has been greatly reduced and somewhat stabilized in recent years as compared to the 1950s to 1970s (Dahl 2011), wetland loss in the PPR represents a very high proportion of recent wetland loss in the entire country (Dahl 2014). Most important are losses of important wildlife habitat, such as emergent wetlands and temporarily flooded basins (prairie potholes), which are greater than rates shown for wetlands in general in the PPR. These losses were primarily due to conversion to deep water lakes and ponds, agriculture, or, to a much lesser extent, development (Figure 14).

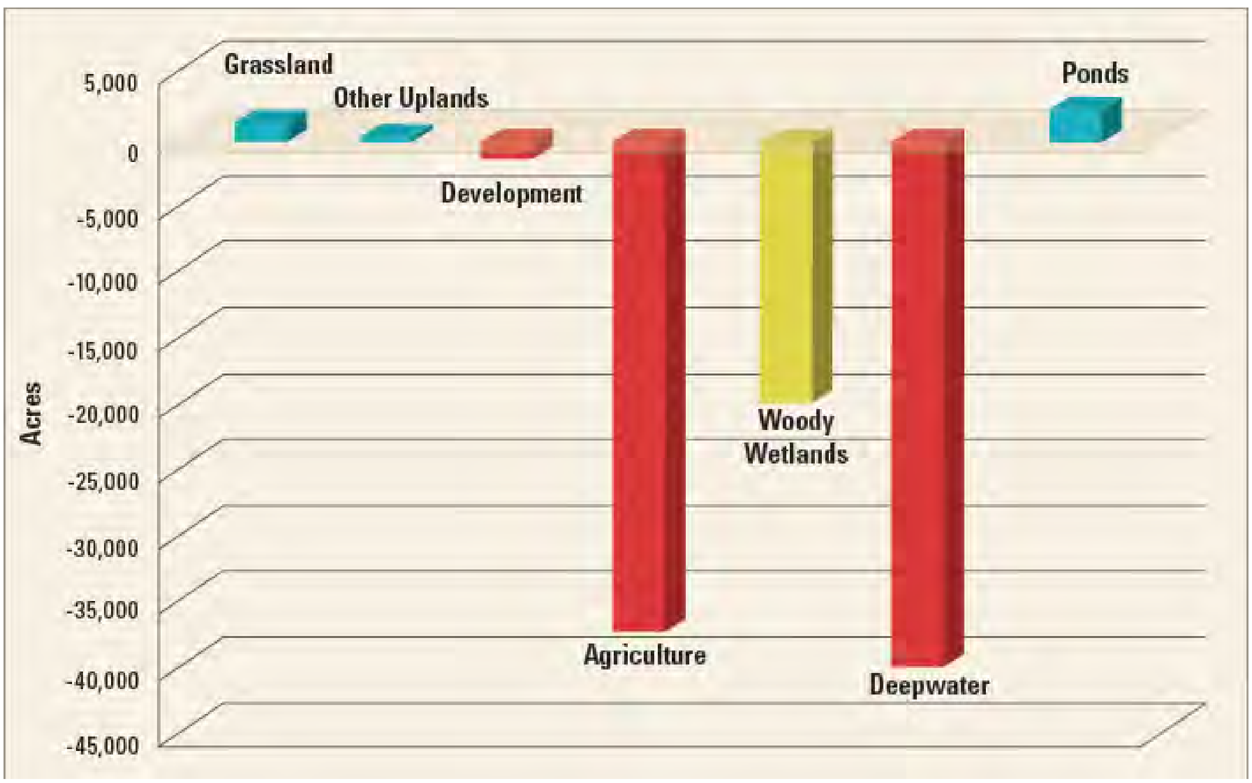

Figure 14: Gains (blue), losses (red), and conversions (yellow) of emergent wetlands in the Prairie Pothole Region (PPR) to other uses, 1997 to 2009. Source: Dahl 2014, Figure 14.

Although the most cost-efficient way to protect wildlife habitats from conversion is to prevent the initial conversion in the first place, the methodology and science of habitat restoration has progressed over the past few decades such that restoration of converted lands is very feasible and can provide numerous habitat and ecosystem services benefits. Perhaps the best examples of this are several of the recent Farm Bills, where various conservation provisions have been implemented and have been demonstrated to lead to a variety of benefits for wildlife and habitats (NABCI 2015). In particular, the CRP, first created in the 1985 Farm Bill, has created millions of acres of wildlife habitat annually ever since its inception. Some wildlife benefits from CRP include (from NABCI 2013):

- CRP lands in the PPR increased waterfowl production by 25.7 million ducks from 1992 to 2004 (Reynolds 2005).
- CRP lands contributed to the creation of large blocks of grassland habitat for sensitive and threatened species like the Greater and Lesser Prairie-Chicken in Kansas, Nebraska, New Mexico, Oklahoma, and Texas (NABCI 2013).
- The advent of CRP has contributed to about a 25x increase in the Henslow's Sparrow population in Illinois compared to before CRP started (Herkert 2007a) and is positively associated with population trends of this species across its breeding range (Herkert 2007b).

Due to the area affected (over 24 million acres enrolled as of December, 2014; Figure 15), demonstrated success, and the familiarity of landowners with its operation, CRP offers a potential model for how to incentivize habitat restoration, particularly on marginal croplands that offer limited return on the farming investment.

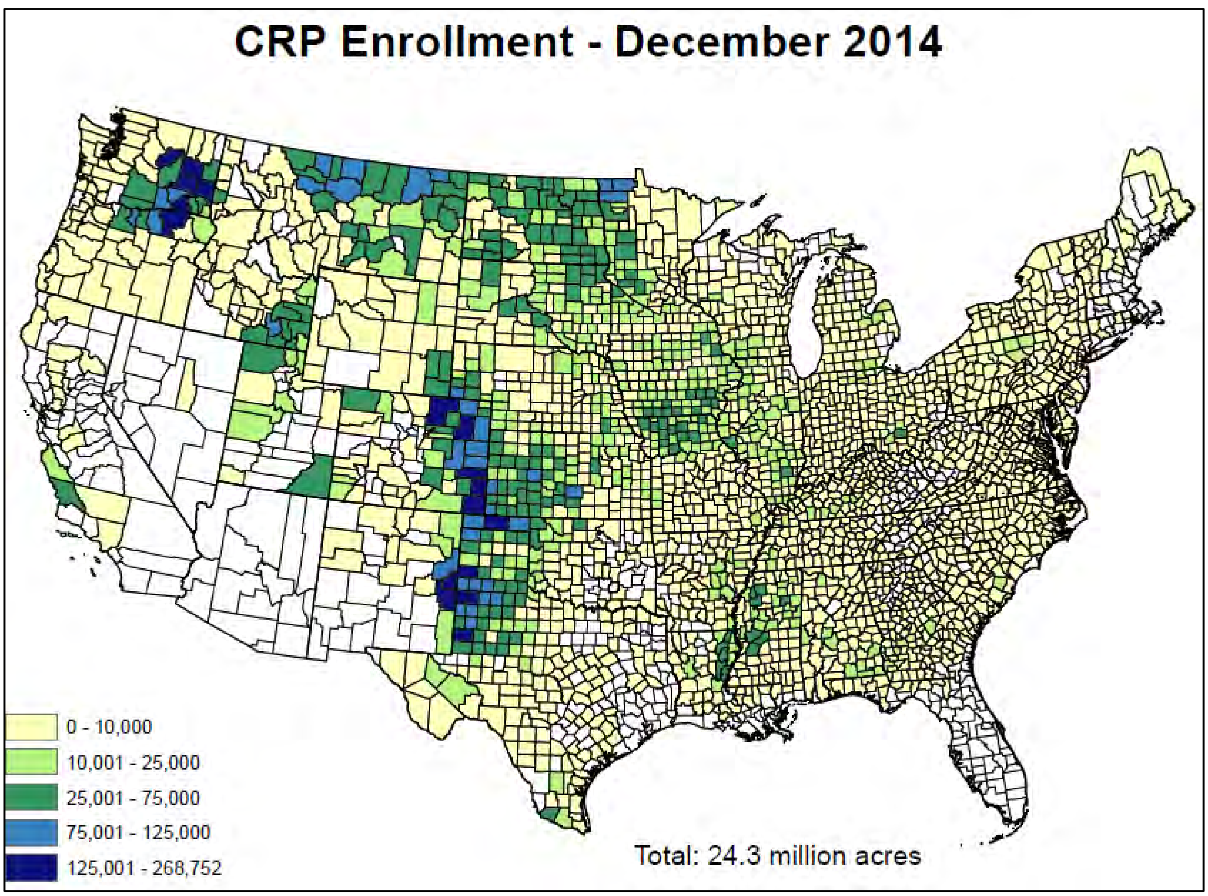

Figure 15: Conservation Reserve Program Enrollment – December 2014. Acres enrolled in the CRP. Source: USDA FSA 2015

There is substantial geographic overlap between existing areas of CRP enrollment (Figure 15), where cattle and processing facilities are located in the U.S. (Figure 11), and areas of high habitat conversion

(Figure 13). By expanding and/or enhancing CRP and rangeland improvement programs in these overlapping areas, habitat could be restored, thus reversing some of the current and historical impacts of the beef supply chain on wildlife.

However, the key issue of uncertainty is how much new habitat conversion to cropland is driven by the need for additional feed for beef cattle as opposed to other drivers (e.g., biofuels). The recent literature is clear that the driving force behind much of this conversion, particularly to corn, is the need to produce renewable fuels from biofeedstocks (Lark et al. 2015, Wright and Wimberly 2013) and not necessarily (or even primarily) for animal feed. Data from USDA's Economic Research Service show clearly that although U.S. corn use has increased from 4.9 billion bushels in 1980 to 11.8 billion bushels in 2014 (an increase of over 142%), the percent of this production going to feed and residual use has declined from 86.5% to 44.5% over the same time period and total production for feed and residual use has only increased by 24.7% (Figure 16). Analysis of this topic is complicated by a lack of traceability in commodities such as corn; addressing this would be an important component of trying to drive improvements in feed production.

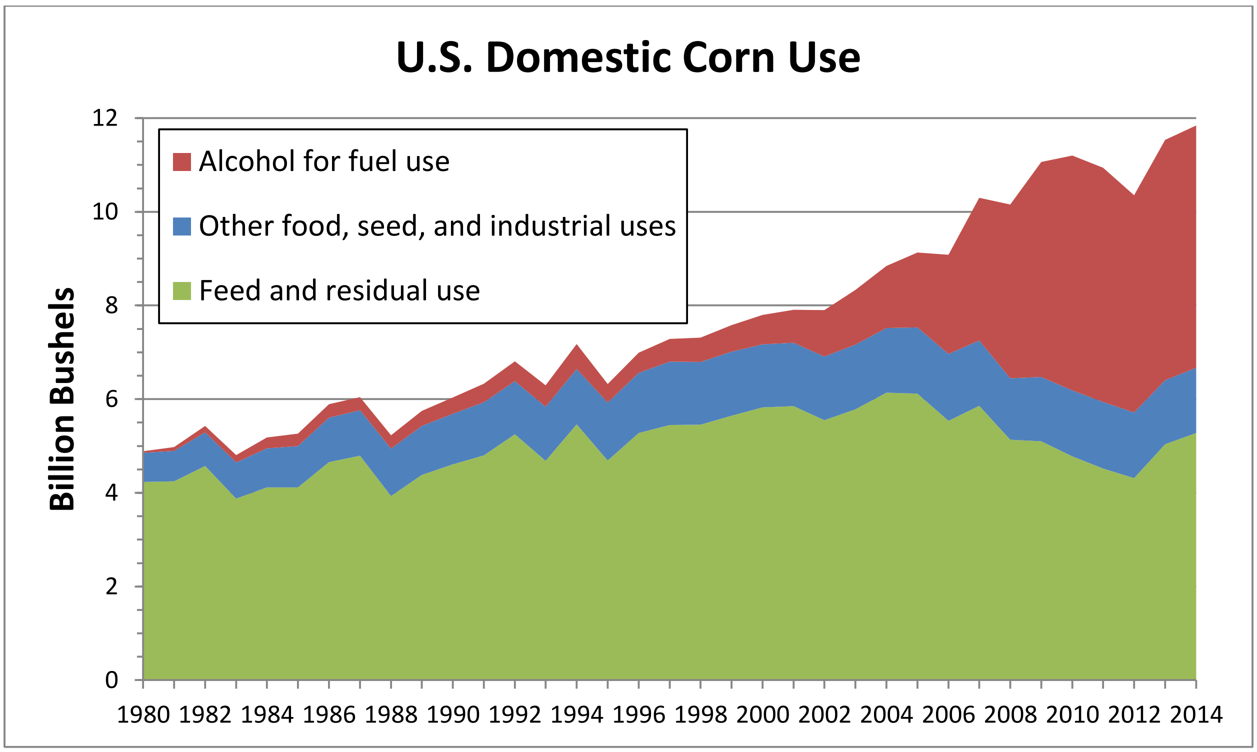

Figure 16: U.S. domestic corn. Data from USDA, Economic Research Service (USDA ERS 2015d). Use for the period 1980 to 2014.

Therefore, more research is required to determine the extent to which crops from newly converted croplands are making their way into the beef cattle food supply chain. As an interim step, buyers could source their cattle from feedlots and suppliers that in turn avoid sourcing feed from recently converted native habitats (e.g., those not converted within the last 10 years) or from grasslands that have been restored with native plant species on former agricultural ground (including CRP plantings). According to Lark et al. (2015), the Energy Independence and Security Act of 2007 allows renewable fuels feedstocks to be sourced only from lands cleared or cultivated prior to December 2007; this criterion offers a model for achieving a more sustainable feedstock supply. Some progress has been reported in reducing deforestation by suppliers to the packer JBS in Brazil through the use of supply chain agreements, which could offer another model (Gibbs et al. 2015).

This topic needs more analysis, but it seems that the beef supply chain is, in general, not a major driver of new habitat conversion at the current time in the U.S. Therefore, this impact, although severe, is probably limited in extent. It is also true that there are numerous other drivers of habitat conversion on the landscape (e.g., Allred et al. 2015). Furthermore, agricultural conversion may have other effects on wildlife and habitats outside of direct loss of habitat (e.g., pesticide and herbicide impacts; Gibbs et al. 2009), which are especially important in considering the impact of conversion on fresh water ecosystems.

3.2.2 Recommendations

- Buyers should source their cattle from feedlots and suppliers that in turn avoid sourcing feed from lands converted to cropland from native habitats or restored grasslands (including CRP plantings) within the last 10 years, and avoid regions with high rates of conversion of native habitats and restored grasslands to agriculture (Figure 13). The work of authors such as Lark et al. (2015) can be used to determine where these areas are located geographically.
- Implement internal sourcing policies that include provisions similar to "Sodsaver" and "Swampbuster" in the 2014 Farm Bill to discourage sourcing from crop producers that have broken new ground or that do not implement basic conservation practices (NABCI 2015), regardless of geographic area.
- Implement a "CRP-like" program to incentivize restoration of wildlife habitats on current croplands, concentrating on geographic areas that are subject to high conversion rates (Figure 13), and that have high current enrollment levels in the CRP program (Figure 15). This could include extending or renewing CRP contracts that have expired or are expiring.

3.2.3 Degradation of native habitats (rangelands) by unsustainable grazing

For the purposes of this analysis, we consider rangelands to follow the NRI definition (USDA 2013): "*A land cover/use category on which the climax or potential plant cover is composed principally of native grasses, grass-like plants, forbs or shrubs suitable for grazing and browsing, and introduced forage species that are managed like rangeland. This would include areas where introduced hardy and persistent grasses, such as crested wheatgrass, are planted and such practices as deferred grazing, burning, chaining, and rotational grazing are used, with little or no chemicals or fertilizer being applied. Grasslands, savannas, many wetlands, some deserts, and tundra are considered to be rangeland. Certain communities of low forbs and shrubs, such as mesquite, chaparral, mountain shrub, and pinyon-juniper, are also included as rangeland.*" Therefore, these are predominantly, but not exclusively, natural habitats, although many have been manipulated in various ways to provide better forage for livestock. Rangelands also include areas formerly in agriculture that have been restored with native plants, such as many CRP plantings. Typically, rangeland also implies a lack of irrigation. USDA (2013) indicates that there are 409.1 million acres of non-federal grazing land in the U.S., predominantly in the Great Plains states and West (Figure 7).

Although there is much controversy on the topic of the impact of grazing on native habitats and wildlife, especially as applied to grazing on public rangelands in the western U.S., grazing can modify habitats in ways that reduce or eliminate some species and increase others. Effects of grazing vary greatly depending on grass stature (short, mid, tall), grass type (warm or cool season), climatic regime (e.g., southwestern arid grasslands, northern Great Plains grasslands), and stocking density / rotation time. As summarized by Fleischner (1994) and Krausman et al. (2009), the negative effects of overgrazing include changes in ecosystem function (e.g., reduced primary productivity, altered successional patterns); lowered plant growth and survival; altered species composition and degradation of the grasses, shrubs, and forbs that provide wildlife with food and cover; and, perhaps most importantly at landscape scales, increased homogenization of grasslands with consequently reduced variability in all the above attributes. Nevertheless, the effects of grazing on wildlife and habitat are complex, vary depending on the specific ecosystem being studied, and rigorous meta-analyses often produce equivocal results (e.g., Curtin 2002, Freilich et al. 2003, Svejcar et al. 2014); there is no simple, black-and-white answer to the question of how grazing affects wildlife. In some cases, grazing may be beneficial to certain species during certain seasons, if stocking density and season of use are managed correctly (e.g., Hagen et al. 2004). It is also important to distinguish between overgrazed systems and systems grazed at levels comparable to historic levels from wildlife. In any case, these effects would primarily occur during the ranch and farm grazing phase of the beef supply chain in which cows are on rangeland and are presumably much more widespread on western rangelands.

Of critical importance to biodiversity, particularly in arid western North America, are riparian areas and the damage, deterioration, and numerous adverse effects of grazing in these habitats are well documented (Chaney et al. 1990, Armour et al. 1991, Belsky et al. 1999, Krausman et al. 2009). However, many of these negative effects can be abated and reversed by applying a variety of improved grazing management techniques. These include: fencing of riparian areas to exclude cattle completely or to provide restricted access points, coupled with additional water sources away from the riparian areas; development of additional fenced pastures to allow a switch from continuous, season-long grazing to rest-rotation cycles that allow riparian zones to recover; lowering stocking levels; long-term rest; or combinations of these techniques. There are numerous examples of how implementation of these and other BMPs on specific allotments have benefited wildlife and habitat (e.g., Chaney et al. 1990). While limiting direct access of cattle to riparian areas is often unappealing to ranchers, given the impacts of such access to both terrestrial and fresh water biodiversity, as well as human health impacts from *E. coli*, these types of interventions should be seriously considered and evidence exists that such grazing management practices can improve the rancher's bottom line by encouraging grazing in areas that may otherwise be underutilized (Tanaka et al. 2007).

Some generalized effects of grazing on rangelands were measured by the NRCS in its rangeland health assessment (USDA 2010). NRCS used NRI data (USDA 2013) to conduct the Rangeland Resource Assessment on the 409 million acres of non-federal rangelands in the U.S., examining three attributes of rangeland health: biotic integrity, hydrologic function, and soil and site stability (Herrick et al. 2010). The Assessment showed that 21.3 ± 1.3 % of the rangelands assessed (of a total of 158.9 million hectare or 392.4 million acres) showed at least moderate departure from reference conditions for at least one of the three attributes and 9.7 ± 1.1 % showed at least moderate departure for all three attributes (Herrick et al. 2010). Moderate or greater departure from reference conditions was recorded as 18.2 ± 1.1% for biotic integrity, 14.9 ± 1.4% for hydrologic function, and 12.0 ± 1.4% for soil and site stability. The distribution of departure from reference conditions, however, is not uniform across rangelands, with the greatest departures in all three attributes being consistently observed in the southwest, southern, and central areas of grasslands in the U.S. (Figures 17A and 17B; see also Herrick et al. 2010, figures 3a, 3b, and 3c).

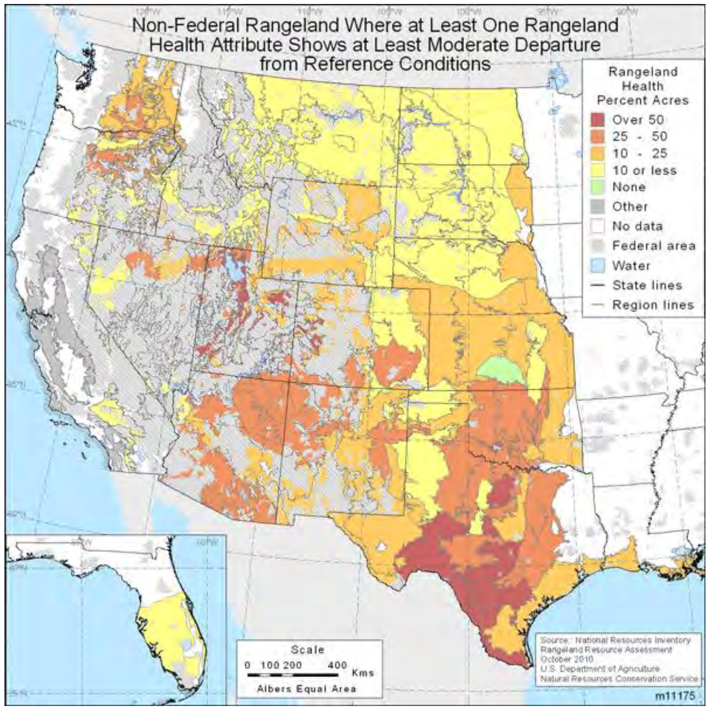

Figure 17A: Rangeland health assessment of non-federal rangeland in the U.S. Data from USDA (2010) and Herrick et al. (2010). Showing ecoregions where at least one health attribute (biotic integrity, hydrologic function, and soil and site stability) shows a moderate or greater departure from reference conditions

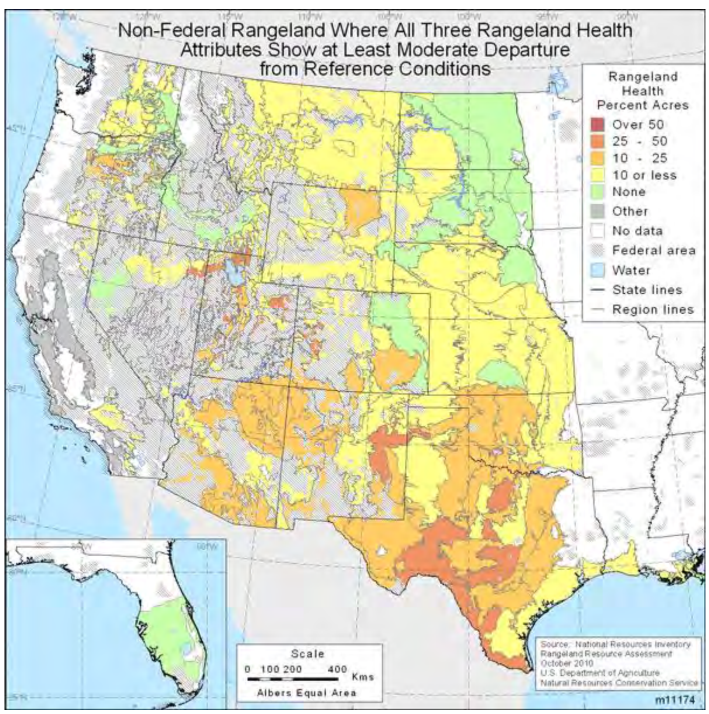

Figure 17B: Rangeland health assessment of non-federal rangeland in the U.S. Data from USDA (2010) and Herrick et al. (2010). Showing ecoregions where all three health attributes (biotic integrity, hydrologic function, and soil and site stability) show a moderate or greater departure from reference conditions.

This would seem consistent with the observation that in many arid lands, grazing is a known contributor to desertification with an increase in woody plant cover and a corresponding decrease in grass and forb cover (FAO 2006). However, the fact that almost 80% of rangelands assessed showed little to no departure from reference conditions highlights several things: (1) in many areas, grazing is compatible with maintaining rangeland health; (2) arid rangelands are very susceptible to degradation in environmental health if not managed correctly; and (3) opportunities exist to preferentially source cattle from less degraded areas, which could be a mechanism to improve rangeland health in the more degraded areas.

Rangeland conservation practices, developed and implemented by NRCS, are the primary guidelines available for private rangeland owners in the U.S to promote better rangeland health and these practices have been analyzed for their effectiveness by Briske (2011) and Spaeth et al. (2013). However, it has long been recognized in the conservation community that NRCS itself has limited capacity to work with landowners to actually implement these practices (e.g., NABCI 2009b), a factor that needs to be addressed to fully realize the potential of these practices to improve habitat for wildlife. Three broad areas of practices were analyzed for their conservation value: prescribed grazing, brush management, and upland wildlife habitat management.

<u>*Prescribed Grazing*</u> This practice is defined by Spaeth et al. (2013) as "*managing the harvest of vegetation with grazing and/or browsing animals … to improve or maintain ecosystem services (i.e., desired species composition, quantity and quality of forage, surface and/or subsurface water quality and quantity, riparian and watershed function, reduction of soil erosion, maintenance or enhancement of wildlife habitat, and maintenance of fine fuel loads).*" The primary conclusions are (Briske et al. 2011):

- Stocking rate is generally at least indirectly negatively correlated with ecosystem function and sustainability (higher stocking rates lead to lower ecosystem function), although the relationship is complicated and, in some ecological systems, low to moderate stocking levels lead to higher ecosystem function than no grazing at all. Some measures, such as plant production, consistently decrease with increased stocking rate; others, such as plant species richness or diversity, increase with increased stocking rate.
- There is no evidence that facilitating practices alone (e.g., fencing, roads, and pipelines) directly promote effective environmental conservation in uplands (except for improved livestock distribution); the key to obtaining both better animal production and environmental results is the use of timely and effective adaptive management actions.
- Therefore, to improve the quality of rangelands grazing practices should emphasize the use of monitoring and adaptive management to determine stocking rate and drought management.
- Experimental research has shown that there is no clear advantage of any one grazing system (rotational grazing, continuous grazing) over another in terms of ecological benefits, due to the overriding influence of stocking rate and weather patterns on these variables.

<u>*Brush Management*</u>. Archer et al. (2011) provide an excellent review of the issues surrounding woody plant (aka "brush") encroachment on native ecosystems, a phenomenon noted for almost the past century worldwide in rangelands. Woody plan invasion and/or encroachment of certain habitats, particularly native grasslands, can eventually lead to a pronounced loss of biodiversity as well as lowered quantity and quality of grazing forage. However, the drivers of these increases in woody plants are complex and varied and they interact over time and place in non-linear and complex ways. Therefore, the earlier view that all brush invasion is "bad" and that brush management actions are essential in rangelands to improve forage quantity has given way to a more nuanced assessment in which brush management needs to be implemented in a controlled fashion that reflects the precise needs of each individual grazing allotment or ranch. Brush management is defined by Spaeth et al. (2013) as "*the management or removal of woody (non–herbaceous or succulent) plants including those that are*

invasive and noxious … to create a desired plant community consistent with the ecological site; restore or release desired vegetative cover to protect soils, control erosion, reduce sediment, improve water quality, or enhance stream flow; maintain, modify, or enhance fish and wildlife habitat; improve forage accessibility, quality, and quantity for livestock and wildlife; and manage fuel loads to achieve desired conditions." The primary conclusions are (Archer et al. 2011):

- Brush management appropriate for a particular site can be used to maintain grassland, steppe, and savanna ecosystems and the biodiversity and services they provide, since loss of grassland-obligate organisms occurs with shrub encroachment, even if overall numerical biological diversity is enhanced or unaffected.
- In most systems studied, reduction in brush cover or density produced increases in forage-related variables such as herbaceous cover, yield, and diversity at least up to some maximum set by local rainfall and climate. Responses of biodiversity, however, varied greatly depending on the exact treatment method and climate regime following treatment.
- In general, brush management may not necessarily produce the hydrological benefits in terms of water quality and quantity that are commonly used to justify the treatment. However, there is evidence that removal of woody species such as eastern redcedar does result in increased surface water runoff and streamflow in some mesic grassland systems (Zou et al. 2014).
- Similarly, the effects of brush management on wildlife and habitat vary, depending on the species or functional group being examined. At best, there are tradeoffs and some species will benefit and others will be negatively affected by a given management regime at a particular site. However, brush management tends to be a positive for both wildlife and rangelands in those habitats where the encroaching woody species convert the habitat to something unusable by the fauna dependent on it, such as juniper colonization of sagebrush habitats (Baruch-Mordo et al. 2013, Knick et al. 2013) and creosote bush or mesquite invasion of grasslands (Whitford 1997, Pidgeon et al. 2001).

Upland Wildlife Habitat Management. This practice is defined by Spaeth et al. (2013) as the provision and management of "*upland habitats and connectivity within the landscape for wildlife … so that the wildlife that inhabit these uplands during a portion of their life are able to move as they need and have shelter, cover, and food in the proper amounts, locations, and times needed to sustain them.*" Unfortunately, Krausman et al. (2011) found that "*very few of the 167 conservation practices listed by the NRCS have been evaluated in the peer-reviewed literature to determine their influence on upland wildlife.*" While the absence of evidence does not necessarily mean that these results are ineffective, alternative strategies that have been demonstrated to be impactful should be prioritized over those lacking such evidence.

3.2.4 Recommendations

- Ensure that ranchers who supply feedlots with cattle follow standard NRCS prescribed practices for their local area (including considerations of sensitive species, and particularly for stocking rate), by contacting and applying for Conservation Technical Assistance at their local NRCS office (USDA NRCS), or working with an agricultural extension agent or other qualified technical assistance specialist. This could be accomplished through market incentives and/or internal sourcing policies.
- Support efforts by NRCS and conservation partners across the country to cost-share Farm Bill Biologist positions to work with landowners to implement priority conservation practices on their lands. This would help address the chronic staffing shortages of NRCS in delivering its practices.

- Encourage ranchers (and feedlots who source from those producers) geographically located in those areas of the country with degraded rangeland health (e.g., areas in red-orange or red in Figures 17A or figures 3a, 3b, and 3c within Herrick et al. 2010) to implement better management practices.
- Encourage producers to pay special attention to conserving riparian areas and wetlands on their ranchlands and to follow recommended grazing management practices in these areas. If possible, fence riparian areas to exclude cattle completely and provide alternate water sources away from these zones.

3.2.5 Degradation of pasture by improper grazing

For the purposes of this analysis, we consider pasture (also known as "pasturelands") to follow the NRI definition (USDA 2013): "*A land cover/use category of land managed primarily for the production of introduced forage plants for livestock grazing. Pastureland cover may consist of a single species in a pure stand, a grass mixture, or a grass-legume mixture. Management usually consists of cultural treatments: fertilization, weed control, reseeding or renovation, and control of grazing. For the NRI, includes land that has a vegetative cover of grasses, legumes, and/or forbs, regardless of whether or not it is being grazed by livestock.*" Pasture is also sometimes irrigated. Sanderson et al. (2011) and USDA (2013) estimated that there are 118.6 million acres of pasture in the U.S., predominantly from the very eastern edge of the Great Plains states east (Figure 7).

Pasture can support many species of wildlife and, in some geographic areas, is a major contributor to "grassland" habitat which has otherwise been lost. Therefore, appropriate management of these pastures in wildlife-friendly ways can contribute to the conservation of some species (e.g., grassland birds in much of the eastern U.S.). From Sanderson et al. (2012): "*There are an estimated 30 million ha [74 million acres] of pasture and hayland in the USA that would provide greater environmental benefits from some form of conservation treatment, such as prescribed grazing, pasture / hayland planting, and nutrient management* (USDA NRCS 2004)." Hayland is similar to pasture but rather than being directly grazed the hay is cut and sent to cattle in need of supplemental feed (either during the ranch and farm grazing phase or in feedlots).

The pasture / hayland Conservation Effects Assessment Project (CEAP; Nelson 2012) focused on primarily eastern grazing lands. Pasture / haylands can provide many ecosystem services while simultaneously providing beef and other food crops. These lands can provide erosion control, water quality buffers, and habitat for various species of wildlife. On the other hand, sediment, nutrients, and bacteria from pastures (especially irrigated and fertilized ones) can also be a source of water quality problems. The detailed analysis of wildlife effects found that the literature was limited and mostly focused on the effects of grazing intensity and avian responses (Sollenberger et al. 2012). Some of the basic findings are (from Nelson et al. 2012, Sollenberger et al. 2012):

- Species-rich or diverse pastures offer more benefits than monocultures since wildlife species vary dramatically in their use of any single species of pasture crop.
- Stocking rate, which determines grazing intensity, is the most important factor that can be controlled on pastures. The correct grazing intensity depends on the geographic location, climate regime, and annual impacts at the given site, but, in general, should be focused on maximizing the beef production, forage production, and wildlife value of the pasture, tract, or allotment, as well as improving and maintaining soil health.
- The effects of grazing intensity on abundance, richness, nest sites, and nesting success of birds have been well studied. In general, high grazing intensity leads to lower abundance caused by loss of nesting habitat, nest trampling, and fewer invertebrate prey. In some geographic areas,

low grazing intensity (as opposed to no grazing at all) benefits populations of some bird species by creating better or higher quality habitat.

3.2.6 Recommendations

- Require or incentivize producers who provide cattle from pasture to follow standard NRCS prescribed practices for their local area including considerations of stocking rate and sensitive species.

3.3 Wildlife

3.3.1 Mortality and reduced survival from haying

It is specifically important to note that haylands where grass and similar crops are cut regularly for forage can be classic examples of ecological “sinks” (areas that attract wildlife that are then killed, or where there is no reproduction) if the timing and cutting height are not adjusted to reflect wildlife concerns (Perlut et al. 2008). Guidelines are available for many geographic regions (e.g., Green 2010, Hyde and Campbell 2012, Jones and Vickery 1997, NRCS 1999, Ochterski 2006, Sample and Mossman 1997) that can be used to increase the survival and reproduction of many species, particularly birds and fossorial animals. Examples of typically recommended techniques include delaying the first cutting of hay until late June, early July, or later (depending on the geographic area of the hayfield); using a mowing pattern that encourages or allows wildlife to escape (e.g., from the center out or back and forth across the field); use of a flushing bar attached to the front of the harvester; or rotating hay harvest among pastures.

However, without specific information on the amount and geographic origins of harvested hay as used in the U.S. beef supply chain, it is difficult to attach specific numbers to this specific effect in the context of this analysis. Nevertheless, producers that use harvested hay should be encouraged either to follow the wildlife-friendly practices discussed in the publications cited and to source hay from growers that themselves follow these practices. This is especially true for the eastern U.S., where haylands are proportionately more important as substitute grassland habitat than in the Great Plains or farther west.

3.3.2 Recommendations

- Postponing the time of first cutting of hay or hay-crop silage can result in many wildlife benefits. For example, delay of first harvest of many cool-season grasses favors nesting success of ground-nesting birds and cutting four inches or higher above soil level improves the survival of turtles.
- Encourage hayland operators to follow wildlife-friendly harvesting procedures (see NRCS or appropriate state or regional hayfield management publications), such as delaying first harvest of hay or hay-crop silage to encourage success of ground-nesting birds. Raise the cutting height for hay to improve nesting and brood rearing habitat for birds, as well as the survival of turtles and other small animals.
- Encourage feedlot and other suppliers to source supplemental feed from growers that follow wildlife-friendly practices.

Part 4: Greenhouse Gas Reduction Opportunities in the U.S. Beef Supply Chain

4.1 Beef's Supply Chain Impacts on Greenhouse Gas Emissions

The U.S. agriculture sector constitutes 9% of all domestic greenhouse gas (GHG) emissions, with beef production being the largest contributor (Figure 18) (U.S. EPA 2015b). The GHGs produced by the agriculture sector are methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2), and for beef cattle virtually all of the impact comes from methane and nitrous oxide (U.S. EPA 2015b).

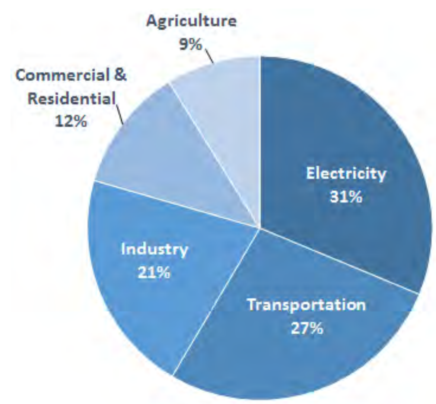

Figure 18: Sources of Greenhouse Gas Emissions in the U.S. (U.S. EPA 2015b).

It is challenging to obtain reliable data for beef cattle broken out by the production phases used in this report. Some sources report impacts by category (like enteric methane) across all phases in a way that they cannot be split up by phase (U.S. EPA 2015b). Others use different phases, e.g. Rotz et al. 2015 looks at emissions by cow-calf operations, backgrounding, and feedlots (each of which includes some "feed production" as we define it, meaning both grain and hay / silage).

Using the national data available from the U.S. EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks (U.S. EPA 2015b), however, it appears that the greatest impact comes from the ranch and farm grazing phase. They report nitrous oxide emissions from "agricultural grasslands" (pasture and rangelands, part of ranch and farm grazing) as 95.9 million metric tons CO_2e (carbon dioxide equivalent), mostly from manure and urine and applied fertilizer for pastures. As estimated in section 2.2.1.1 above, 76% of these lands are used for beef cattle, so beef cattle N_2O emissions are roughly 72.9 million metric tons CO_2e. Enteric methane for beef cattle produced another 116.7 million metric tons CO_2e (U.S. EPA 2015b), and the majority of enteric methane is produced during the ranch and farm grazing phase (since cows spend more time there, and emit more methane per unit time due to the less digestible grass). By comparison, emissions from manure solely during the feedlot phase represent only 10.6 million metric tons CO_2e. Feed production for grains and silage is the most difficult to estimate (and the EPA's Inventory omits the GHG of fertilizer manufacture), but total nitrous oxide emissions from cropland / hayland in the U.S. is 167.8 million metric tons CO_2e, and as noted in section 2.2.1 only a relatively small fraction of that land is used to feed cattle (10-13% of corn, plus silage and a few other grains). Based on these high level estimates we recommend a focus on the ranch and farm grazing phase, with secondary emphasis given to both feed production and feedlots.

Similar to the estimate above, emissions of GHGs are highest in the *cow-calf* phase of the U.S. beef supply chain (Rotz et al. 2015). Methane has the highest relative contribution during this phase primarily due to high levels of forage consumed and the length of time on pasture. Enteric methane emissions are comparatively small during the feedlot stage because of a diet of processed feed, nutrition management, and shorter residency (Figure 19) (Rotz et al. 2015). Determining the relative contribution of feed production, enteric methane, and manure management on the total emissions of each of the three beef supply chain segments shown in Figure 19 is limited by the amount of available literature. A few regional studies attempt to disaggregate GHG emissions for the three segments and mentioned in the proceeding sections.

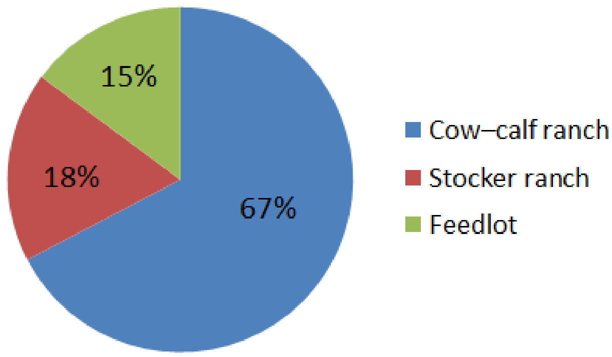

Figure 19: Estimated GHG emissions associated with the U.S. beef supply chain. Cow-calf and stocker ranch are both considered part of the ranch and farm grazing phase in this paper, and "Feedlot" represents the combination of our "feed production" and "feedlot" phases. Adapted from Rotz et al. (2015).

More than one-third of anthropogenic methane emissions in the U.S. originate from livestock, with enteric methane accounting for 25% of the total and manure making up the other 9% (EPA 2015b). The main sources of nitrous oxide are animal manure applications to land, emissions from other fertilizers used to grow feed for animals, and urine deposition by grazing animals (Monteny et al. 2006). Methane and nitrous oxide are 34 and 298 times, respectively, more potent GHGs than carbon dioxide in terms of their contribution towards global warming over 100 years for each unit of mass emitted (over 20 years, methane is 86 times stronger and nitrous oxide is 268 times stronger, IPCC 2013). Note that until the 2013 IPCC report, a factor of 25 rather than 34 was used, so most existing studies (and the U.S. EPA) use the older number. Reductions in these emissions can have profound effects on overall production of GHG in the U.S. In this report we will present different GHG in units of CO_2e. For example, one metric ton of carbon (C) when emitted into the atmosphere is equivalent to 3.67 metric tons of CO_2 (as the oxygen adds mass to the carbon), so it is simply reported as 3.67 metric tons CO_2e. Likewise, one metric ton of methane in the atmosphere has a carbon dioxide equivalent of 34 metric tons CO_2e (IPCC 2013).

Emissions from beef production are not limited to methane and nitrous oxide. Large amounts of carbon are stored in the soils of grazing lands across the U.S. and only through proper management activities will this carbon stay locked in the soil and not become a compounding source of CO_2 emissions from the agriculture sector. As noted in the wildlife habitat section, roughly 41% of the U.S. (812 million acres) of the land in the lower 48 states is used for grazing. Reducing land degradation by enhancing vegetation cover, improving soil structure, and decreasing runoff represent manageable activities to improve or maintain the condition of grazing lands while reducing the loss of soil carbon to the atmosphere. In addition to preventing the loss of trapped soil carbon, improving grazing techniques can promote additional carbon storage by sequestering carbon from the atmosphere. Sequestration is the process of removing or capturing carbon dioxide from the atmosphere. There are many mechanisms to do this but for the purposes of this report we will only focus on the biological process of sequestration. Biological sequestration in this context occurs when carbon is absorbed by plants through the photosynthetic process and stored in the plant's stems and roots as the plant grows.

This section will discuss the GHG impact of the beef supply chain in the U.S. as it relates to ranch and farm grazing, feed production, feedlots, and harvest facilities with discussion and recommendations to reduce emissions through selected activities and management options.

4.2. Ranch and Farm Grazing

Cow/calf and stocker/backgrounder operations in the U.S. with less than 1,000 head of cattle (904,400 farms) account for nearly 65% of the beef cow inventory (USDA 2013). Large scale operations of 1,000 or more head constitute 0.01% of all grower and stocker operations yet are responsible for over a third of the total beef cow inventory (Figure 20a) (USDA 2013). Beef cattle grazing operations are spread throughout the U.S., although there are more in Texas than in any other state (Figure 20b) (USDA NASS 2012). Most of the small operations (100 head or less) are located in the central and eastern states and the larger farms (200+ head) are distributed across the western U.S. For the vast majority of farms with beef cows, beef is not their primary source of income. This presents challenges for assessing the GHG impacts of ranch and farm grazing as well as implementing broad scale reduction or mitigation recommendations. However, in large scale operations, grazing takes place in relatively large landscapes with the potential for commensurate greater impact from GHG reduction strategies especially in grazing practices. Based on a regional analysis of beef production in the Upper Midwestern US (Pelletier et al. 2010) the predominant GHG emission during cow-calf operations (representing much of the ranch and farm grazing phase) originated from enteric methane (43.4%), followed by production of grass and hay (32.9%), and manure (21.1%). It should be noted that production of grass and hay mentioned here includes emissions from the management of grazed pastures including the production and use of fertilizers and seeding as well as those activities associated with "off-site" hay production used as supplemental feed during winter months (Pelletier et al. 2010).

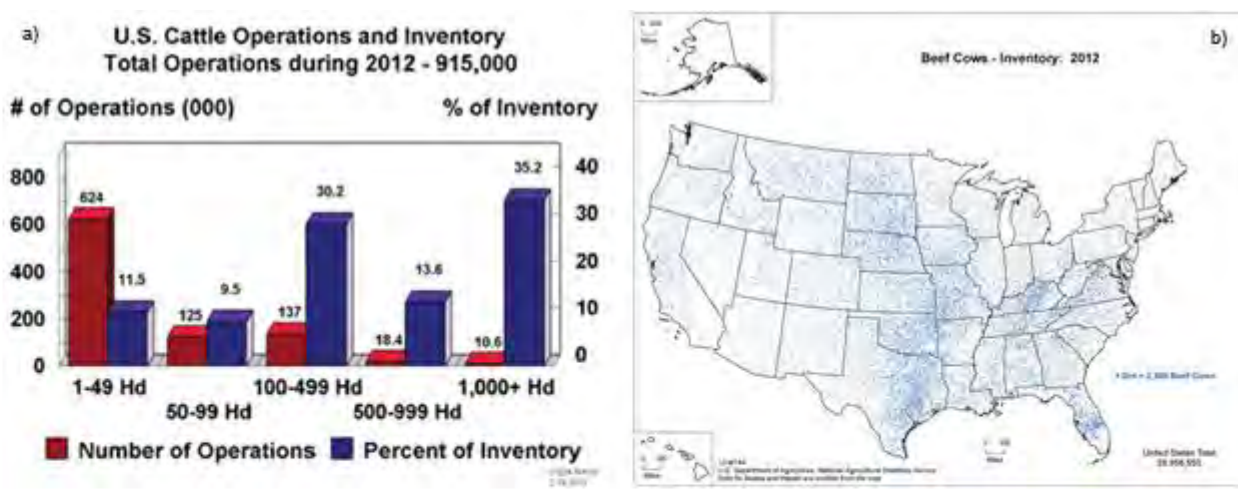

Figure 20: (a) U.S. cattle operations and inventory (USDA 2013)**. (b) Geographic distribution** (USDA NASS 2012).

A typical cow-calf operation (the first component of ranch and farm grazing) in the U.S. contains cows and their young who, once born, both drink milk and graze for about six months until they are weaned and achieve an average weight of 400-700 lbs. After that time the young beef cow is usually sold to a backgrounder operation (also part of ranch and farm grazing) which manages the transition from weaning to either grass or grain fed finishing. Most calves in the U.S. are finished on grain in feedlots (USDA NASS 2015). In grass-fed/grass-finished supply chains, cattle can either be kept on the farm on which they were born or sold to grass finishing operations (Kensky and Preston 2010).

During a cow's time on the ranch, its main source of nutrition is from grazing on pasture supplemented with hay and silage provided by the farmer. Grains are rarely used during this phase of a beef cow's life. Pastures usually contain a mix of grasses and legumes depending on the conditions of the pasture, grazing practices of the farm, and seasons. For those cows that will be sold to feedlots, after about 6-7 months on pasture or as the cow approaches a weight of 800 lbs., the farmer will begin to introduce grain and corn silage to their diet preparing those cows for their feedlot diet (NCBA 2015).

For the purposes of this study we will only assess the GHGs for ranch and farming grazing related to grazing management, soil degradation, manure and enteric methane, and fertilizer applications including manure. We do not assess the GHG emissions related to transportation and harvest facilities / processing, which are only about 6% of beef sector emissions (FAO 2013).

4.2.1 Grazing management

Grazing lands occupy nearly 25% of global land area making them the most prevalent land use activity on the planet (Asner et al. 2004). Improving grazing techniques show similar benefits for both rangelands' and pasture ability to sequester carbon from the atmosphere. Carbon benefits of grazing practices (whether increasing the land's ability to sequester carbon or through the reduction of CO_2 emissions) are tied to grazing management and maintaining good forage quality (Eagle et al. 2012; Teague 2014). Pastures are often managed using irrigation, fertilization, tillage and grass planting and unlike their rangeland counterparts their carbon emissions and sequestration rates can be greatly affected by changes in land management practices (O'Mara 2012). The benefits of grazing management on rangelands are unclear and difficult to quantify. Carbon fluxes are often low because of the low plant productivity in rangelands (Eagle et al. 2012; McSherry and Ritchie 2013).

Grazing management is complex and varied and requires an adaptable understanding of animal movement, grazing times, changing vegetation, and climate conditions (McSherry and Ritchie 2013). There is continued research into carbon retention and emission of soils relating to grazing intensity. Results vary among studies measuring pasture and rangeland health under different grazing practices ranging from Holistic Management promoted by the Savory Institute and others and more traditional and less intensive grazing techniques of lower stocking rate, larger number of paddocks, and longer rest periods between grazing. However, where conditions of drought are prevalent, frequent moderate to high grazing has been shown to cause a substantial loss of soil carbon. Zhang et al. (2010) found that if more than 65% of the area is experiencing drought, rangelands can become a source of carbon rather than a sink. Emerging from these studies is the recognition that "adaptive management," where grazing systems are continually tailored to meet the climate conditions and the goals of the ranchers, is essential to working in the diverse and complex grazing landscape of the U.S. (Briske et al. 2014; Teague 2014).

4.2.2 Soil Degradation

Reducing land degradation is a manageable activity that ranchers can undertake to improve or maintain the condition of privately owned grazing lands and enhance the soil's ability to both reduce carbon emissions and sequester more carbon from the atmosphere. Strategies involve enhancing the vegetation cover, improving the soil structure, and decreasing runoff.

Specific activities to achieve these strategies include contour trenching or pitting and ripping, which is a form of tillage (Follett et al. 2001). Pitting and ripping involve fracturing the surface of the soil to promote water and root penetration. This activity does release carbon trapped in the soil and constitutes a GHG emission, however forage yield increases of 100-300% after soil fracturing have been measured which more than offsets the initial carbon emissions (Schuster et al. 2001). Implementing these practices on previously converted grazing lands and degraded lands can increase vegetation cover and reduce carbon emissions from soil erosion. However, if this activity is undertaken in native habitats, carbon emissions and habitat degradation would likely outweigh any carbon sequestration benefit relating to infiltration and decreasing runoff, and as such we do not recommend these practices on rangelands. Ground cover in the range of 70-90% is needed to effectively reduce the risk of soil erosion (Follett et al. 2001). Improving the land's ability to sequester and store carbon can also be achieved by changing land cover type altogether. Converting marginal cropland to pasture can increase the amount of carbon stored in the soil. Where there's an economic disincentive to maintain cultivated land, converting from highly degraded croplands to well-managed grazed rangeland or pasture can in some cases absorb enough carbon in its soil to offset the other emissions from the beef produced on that land (Beauchemin et al. 2010), e.g. in Eastern pasture where there is consistently high precipitation to maintain robust forage growth.

4.2.3 Diet and Enteric Methane

As feed ferments in the rumen and lower digestive tract of cattle, methanogenesis occurs, and the gases released account for 2-12% of the gross energy from the animal's feed (Patra 2012). In recent decades the annual emissions from enteric fermentation were responsible for as much as 2.5% of all the GHGs produced in the U.S. Between the years 2000 and 2009 methane from enteric fermentation ranked second of all anthropogenic methane sources in the U.S. (U.S. EPA 2012a). The rate of enteric methane produced is directly related to the amount and type of food consumed by cattle (IPCC 1997, Monteny et al. 2006). A recent study compared two grazing systems in North Dakota and found that enteric fermentation affected GHG fluxes more than the carbon changes between grazing intensity (Liebig et al. 2010). The production of methane represents a quantifiable loss in energy from the cow. For a 1,000 pound beef cow the 110 - 198 pounds of methane produced per head per year equates to 33-60 lost grazing days (Eckard et al. 2010). Enteric methane reduction during the ranch and farm grazing phase can be achieved by altering grazing strategies to favor more digestible plant species (including legumes), and / or adjusting the composition of supplemental silage. Decreasing the time to market can also potentially reduce enteric methane (as the cow is emitting methane for less time) as long as other variables remain stable. While research is ongoing to breed cattle which produce less enteric methane (e.g. Basarab et al. 2013), it is in the early phases and is not commercially viable yet.

On rangelands, which constitute the bulk of large scale grazing operations in the western U.S., improving the quality of forage with lower fiber and higher soluble carbohydrates such as changing from C_4 to C_3 grasses can reduce methane production (Ulyatt et al. 2002, Beauchemin et al. 2008, Eckard et al. 2010). C_3 grasses such as various wheatgrasses, needlegrass, bromegrass, and bluegrass are better in more northern and eastern range and pastures in the U.S. since they are adapted to cool season growth in either wet or dry conditions. These grasses produce high quality forage early in the spring, then growth slows during the summer months and often additional growth occurs during the cooler fall months. C_4 grasses such as blue grama, buffalograss, and bluestems are better adapted to warm and hot season growth and can tolerate drier conditions than C_3 grasses. C_4 grasses tend to be more fibrous which makes them less digestible. Therefore, livestock normally prefer C_3 grasses if they are available (Trlica 2013).

The Government of New South Wales, Australia, which has grazing land conditions similar to the U.S. recommend grazing lands have both C_3 and C_4 grasses where applicable. On lands of moderate topographic relief C_4 grasses are better suited for drier, full sun conditions of the south facing slopes whereas C_3 grasses grow better in the cooler shade of the north facing slopes. Introducing more native C_3 grasses in grazing lands where they are not traditionally present provides cattle a higher forage quality with lower rates of enteric methane production. However, introducing non-native species poses additional concerns and is not recommended here.

Scientists have also seen reductions in enteric methane emissions by introducing higher proportions of forage legumes in grazing cows' diets (Beauchemin et al. 2008, Eckard et al. 2010). Legumes can also increase soil carbon (Schjønning et al. 2007) and improve plant productivity without fertilizer (Thomas and Asakawa 1993). On the other hand, as they decompose in fields they can produce volatile ammonia (Janzen and McGinn 1991) which is an indirect precursor to nitrous oxide (Powers et al. 2014), increasing the consumption of legumes by cattle leads to higher nitrogen losses via manure (Thomas and Asakawa 1993).

Genetically engineered legumes such as alfalfa are being developed that may have the dual benefit of reducing enteric methane while stimulating weight gain in livestock. Research is still ongoing and to date the effects are varied. A recent comparison of alfalfa and grass saw only a slight difference in methane produced through enteric methane (Chaves et al. 2006), but more research is needed.

4.2.4 Nitrous Oxide

Synthetic fertilizers, manure, and urine from grazing animals are the primary sources of nitrous oxide emissions in the U.S. (Brown et al. 2001, Monteny et al. 2006). Fertilizing pasture to improve forage quality can increase carbon sequestration rates from 0.83 – 13.15 metric tons CO_2e per acre per year (originally cited as 0.1-1.6 t CO_2e ha^{-1} yr^{-1}; Eagle et al. 2012). However, without proper nutrient management practices such as application amount and timing, the carbon sequestration benefit can be offset by an increase in nitrous oxide. Restricting grazing during periods when the ground is wet, the period where denitrification rates are highest, has also been shown to reduce nitrous oxide emissions from manure on pastures and rangelands by as much as 10% (Eckard et al. 2010, Luo et al. 2010). Better nitrogen management is needed to improve carbon sequestration via fertilization while minimizing nitrous oxide emissions. Some studies suggest there could be a reduction of 12-20% without negative yield impacts (Miller 2010).

New research is focusing on understanding the sources of nitrogen releases, timing of application and improved or combined use of manure. Some studies show increases in soil carbon with manure applications equivalent to 0.44-11.45 metric tons CO_2e per acre per year (originally reported as 0.2-5.1 t CO_2e ha^{-1} yr^{-1}; Chesworth 2008). Higher retention rates have been found in cooler climates and less in warmer climates (Risse 2006). The USDA provides nutrient management information and standards to ranchers through the NRCS. These conservation practice standards document the requirements needed for nutrient management plans that address the application of both natural and synthetic fertilizers (including variables like which type of fertilizer to use, how much to apply, and when to apply it).

4.2.5 Recommendations

- Improved pasture operations should manage forage crops to include approximately 20-30% native legumes, which can reduce enteric methane production and enhance soil carbon retention of managed pastures and rangeland where appropriate.
- Improve soil carbon retention rates of pasture under forage management by proper timing of application and improved or combined use of manure with synthetic fertilizers. Use established standards and recommendations as those defined in the USDA's Conservation Practice Standard.

- Convert marginal or unproductive cropland to pasture.
- Avoid overgrazing by setting an appropriate stocking rate, or changing the timing or frequency of grazing. This can improve soil condition, which promotes vegetation growth and increases carbon sequestration and retention rates, reduces N_2O emissions from deposited urine and manure, while also offering the co-benefit of improving forage productivity.
- Maintain and adapt appropriate stocking density as determined by total area and rotation periods to provide longer rest periods between grazing bouts in managed pasture.

4.3 Feed Production

Of the 13.6 billion bushels of corn grown in the U.S. in 2015, 13% or 1.8 billion bushels were consumed in U.S. feedlots (USDA ERS 2015c). While this only represents a modest portion of the total corn yield in the U.S., the 1.8 billion bushels were grown on just over 10 million acres of croplands (USDA ERS 2015c). N_2O from fertilizer application is the predominant GHG emitted from corn production. Proper nutrient management applied to 10 million acres can produce a significant reduction in N_2O emissions not to mention additional benefits in runoff and water quality issues. While we do not have reliable data on how much of the U.S. hay crop is fed to cattle, as 54 million acres are used for hay total, improving fertilization practices on haylands is likely another significant opportunity to reduce GHG impacts.

Fertilizer applied to croplands that is not consumed by the plant is can decompose and release N_2O. It is estimated that 1% of nitrogen based fertilizers applied to agriculture lands is emitted as N_2O (Snyder et al. 2009), although it can be considerably higher in some cases (Shcherbak et al. 2014). In addition to direct N_2O emissions from fertilizer application, the emissions from nitrogen removed through runoff could be as much as 63% of the total nitrogen applied (Snyder et al. 2009). Finally, the *production* of nitrogen-based fertilizer also requires substantial amounts of energy; it varies by fertilizer type and production location and ranges from 0.8 kg CO_2e / kg N to 13.3 kg CO_2e / kg N (Wood and Cowie 2004). The key to reducing GHG emissions from fertilizer applications is to improve use and efficiency by reducing losses to air and water, and thus requiring lower inputs. This can be achieved through precision application, proper timing to lower the risk of runoff with irrigation and rainfall, and avoiding excessive application. With growing interest in intensification and the need to feed a growing population on nearly fixed amounts of arable land, fertilization has become a topic of growing interest and research. Enhancing crop growth through fertilization should be balanced by emissions from producing synthetic fertilizers (Powlson et al. 2014) as well as N_2O emissions from application techniques. Some studies suggest there could be a reduction of 12-20% without negative yield impacts (e.g., Millar et al. 2010).

Reducing CO_2 emissions and promoting carbon retention in managed cropland soils dedicated to feed production must also be considered in GHG reduction strategies. Carbon present in agricultural soils is emitted as CO_2 when the soil is disturbed, primarily during tilling. It is widely reported that the loss of carbon in the top 30 cm of grassland soils upon initial conversion to agriculture is between 20 and 40 percent (Poeplau et al. 2011, Post and Kwon 2000, Davidson and Ackerman 1993, Schlesinger 1984). Improving agricultural management practices will not completely offset soil carbon losses resulting from conversion or continued cultivation, but activities such as fertilizer management, no-till, cover cropping, and biochar can reduce annual CO_2 emissions and enhance carbon sequestration.

No-till agriculture is based on the premise of reduced or minimal soil disturbance as opposed to traditional cultivation by plowing (Powlson et al. 2014). In the U.S. no-till is practiced on roughly 30% of cropland (Eagle et al. 2012). Many studies reported in Eagle et al. (2012) show increases in soil carbon retention of 0.33 t C/ha/yr and 0.12 t C/ha/yr for no-till and reduced tillage, respectively. The carbon retention effects of reduced tillage are not uniform across geographies. Tillage practices need to account for varying climate and moisture conditions. No-till has a higher carbon sequestration potential in sub-humid regions typical of the U.S. Midwest and Southeast and lower rates in cooler, wetter regions. Subsequently any modest increase in carbon storage in wetter soils may be negated by increase in N_2O due to the poor aeration of the wet soils (Powlson et al. 2014, Eagle et al. 2012). A global analysis of 74 studies looking at productivity between no-till and full-till showed productivity dropped in cooler, wetter climates (Ogle et al. 2015).

Cover cropping is a long practiced management activity where crops are grown during fallow periods to maintain nutrients between growing seasons, but the effects on carbon retention and nitrogen fixation can reduce overall greenhouse gas emissions (Eagle et al. 2012). When combined with reduced tillage practices, especially in moist climates, an additional ton of carbon per hectare can remain trapped in the soil (Eagle et al. 2012, Abdalla et al. 2013, Govaerts et al. 2009). Cover cropping has also been shown to reduce the need for fertilization through improved water retention and reducing runoff of nitrogen which in turn lowers N_2O emissions (Branca et al. 2013).

4.3.1 Recommendations

- Source feed from growers that operate farms using BMPs to reduce GHG emissions by implementing proper nitrogen management, crop rotation, tilling practices, and land management.

4.4 Feedlots

The majority (95%) of beef feedlot operations in the U.S. have less than 1,000 head of cattle (meaning they are classified as a medium CAFO, small CAFO, or AFO). However, this only accounts for 10% of the grain fed cattle supply (USDA 2012). The other five percent of the feedlots in the U.S. have greater than 1,000 head (large CAFOs) and are responsible for nearly 90% of the grain fed cattle supply (USDA 2012). These large CAFOs can produce more waste annually than some large U.S. cities (GAO 2008). Because of their large size and close geographic distribution these operations present substantial challenges in the management and reduction of greenhouse gases. The predominant GHG emissions from feedlot operations are methane and nitrous oxide resulting from enteric methane and manure management (Pelletier et al. 2010, U.S. EPA 2015b).

Feedlot operations consist of placing weaned calves from the ranch and farm grazing operations in a feedlot for approximately 90 to 120 days until they reach a live weight of 1,100 to 1,250 pounds (U.S. EPA 2012b). Each animal produces around 60 pounds of waste (manure and urine) per day. A single animal may produce 5,400 – 7,200 pounds of waste during the entire feedlot phase.

Total emissions from grass finished beef are often higher than that of grain finished beef (Capper 2011b, Desjardins 2012). The comparative factors are time to market and feed sources. Grain fed cattle reach harvest weight 226 days sooner than grass fed cattle thereby reducing their cumulative per day methane emissions from enteric methane (Capper 2011b). This large discrepancy seemingly gives grain fed cattle the advantage with regards to total methane emissions; however, the gross emissions resulting from manure and enteric methane in feedlots negates much of this advantage whereas only some manure in grass-finished operations produces methane, with the rest decomposing in rangeland and pastures and enhancing soil structure, storing organic carbon, and promoting plant growth (Desjardins 2012).

In this section we will assess the greenhouse gas emissions from enteric methane and manure production with special attention to recommendations to improve nutrition and waste practices of large scale feedlots in the U.S. We will not directly address emissions relating to fossil fuel use in transportation aside from some general recommendations.

4.4.1 Enteric Methane

Enteric fermentation accounts for 74% of methane from livestock (U.S. EPA 2015b), and depends greatly on feed consumption and composition. Implementing animal feeding practices that minimize the loss of methane will thus increase animal productivity by increasing feed conversion ratios, as well as reducing the overall carbon footprint (Desjardins et al. 2012).

Research is ongoing in the use of inhibitors that reduce methanogenesis directly or indirectly in the rumen, but more testing is needed regarding their effectiveness and economic feasibility before widespread adoption is feasible (Patra 2012). Among the most successful compounds as reported in a recent review (Hristov et al. 2013) were bromochloromethane (BCM), 2-bromoethane sulfonate, chloroform, and cyclodextrin. The methane inhibitors were able to reduce production of methane in livestock by up to 50%. However, the use of BCM is not a viable option since large scale production is banned due to its ozone depleting attributes. It does point to alternative anti-methanogens with a similar mechanism of action which may have practical commercial relevance (Tomkins 2009).

Ionophores are commonly used in the feedlot industry in the U.S. When added to feed, certain ionophores function as antibiotics, inhibiting the bacteria responsible for producing methane, stimulating an increase in different bacteria in the rumen that are more efficient in converting the cellulose in silage to protein. This increased efficiency results in lower rates of methane emissions and a better food to energy ratio. This results in a reduction in the food intake of the cow which reduces the overall feed requirements of the feedlot. Feed management and quality are very important factors when ionophores are used. Since the food intake is reduced, high quality forages must be used to offset any nutritional deficiencies resulting from reduced intake (Beauchemin 2008). The effects of ionophores on the generation of methane in livestock may be short-lived (Johnson and Johnson 1995). Guan et al. (2006) recently reported that monensin, the most commonly used ionophore, lowered methane production in beef cattle by 30%. However, methane generation levels were restored to pretreatment levels after only two months. This however may be a practical solution to reduce the total emissions since it represents a significant amount of time spent in a feedlot. On the other hand, as noted above, the use of antibiotics in this way has a negative impact on water quality, and has been associated with reducing the effectiveness of antibiotics in treating human disease (Gilchrist et al. 2007) and as such these trade-offs should be carefully considered.

Shifting the diet of cattle in feedlots from grass silage to corn and legume silage has been shown to reduce methane production (Hassanat et al. 2013). Proper management and storage are necessary to preserve and maintain the quality of silage in order to reduce enteric methane levels. Silage is harvested with a moisture content of 40-70%. Proper storage maintains high moisture content and conditions that allow the anaerobic creation of lactic acid that helps preserve the silage. There is growing evidence that diets with a high supplement of fatty acids do reduce enteric methane production in ruminants. In a review of nutritional management studies researchers found that with high levels of fat supplements in animal feed enteric methane reductions of up to 40% were realized. However, the cost associated with supplementing feed at commercial levels needed to obtain these reductions was not economically viable. Methane reduction levels of 10-20% from fat supplementation are more feasible in most large-scale feedlot operations. Likewise, the grinding and pelleting of forages can reduce methane emissions by 40% and pelleting of lower quality silages may improve nutritional value; however, the costs associated with this practice at scale may be prohibitive (Ishler 2008). One caveat is that this type of analysis does not include all effects, such as how much increased nitrous oxide emissions may be associated with a switch from grass to corn silage (which would counteract the enteric methane benefits to some degree).

4.4.2 Waste Management

As the organic material in animal waste decomposes, methane and nitrous oxide are released into the atmosphere and soil. Effective manure management involves controlling how manure decomposes in an effort to reduce methane and nitrous oxide emissions. Historically, before the proliferation of feedlots, manure management consisted of spreading the manure over the surrounding cropland and allowing the land to absorb the waste. This generally involved limited amounts of manure which typically resulted in improved soil conditions, enhanced plant growth and carbon sequestration. With the advent of feedlots in the U.S. beef industry the high concentration of waste presents significant environmental impacts.

Collecting manure as a solid and using it to supplement or replace synthetic fertilizers would likely reduce overall emissions especially those GHG generated from the production of synthetic fertilizers, but may increase nitrous oxide emissions if proper application methods are not used. Manure from feed lots using higher concentrations of distiller grains is far more nitrogenous than grass-fed manure, creating challenges for use as fertilizers because of excess nitrogen runoff and nitrous oxide emissions (Hao et al. 2011). Furthermore, fossil fuel emissions from the transportation of dry manure if carried long distances would most likely offset any carbon sequestration benefit related to nutrient management. The majority of manure produced in U.S. feedlots is managed as a solid and when it is properly maintained to reduce moisture, primarily from rain and humidity, a relatively low amount of methane is released during storage. However, after application as a fertilizer, conversion to nitrous oxide can be significant.

There appears to be a slight shift from dry manure storage to liquid storage in the feedlot industry. Manure stored in liquid slurry form (in tanks, lagoons, and holding ponds) generates particularly high levels of methane emissions, as well as poses significant risks to water resources as described in Part Two of this report. When animal waste is stored as liquid or slurry in lagoons, ponds or tanks, these systems create anaerobic conditions of decomposition which produce high amounts of methane. The amount of methane produced is directly related to the type of storage facility, moisture content, temperature, and time exposed to open air (U.S. EPA 2015b). One method with significant promise in reducing GHG emissions, producing energy, and controlling water contamination is the use of anaerobic digesters.

The U.S. Environmental Protection Agency's AgSTAR program estimated there were approximately 247 anaerobic digesters (ADs) in operation throughout the commercial livestock industry in the U.S. (U.S. EPA 2014b), although almost none on beef operations. Anaerobic digesters capture the biogas that is released from the decomposition of organic matter including manure. There is a growing industry that uses this technology to capture the methane produced from manure lagoons and use it to generate energy in place of traditional fossil fuels. Burning methane to produce electricity does emit CO_2, but since methane is a GHG 34 times more potent than CO_2 (IPCC 2013), burning 1 ton of methane only releases the equivalent of 2.75 metric tons of CO_2 as opposed to the 23 equivalent metric tons of CO_2 if the methane was allowed to vent from a slurry pond (Shih et al. 2008).

The effluent remaining after controlled anaerobic decomposition is relatively low in odor and rich in nutrients and can be used as fertilizer replacing or supplementing the use of synthetic fertilizers in crop production, although proper management remains essential to avoid water quality impacts. Using anaerobic digestion in feedlots reduces GHG emissions by directly limiting the methane and nitrogen emissions from the collection of animal and reducing fossil fuel based energy requirements of the operation. There are a variety of types of anaerobic digesters and an individual farm or feedlot must balance cost, size, and ease of operation with technical requirements of installation and reliability of gas utilization and flow (Energypedia 2014).

Wide scale adoption of ADs by large-scale feedlots would be beneficial to both the business operations and the environmental impact associated with highly localized and concentrated animal waste. Operations could use the methane gas to power the operations of the facility and potentially sell carbon credits or the unused gas to customers or back to utility companies. This would add revenue to the operation, cut waste management costs, reduce odor, and reduce water quality issues.

There are several issues that have prevented widespread adoption of ADs in beef operations. Currently most manure is stored as dry solids, and either AD technology would have to be adapted or feedlot operations would have to be altered to manage manure in a form that is conducive to scraping or pumping in concert with installation of the digester. Most feedlots in the U.S. utilize “soil-based pens” (Watson 2014). This poses challenges for collecting manure for use in anaerobic digesters since traditional AD technologies are ill-equipped to handle the dirt and rock that are mixed with the manure during scraping from these pens. Options do exist to overcome these challenges and there are examples emerging in the industry where new technologies and financial incentives make AD of manure a feasible option for energy generation. In the Hampton Feedlot in Triplett, Missouri, using renewable energy grants and USDA guaranteed loans a series of 8 ft. deep “pits” were constructed under covered feedlots structures that had been retrofitted with slatted floors to allow 60,000 gallons of clean manure to be flushed and scraped daily and pumped into AD tanks (Greer 2011). Waste from only half of the cattle on the Hampton Feedlot are used in AD but this is still enough to operate the on-site generator that meets all the electrical demands of the operation and any excess can be sold to the local electric provider. Where retrofitting feedlot cattle pens is not a viable option there are ADs that have the ability to generate biogas from either clean or dirty manure (Kryzanowski 2013). Western Plains Energy is using manure from a nearby feedlot as fuel for production operations. The Kansas based operation identified an “open-pen” feedlot within eight miles capable of supplying manure to what has become one of the largest, if not the largest, ADs in the country. Western Plains Energy estimates it can save roughly $8 million per year in energy costs which is a significant offset of the $35-$40 million installation cost (Kryzanowski 2013).

There also may be issues around NO_x emissions in areas with air quality issues, although NO_x removal systems for ADs have been recently developed which can reduce this concern.

Ultimately we can also reduce the individual GHG footprint of beef cattle by bringing them to harvest weight more quickly, effectively reducing their cumulative daily methane production per unit of beef. Between 1977 and 2007, the weight of beef cattle going to harvest rose from 544 to 779 pounds. It also took less time to reach that harvest weight, decreasing from 602 to 482 days. These and other changes in management practices have lowered the carbon footprint by 16 percent for each pound of beef produced (Dixon et al. 2011). If beef consumption stays flat or decreases, then advancements in nutrition and waste management can have a significant effect on domestic GHG emissions. However, such an approach will likely have trade-offs with other issues like animal welfare and the use of antibiotics.

4.4.3 Recommendations

- Increase accountability and traceability in nutrition management.
- Collaborate with research organizations, universities and agricultural extension programs to test the effectiveness of methane inhibitors and other feed supplements or additives at large scales, including potential trade-offs.
- Maintain proper storage and moisture content of stored forage to improve digestibility and limit enteric methane production.
- Supplement feed with lipids (fatty acids).
- Encourage grinding and pelleting of feed especially with lower quality silages.
- Install anaerobic digesters at feedlots to reduce GHG emissions, add revenue to the operation, cut waste management costs, reduce odor, and reduce water quality issues. This will require changes to manure management in most cases.
- Look into the best practice of composting manure solids.

4.5 Harvest Facilities

Harvest facilities can have significant GHG emissions but they are mostly fossil fuel based relating to the operation and transportation requirements of the facility and the uses of the non-edible byproduct in downstream industries. Refrigeration and water pumping are the primary energy demands of processing facilities. Boneless trimmed beef only makes up 40% of the cow's live weight. Most of the other 60% is sold as edible and non-edible by-product to other industries (e.g., organs, tongue, hide, bone). Only the rumen, stomach and intestinal contents, food waste, and liquid manure are disposed of by the harvest facility (Desjardins 2012). The options for GHG reductions are limited, but there are options for recovering biogas from the disposal process. There are small scale operations that collect stomach and intestinal contents for use in anaerobic digesters to produce methane for use in on-site energy and power needs but the energy benefits may not scale to the overhead costs needed to produce sufficient amounts of energy.

There may be an opportunity to offset the electricity and power needs of those processing facilities that are associated with large-scale feedlots (Figure 21). Where large CAFOs exist in close proximity to processing facilities, ADs can be built to capture biogas from methane digestion for use by both the feeding operation and the processing facility, thereby reducing the total GHG emissions from animal waste management (discussed in earlier sections) and fossil fuel based energy demands of the processing facility.

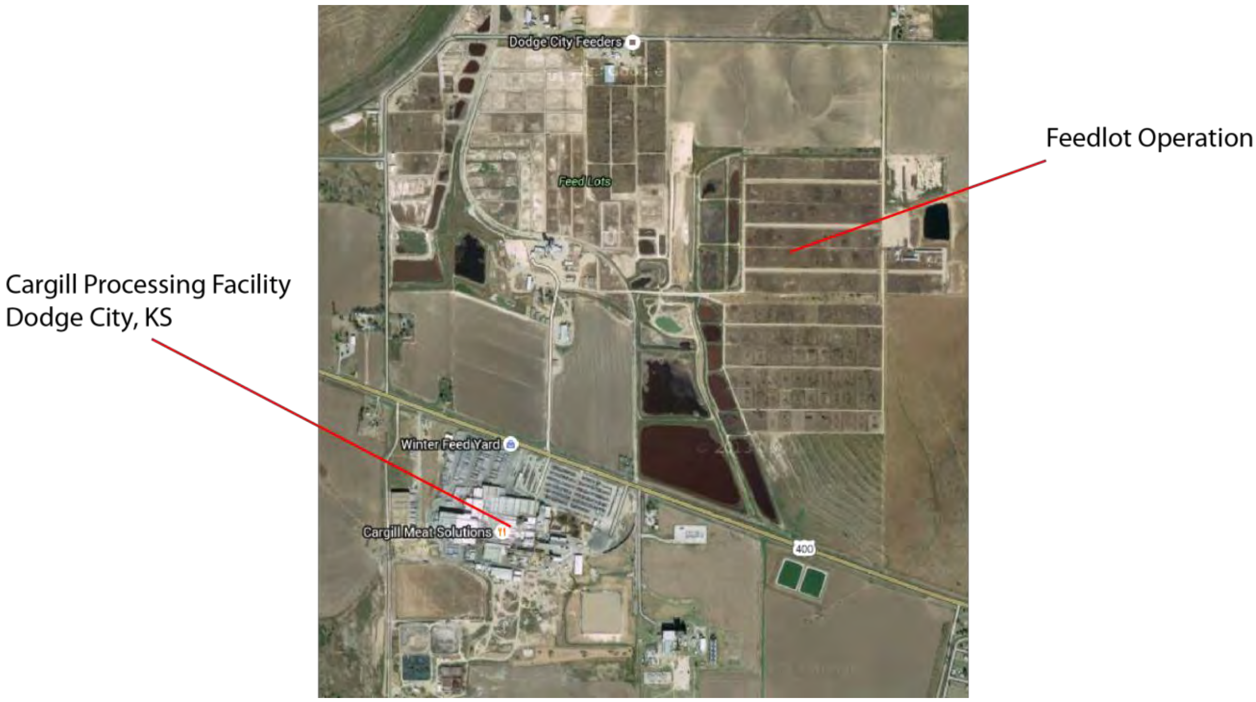

Figure 21: Feedlot and processing facility. Source: Google 2015.

4.5.1 Recommendations

- In large combined feed and processing operations look for ways to capture biogas; methane digesters can offset or supplement the energy requirements of the nearby processing facility.
- Identify markets that are within relatively short distances to the facilities for both incoming and outgoing products to limit upstream GHGs emissions related to fossil fuel use.

Appendix

I. U.S. Beef Supply Chain Recommendations Table

Attached in pdf and excel format

Excerpts pasted below

Note that estimates of investment, scientific certainty, and environmental impacts were assessed subjectively by the authors, and do not represent firm quantitative estimates. See the introduction for more detail.

Table I-1 Ranch and Farm Grazing Action Table. Summarizes the processes and results of pursuing the listed actions.

Improvement Pathway	Action	Investment	Current uptake (of improvement opportunity)	Scientific Certainty	Environmental Impact		
					Fresh Water	GHGs	Habitat
Enteric Methane	Manage for increased porportion of native legumes to reduce enteric methane production and enhance soil carbon retention of managed pastures and rangeland where appropriate.	Mod-High	Unknown	Moderate	Low	Moderate	Negligible
Grazing	Convert marginal or unproductive cropland to pasture land	Moderate	Unknown	Moderate	Low	Moderate	Low
	Avoid overgrazing by reducing stock density or changing the timing or frequency of grazing. This can improve the soil condition, which promotes vegetation growth, increases carbon sequestration and retention rates while providing effective forage for cattle.	Moderate	Unknown	Moderate	High	High	High
	Investigate how to scale up the preparation, implementation, and use of adaptive management grazing plans. Consider supporting efforts by the Natural Resources Conservation Service (NRCS) and conservation partners across the country to cost-share Farm Bill Biologist positions to work with landowners to implement priority conservation practices on their lands	High	High	High	Moderate	Moderate	Moderate
	Higher numbers of grazing paddocks in managed pasturelands (not rangelands), determined by total area and rotation periods, provide longer rest periods between grazing bouts.	Mod-High	Unknown	Moderate	Moderate	High	Moderate
Increased quality and quantity of rangeland riparian areas	Encourage producers to pay special attention to conserving riparian areas and wetlands on their ranchlands and to follow recommended grazing management practices in these areas	Low	High	High	High	Negligible	Moderate

Table I-1 Ranch and Farm Grazing Action Table (cont.)

Ground and surface water conservation	Encourage grazing operations to adopt crop and livestock management practices that increase water infiltration and reduce loss run-off i.e. irrigation efficieny, crop and livestock integration, rotational grazing.	Moderate	Unknown	Low	Mod-High	High	Low
Nutrient management, bacteria and pathogen control	Encourage grazing operations to apply practices that spatially distribute cattle throughout the landscape and away from riparian areas i.e. Rotational grazing, riparian fencing and upland water sources. (Key is overall density across ranch over a year, not counter to intensive rotational practices)	Mod-High	Moderate	High	High	Negligible	High
	Encourage grazing operations to adopt water quality best management practices that reduce nutrient, sediment and pathogen runoff, i.e. riparian buffers, riparian fencing and alternative watering points.	Mod-High	Moderate	High	High	Negligible	High
Reduced sediment runoff	Ensure grazing operations maintain stocking densities that are not in excess of land carrying capacity.	Moderate	Unknown	High	High	High	High
Watershed management	Support coordinated watershed management efforts for farms and ranches (Local and regional initiatives, cost sharing, policy development, outreach)	High	Low	Moderate	Mod-High	Negligible	High

Table I-2: Feedlot Action Table. Summarizes the processes and results of pursuing the listed actions.

Improvement Pathway	Action	Investment	Current uptake (of improvement opportunity)	Scientific Certainty	Environmental Impact		
					Fresh Water	GHGs	Habitat
Enteric Methane	Maintain proper storage and moisture content of stored forage to improve digestibility and limit enteric methane production	Mod - High	Moderate	High	Low	High	Negligible
	Use nutrionally high quality grains and forages	High	NA	High	Unknown	Moderate	Varies
Waste Management	Install aerobic digesters at feedlots to reduce GHG emissions, add revenue to the operation via energy production, cut waste management costs, reduce odor, and reduce water quality issues. This will require changes to manure management in most cases.	High	Low	High	Low to moderate	High	Negligible
	Encourage large facilities to lower emission rates over time based on industry statistics. (New EPA regulations require facilities with more than 29,300 head to annually monitor GHG emissions.)	Mod-High	NA	High	Negligible	High	Negligible
Improved rangeland health	Encourage ranchers (and feedlots who source from those producers) geographically located in those areas of the country with degraded rangeland health (e.g., areas in red-orange or red in Figures 17A or figures 3a, 3b, and 3c within Herrick et al. 2010) to implement better management practices	Moderate	Unknown	Low	High	Moderate	Moderate
Reduction in mortality and increased survival of adult and young animals in grasslands	Encourage feedlots and other suppliers to Walmart to source supplemental feed from growers that follow wildlife-friendly practices	Low	Unknown	High	Low	Low	Moderate
Manure management	Source cattle for feedlots from farm/grazing operations with nutrient management plans in place.	Mod-High	NA	High	Moderate	High	Negligible
	Encourage feedlots to adopt sound manure management practices, including safe manure storage to prevent runoff, and applying manure to fields following the "4R philosophy" (apply the right fertilizer source, at the right rate, at the right time, in the right place, TFI 2016).	Mod-High	Unknown	High	High	High	Negligible
	Encourage feedlots to store manure (preferably dry) for longer periods to destroy potential pathogens, prior to spreading.	Mod-High	Unknown	Moderate	High	Varies	Negligible
Reduce nutrient run-off	Feed should be sourced from farms that use efficient irrigation techniques.	High	Low	High	High	Varies	Negligible

Table I-3: Feed Producers Action Table. Summarizes the processes and results of pursuing the listed actions.

Improvement Pathway	Action	Investment	Current uptake (of improvement opportunity)	Scientific Certainty	Environmental Impact		
					Fresh Water	GHGs	Habitat
Reduce water consumed by irrigated feeds.	Encourage farmers and ranchers to reduce water consumption via improved irriigation efficiency methods; optimizing the timing and amount of water application (e.g. drip irrigation) and using early maturing corn varieties	High	Low	Moderate	High	Varies	Negligible
Reduce nutrient run-off	Encourage feed grain and pasture farmers to adopt water quality best management practices that reduce nutrient and sediment runoff i.e. riparian buffers and vegetated treatment systems.	Mod-High	Low- Mod	High	High	Varies	Low
	Encourage feed grain and pasture farmers to improve efficiency of fertilizer and manure use by using practices such as soil testing and timing applications to reduce excess nutrient supply. (e.g. 4Rs Nutrient Management, Continious Improvement under Fieldprint Calculator).	Mod-High	Low- Mod	High	High	High	Negligible
Reduction in rate and amount of loss of native habitats	Source cattle from feedlots and suppliers that in turn only source feed from croplands which have not "recently" been converted from natural habitat (within the last 10 years); avoid sourcing feed from regions of the country experiencing high conversion rates or requiring significant irrigation	Low	Unknown	High	Moderate	Moderate	Moderate
	Implement internal sourcing policies that include provisions similar to "Sodsaver" and "Swampbuster" in the 2014 Farm Bill to prohibit sourcing from crop producers that have broken new ground or that do not implement basic conservation practices across Walmart's supplier network, regardless of geographic area	Moderate	Unknown	Moderate	Moderate	Moderate	Moderate
	Implement a "CRP-like" program to incentivize restoration of wildlife habitats on current croplands, concentrating on geographic areas that supply Walmart harvest facilities, that are subject to high conversion rates, and that have high current enrollment levels in the CRP program; include provisions to extend or renew CRP contracts that have expired or are expiring	Moderate	Low- Mod	High	Moderate	Moderate	High
	Ensure that ranchers who supply feedlots with cattle follow standard NRCS prescribed practices for their local area (including considerations of sensitive species, and particularly for stocking rate), by contacting and applying for Conservation Technical Assistance at their local NRCS office (USDA NRCS), or working with an agricultural extension agent or other qualified technical assistance specialist. This could be accomplished through market incentives and/or internal sourcing policies	Low	Low	Moderate	Low	Moderate	Low
Improved Rangeland Health	Encourage ranchers (and feedlots who source from those producers) geographically located in those areas of the country with degraded rangeland health (e.g., areas in red-orange or red in Figures 17A or figures 3a, 3b, and 3c within Herrick et al. 2010) to implement better management practices	Low	Unknown	Low	Moderate	High	Moderate
Improved value of pastureland as wildlife habitat	Require or incentivize producers who provide cattle for Walmart or its suppliers from pasture to follow standard NRCS prescribed practices for their local area (including considerations of sensitive species, and particularly for stocking rate).	Low	Unknown	Moderate	High	High	Moderate
Reduction in mortality and increased survival of adult and young animals	Encourage hayland operators to follow wildlife-friendly harvesting procedures (see NRCS or appropriate state or regional hayfield management publications), such as delaying first harvest of hay or hay-crop silage to encourage success of ground-nesting birds. Raise the cutting height for hay to improve nesting and brood rearing habitat for birds, as well as the survival of turtles and other small animals	Moderate	Moderate	High	Negligible	Low	High

Table I-4: Harvest Facilities Action Table. Summarizes the processes and results of pursuing the listed actions.

Improvement Pathway	Action	Investment	Current uptake (of improvement opportunity)	Scientific Certainty	Environmental Impact		
					Fresh Water	GHGs	Habitat
Energy consumption	In large combined feed and processing operations look for ways to capture biogas; methane digesters can offset or supplement the energy requirements of the nearby processing facility	High	NA	Moderate	NA	Moderate	Negligible
	Reduce packaging material in product sales	Moderate	NA	High	Low	Moderate	Negligible
Upstream emissions	Source cattle from feedlots that are working to lower emission rates over time based on industry statistics. (New EPA regulations require facilities with more than 29,300 head to annually monitor GHG emissions.)	Mod-High	NA	High	Varies	Moderate	Negligible
	Identify markets that are within relatively short distances to the facilities for incoming product to limit upstream GHGs emissions related to fossil fuel use.	Mod-High	NA	High	NA	Moderate	Negligible
Downstream emissions	Identify markets that are within relatively short distances to the facilities for both incoming and outgoing product to limit upstream GHGs emissions related to fossil fuel use.	Mod-High	NA	High	NA	Moderate	Negligible
Water conservation	Encourage meat packers and processors to adopt and meet industry water conservation guidelines. (eg. Transport waste in solid form after drying, automatic water shut off, etc.)	Mod-High	Moderate	High	Low	Negligible	Negligible
Effluent management	Encourage packers and processors to adopt and meet water conservation measures that reduce the concentration of nutrient and other forms of BOD (biochemical oxygen demand) in waste discharges such as those recommended in by the EPA Industry effluent guidelines.	Mod-High	Mod-high	High	Low	Negligible	Low

Includes slaughter, first level of processing (hide, head, internal organs) to "hot carcass weight" stage

More about efficiency than anything else. Relatively minor opportunities for impact as low hanging fruit is likely already done b.c of cost savings

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The information in this report was designed primarily to be a resource to help prioritize strategies for reducing the environmental impacts in the United Stated beef supply chain. Results are based on a rapid assessment produced from a combination of a thorough literature review and some high level analysis where insufficient data existed. These recommendations are broadly applicable, but are not intended to be a replacement for site-specific knowledge nor a prescription for on-the-ground action. Every commercially reasonable effort has been made to assure the accuracy of the recommended strategies. However, the recommendations being provided herein are intended for informational purposes only. No guarantee is made as to the accuracy of the recommendations and they should not be relied upon for any purpose other than general information.

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*A * before the reference indicates funding by the beef industry, a group opposed to beef production, or a related group.*

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