

**Evans School Policy Analysis and Research (EPAR)**

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**Introduction**

This literature review examines the environmental impacts of buffalo in pastoral and mixed farming systems in developing countries. Even within these two farming systems, the ecological implications of livestock production still vary significantly across countries and regions in Sub-Saharan Africa (SSA) and South Asia (SA). The types and magnitude of the environmental impact of ruminants depends on how much consumption is from grassland grazing, feed crops and feed crop residues.<sup>1</sup> Local climate, soil, and vegetation conditions, however, also determine the severity and pervasiveness of environmental impacts associated with specific livestock species. Decision-maker evaluations of environmental impacts of livestock and resulting mitigation strategies should be site-specific whenever possible.<sup>2,3,4</sup>

The environmental impacts identified in this brief are categorized as being primarily related to either climate change and air pollution, land degradation, biodiversity, or water resources. However, in reality the environmental impacts of livestock do not follow these neat delineations: greenhouse gas emissions which cause climate change, which in turn affects biodiversity; soil degradation also reduces water quality; nitrate and sediment pollution of water resources impacts biodiversity, and so on. In addition, to the extent that the need to feed livestock grain and/or crop residues is a driver of the expansion of crop production in mixed farming systems into lands previously allocated to other uses, the impacts of that land conversion on soil, biodiversity, greenhouse gas emissions and water quality are incorporated in this assessment.

Two types of interventions to mitigate the negative

environmental impacts of livestock and enhance the positive impacts are mentioned in this series of briefs: Biophysical interventions directed at natural resource components of farming systems, and socio-political-economic interventions directed at policies and institutions.<sup>5</sup> Mitigation strategies entail their own risks. For example, increased dietary reliance on crop residues in order to increase the water use efficiency of ruminant livestock may be simultaneously counterproductive to the goal of reducing greenhouse gas emissions because ruminant consumption of residual crop material increases enteric methane production during digestion. Furthermore, technologies or interventions that improve the profitability of cattle or other ruminant rearing can increase the incentives to convert additional lands for grazing or feed production uses.<sup>6</sup>

FAO's Livestock, Environment and Development Initiative team warns that "Increasing herd size generally causes overall increasing (environmental) damages."<sup>7</sup> Most analyses of environmental impacts across livestock types recommend both a reduction in overall meat consumption by those who can nutritionally afford it, and a shift in dietary emphasis from ruminant species (cattle, water buffalo, goats), to monogastric species (poultry).<sup>8,9,10</sup> Compared to ruminants, chickens produce lower carbon dioxide, methane, and nitrous oxide emissions, are a less significant driver of human expansion into natural habitat or of overgrazing, have lower impacts on the water cycle, and cause less destruction of natural habitats.<sup>11</sup> Fewer studies have specifically examined the environmental impacts of water buffalo than the other livestock species included in this series; typically, as in Steinfeld et al. (2006), the environmental impacts of water buffalo are

NOTE: The findings and conclusions contained within this material are those of the authors and do not necessarily reflect positions or policies of the Bill & Melinda Gates Foundation.

incorporated into discussions of cattle, without more detailed impacts being broken down by bovine type. In Asia and India, where the majority of buffalo are raised, buffalo are typically kept in small herds of only a few animals, which may minimize the local impacts of their grazing on vegetation, soil erosion and water pollution.<sup>12</sup>

The briefs included in this “environmental implications of livestock” series (EPAR briefs 155-158) contain context-providing sections entitled “general livestock impacts” for each category of environmental analysis. These general livestock sections are identical across briefs in the series, thus readers who have previously read other briefs in the series may choose to read only the sections on species-specific impacts and the sections on mitigation strategies in the present brief, denoted with an “\*\*” *Appendix 1* contains a summary of the environmental impacts and benefits of each livestock species examined in this series.

### **Climate Change and Air Pollution**

#### *Climate Change: General Livestock Impacts*

As a group, livestock-derived foods are more greenhouse gas intensive to produce than crops, with the greatest impacts coming from direct farming activities rather than processing and transport to market.<sup>13</sup> A seminal analysis by the FAO’s Steinfeld et al. (2006) estimated that livestock are responsible for 18% of global anthropogenic greenhouse gas emissions.<sup>1</sup> Globally, 25% of all greenhouse gas emissions associated with livestock production is attributable to methane emissions from ruminant digestion and manure, 31% is attributable to nitrous oxide from manure and manure management, and 32% is attributable to land use and land use changes.<sup>14</sup> The remaining 12% stems mainly from emissions associated with animal processing and transport.

Methane is a potent greenhouse gas with a global warming potency of more than 20 times that of a similar amount of carbon dioxide.<sup>15</sup> Ruminants, including bovines, goats and sheep, emit a greater amount of methane during their digestive process than do monogastrics (e.g., chickens and pigs).<sup>16</sup> Meanwhile nitrous oxide emissions, whose primary

source is manure management, have more than 300 times the global warming potential of carbon dioxide.<sup>17</sup> Both nitrous oxide and methane may be formed from manure decomposition in anaerobic environments, and specific emission levels depend on how manure is collected, stored and spread, and whether the local climate is arid or humid.<sup>18</sup>

Meanwhile the conversion of forestland to cropland or pastureland contributes to global warming in several ways.<sup>19</sup> First, the land conversion process is frequently accomplished by the burning of forestland, which immediately releases stored carbon dioxide<sup>20</sup> while also limiting the land’s long-term carbon storage capacity (since forests have a greater carbon sequestration ability than pasture or croplands)<sup>21</sup> Second, the expansion of agricultural systems into forestland increases the number of livestock raised there, and thus increases greenhouse gas emissions from digestion and manure.<sup>22</sup> Heavy livestock grazing on pastureland further reduces soil carbon: in a study in Argentina, soil organic carbon decreased 25-80% in areas subjected to overgrazing.<sup>23</sup> However, to the extent that continued pastoral grazing helps preserve the 27% of the world’s carbon stocks currently in natural grasslands from conversion to other land uses, grazing activities could in theory contribute to carbon sequestration.<sup>24</sup>

In addition to the emissions associated with feed production and land conversion, the post-slaughter livestock processing of each species entails substantial energy consumption, although the amounts reported across studies vary widely.<sup>25</sup> The degradation of unused byproducts of carcass processing, such as intestines, also produces methane.

Monogastric species such as poultry and pigs are more efficient converters of plant energy into animal food products (meat, eggs and dairy) than are ruminants.<sup>26</sup> However, several counterarguments may reduce the gap in production efficiency vis-à-vis greenhouse gas emissions between ruminants and poultry. First, poultry require a more grain intensive diet than ruminants, which raises the opportunity costs of their feed consumption above ruminants.<sup>27</sup> The opportunity costs of livestock consuming grain are high both because it decreases the

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<sup>1</sup> Building upon the work of Steinfeld et al. (2006), a second estimate by Goodland & Anhang (2009) placed the overall contribution of livestock to anthropogenic greenhouse gas emissions at 51%. However, this estimate relied upon a somewhat controversial methodology, and has not been as widely-cited as the estimate of Steinfeld et al.

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<sup>2</sup> Likewise, the conversion of pastureland to cropland can entail significant reductions in the land’s carbon sequestration ability: 95% of aboveground carbon and 50% of soil carbon may be lost during conversion. (Reid et al., (2004), p. 99).

availability of grains for human consumption, and it reduces the availability of the land used to grow the grain to other uses. Second, draft animals such as cattle and water buffalo can plow fields and thereby increase crop production efficiency<sup>28,29</sup> while limiting the need for tractors or other machinery powered by greenhouse emissions-intensive fuel (although this drafting function also makes it easier to convert land to agricultural uses).<sup>30</sup> Third, when cattle eat crop residues which would have otherwise been burned, they reduce the greenhouse gas emissions and other air pollution which would have been produced from the burning.<sup>31</sup>

*\*\*Climate Change: Buffalo-and Ruminant-Specific Impacts:*

Our literature review did not encounter any estimates of water buffalo production efficiency vis-à-vis greenhouse gas emissions that were specific to livestock raised in pastoral or mixed rain fed agricultural systems<sup>3</sup>.

A study cited by Thorpe (2009) estimated that buffalo emit between 56 to 77 kilograms per animal per year, slightly more enteric methane during digestion than range cattle.<sup>4</sup> However, the IPCC estimates water buffalo enteric fermentation methane emissions at 55 kilograms per animal per year, similar to cattle which produce 46-58 kilograms of methane per animal per year.<sup>32</sup> In addition, the IPCC estimates that in India, buffalo manure produces an additional 4-5 kilograms of methane emissions per animal per year, as compared to 5-6kg per animal per year for dairy cows.<sup>33</sup> Buffalo are estimated to excrete 0.32 kg of nitrogen annually per animal in Africa and Asia, of which between 30 and 45% may volatilize in the form of ammonia, nitrogen oxides, nitrous oxide and nitrogen gas.<sup>5,34</sup> By comparison, dairy cattle are estimated to excrete

0.47 kg of nitrogen annually per animal in Africa and 0.60 kg in Asia, of which between 22 and 40% volatilizes<sup>35</sup> causing additional greenhouse gas emissions, as well as land degradation and water pollution.

Some aspects of buffalo feeding and life cycle patterns help illuminate why their greenhouse gas emissions might differ from that of cattle. Buffalo can fatten on a wide range of grasses, including less digestible feeds that are difficult for other bovines to obtain energy from.<sup>36,37</sup> In the Brazilian Amazonian lowlands, buffalo are significantly more productive than cattle, reaching market size in 28 months in comparison to 38 months, while having a heavier slaughter weight, which may reduce the per-kilogram-meat methane emissions from buffalo from birth to slaughter.<sup>38</sup> Buffalo are also reported to fare better than cattle during the transition from dry to wet seasons in the Brazilian Amazon lowlands, where buffalo production has recently experienced significant growth.<sup>39</sup> Buffalo are more resistant to bovine diseases in the Amazon floodplains (increasing efficiency by reducing loss to illness and mortality).<sup>40</sup> Buffalo can also graze more efficiently and longer under flooded conditions than cattle, which makes their fattening more profitable under adverse conditions.<sup>41</sup>

The relative greenhouse gas inefficiency of developing region buffalo and cattle production may be partially explained by two phenomenon: (1) Pasture-raised livestock may emit from three to 3.5 times the amount of methane as intensively raised livestock due to the lower digestibility of their feed.<sup>42, 43, 44</sup> In one study from Australia, cattle grazing on pasture converted 7.7-8.4% of the energy of their food consumption into methane, compared to converting 1.9-2.2% of feed energy into methane when the same cattle were fed a digestible grain-intensive diet.<sup>6,45</sup> (2) In resource-constrained farming systems, a large proportion of feed is often spent on minimal maintenance, and not on generating products (beef, dairy) or services useful to humans, which makes their resource intake inefficient.<sup>46,47</sup> Overall, dairy systems which combine milk and meat production are more efficient in terms of greenhouse gas emissions per unit of output than systems which produce beef alone.<sup>48</sup>

*Other Air Pollution: General Livestock Impacts*

The volatilization and release of nitrogen from animal

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<sup>6</sup> In general, cattle may lose anywhere from 2 to 12% of ingested energy to methane production.

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<sup>3</sup> The majority of life cycle assessments (LCAs) of livestock-derived food products have focused on intensive agricultural food systems in OECD countries (De Vries & Boer (2010), p. 3). Since industrial systems differ considerably in their environmental impacts from extensive grazing and mixed rain-fed livestock production, those more-comprehensive assessments are not reported here.

<sup>4</sup> 56 kilograms of methane has a global warming potential equivalent to over 1120kg, or 1.12 metric tons of carbon dioxide. As a frame of reference, the combustion of one gallon of gasoline is also estimated to emit 2.4kg of carbon dioxide (EPA 2005).

<sup>5</sup> Estimates of N volatilization depend on manure management systems in place. Estimates exclude emissions from anaerobic lagoon systems, which have substantially higher Nitrogen volatilization rates than do other manure management systems.

production (including crop fertilizers) and processing byproduct (including manure) can also impact air quality.<sup>49</sup> The volatilization of nitrogen leads to the production of ozone and aerosols in the troposphere that can cause respiratory illness, cancer and cardiac disease.<sup>50</sup> Local air quality is also affected by livestock production when people burn forests to convert land to agricultural uses.

#### *\*\*Other Air Pollution: Buffalo and Ruminant-Specific Impacts*

The burning of buffalo dung for fuel lowers local air quality, and reduces the recycling of fertilizing nutrients to the soil.<sup>51</sup> Disposal of dead animals may pose air pollution risks if incinerated.<sup>52</sup>

#### *\*\*Mitigation Strategies*

Garnett (2009) categorizes attempts to mitigate the greenhouse gas emissions from livestock into four approaches: (1) improve productivity (2) change management systems (3) manage waste outputs and (4) reduce livestock numbers.<sup>53</sup> Specific suggestions encountered in the literature include the following:

- *Reduce ruminant methane emissions by improving diets* (feed additives and supplements, such as cereal grains and oilseeds).<sup>54</sup> The greatest potential for methane reductions occurred in districts with the poorest livestock feed.<sup>55</sup> However, producing the grain supplements can produce other greenhouse gas emissions that offset these benefits.
- *Make genetic improvements through selective breeding or engineering to render ruminant digestive processes more efficient and less methane-emission intensive.*<sup>56,57</sup> Breeding options include: selecting among or within breeds, selecting large and fast-growing breeds, and manipulating dietary requirements.<sup>58</sup> Genetic improvement options include increasing efficiency and productivity from nutrient and resource inputs, reducing wastage due to disease, death and wasted reproductive cycles, and selection of low-methane emissions traits or breeds.<sup>59</sup> Reduced methane production is usually also associated with increased milk and meat productivity.<sup>60</sup>
- *Encourage households to maintain fewer, but better-quality, more productive animals.*<sup>61</sup>
- *Develop or utilize digestive microorganisms* that help break down feed into amino acids and nutrients more

efficiently and completely.<sup>62</sup>

- *Manage soil nutrients* through a climate and soil-appropriate combination of inorganic fertilizer, mulching, crop residue and manure to sequester carbon and also boost yields.<sup>63</sup>
- *Use buffalo instead of tractors* for field plowing, which reduces fossil fuel use.<sup>64</sup>
- *Convert methane and other biogases* recovered from anaerobic digestion of manure into electricity through the use of small-scale digesters.<sup>65</sup>
- *Manage manure to minimize methane and nitrous oxide emissions* from decomposition.<sup>66</sup>
- *Increase vegetative cover*, and employ other land management strategies that increase the carbon sequestration ability of grazing and feed production lands, or which slow the release of stored carbon via respiration, erosion and fire.<sup>67,68</sup> Adopting conservation tillage practices can sequester between 0.1 and 1.3 tons of carbon per hectare per year.<sup>69</sup>
- *Develop dual food/feed crops for mixed rain-fed systems* that reduce methane emissions per unit of feed intake.<sup>70</sup> An example of this type of modification would be to increase the digestibility of maize stover.
- *Reduce the number of sick and unproductive animals* by improving animal nutrition and health.<sup>71</sup>
- *Increase use of artificial insemination*, which reduces the numbers of bulls required to maintain herds and increases dairy production efficiency.<sup>72</sup>
- *Manage grazing* to reduce methane production by encouraging cattle to consume younger, more easily digestible forage.<sup>73</sup>

## **Land Degradation**

### *General Livestock Impacts*

Livestock grazing and trampling have marked effects on vegetative cover, soil quality and nutrient loss due to erosion. Evidence of this impact is found in the 10-20 percent of grasslands worldwide that are degraded due to

overgrazing.<sup>74</sup> Overgrazing of pastureland causes soil erosion and releases carbon from decaying organic matter, compacts wet soils and disrupts dry soils. The effects of trampling depend on soil type.<sup>75</sup> Desertification due to overgrazing causes a loss of 8-12 tons of carbon per hectare from soils and 10-16 tons of carbon in above-ground vegetation.<sup>76</sup> In mixed farm systems, land tillage and crop production further compound the loss of native vegetative cover and leads to soil erosion, while soil compaction and soil disruption result in increased runoff and erosion.<sup>77</sup>

#### **\*\*Buffalo-and Ruminant-Specific Impacts**

Like range cattle, buffalo grazing removes vegetation, and frequent trampling can cause trails and wallows to form.<sup>78</sup> Trampling and land degradation may be most severe around water sources during dry seasons.<sup>79</sup>

Nonetheless, buffalo can contribute to nutrient and resource cycling in farming systems. First, their manure is good fertilizer, with a low risk of over-fertilization and positive benefits for soil structure.<sup>80</sup> Soil fertilized with manure has been found to be more fertile and biologically active than soil fertilized with mineral fertilizer alone.<sup>81</sup> Second, grazing animals like buffalo can provide positive ecosystem benefits and improve plant species composition by removing biomass that could fuel fires, by controlling vegetative growth, and by dispersing seeds.<sup>82</sup> Third, ruminant consumption of crop residues allows for a more complete utilization of the biomass grown on agricultural plots, and converts inedible vegetation into human food.<sup>83,84</sup> However, when fed grains that could otherwise be consumed by humans, buffalo reduce food efficiency and increase land converted to produce crops: In general, across livestock species raised for meat production, the ratio of the weight of grain fed relative to the weight of meat produced is generally about three to one, and the ratio of the weight of grain fed to the weight of milk produced is about one to one.<sup>85</sup>

#### **\*\*Mitigation Strategies**

- *Engage in nutrient management strategies* that encompass: (1) effective nutrient cycling between plants, soil and animals, (2) improved plant and animal nutrient retention and efficiency, (3) alternative uses of grazing land and (4) multi-use buffers on grazing or cropland periphery.<sup>86</sup>

- *Increase reliance on forage legumes* as a supplement to ruminant diets heavy in crop residue and grasses. Legume consumption shifts nitrogen excretion from urine to feces, which results in less nitrogen manure volatilizing and being lost as water effluent, and more nitrogen being returned to fertilize the soil.<sup>87</sup>
- *Decrease animal morbidity and mortality.*<sup>88,89</sup> Unproductive or unusable livestock represent an investment of feed with low or no output, and producing feed (or grazing of land) is inextricably linked with some degree of land degradation.
- *Implement crop rotation and fallowing of feed crop fields* to increase water retention and decrease nutrient losses, which reduces the variability of maize yields and lessens farmer risks.<sup>90</sup> Cover crops should be planted immediately after crop harvest.<sup>91</sup>
- *Decrease stocking density* to levels appropriate to local biomass and water resource capacity.<sup>92</sup>
- *Remove grazing from marginal areas* and concentrate it in productive areas where ecosystem resilience and degradation resistance is greatest.<sup>93</sup>
- *Support and clearly delineate grazing land and water resource management regimes through local institutions.*<sup>94</sup> Clarify government expectations and penalties for management of communal land, and what resources (i.e. timber, water, and vegetation) can be utilized and extracted and at what times.<sup>95</sup>
- *Minimize animal stress* through brooding, ventilation and healthcare to improve their weight gain and feed efficiency, and thereby lower grain demand and associated land conversion pressures.<sup>96</sup>

## **Biodiversity**

### *General Livestock Impacts*

Converting forests and grasslands for agricultural uses (for direct livestock grazing or feed production) are considered by some to be a paramount threat to biodiversity.<sup>97,98</sup> Biodiversity also may decrease with agricultural intensification, including pesticide application, eliminating wildlife corridors and space between plantings, and displacing traditional crop varieties in favor of uniform

improved varieties.<sup>99</sup> In developing countries, an estimated 40% of threats to bird species are attributable to agricultural changes, including land conversion and intensification.<sup>100</sup> Habitat fragmentation exacerbates the negative effects of this land conversion on biodiversity by reducing natural habitat below levels needed to maintain species key to continued ecosystem functioning.<sup>101,102</sup>

Livestock-induced damage to water resources, described in more detail in the section below, is also a significant threat to aquatic biodiversity.<sup>103</sup> Livestock biodiversity itself also declines when farmers adopt commercial livestock breeds with superior production under controlled living conditions.<sup>104</sup> Another indirect pressure occurs through a livestock system's contributions to climate change, which is expected to have negative implications for biodiversity.<sup>105</sup> Invasive alien species which accompany livestock, including parasites, pathogens and plant seeds dispersed in feces, also pose the potential to interrupt natural ecosystems and negatively impact biodiversity.<sup>106</sup>

One positive effect of livestock production for biodiversity is that consuming livestock may reduce pressure to consume endangered meat sources such as bush meat.<sup>107</sup>

#### *\*\*Buffalo-and Ruminant-Specific Impacts*

Intensive grazing activities reduce native plant populations and vegetative canopy and render land susceptible to desertification, which stimulates further biodiversity loss.<sup>108</sup> Concentrated and persistent grazing in an area can lead less-palatable woody shrubs and trees (left behind by grazing cattle) to out-compete more nutritious feed sources.<sup>109</sup> Grazing also alters plant biomass production, reducing root biomass and increasing foliage biomass, which can reduce plant survival during environmental stresses such as droughts.<sup>110</sup> Furthermore, in some areas native grassland species may be plowed under and replaced with introduced exotic pasture vegetation.<sup>111</sup>

Conflict between livestock herders and wildlife also has negative consequences for biodiversity when herders kill or restrict the range of predators such as lions, cheetahs, wild dogs, hyenas and leopards in order to protect their stock.<sup>112</sup> Livestock and wildlife may also compete for scarce water resources,<sup>113</sup> with livestock tending to drive wildlife away from watering points during daylight.<sup>114</sup>

Water buffalo grazing preferences may produce selection pressures against palatable high-protein grasses.<sup>115</sup> Water

buffalo also consume floating vegetation in riparian environments that are not easily accessible to cattle.<sup>116</sup> By changing vegetation structure where they graze, the presence of buffalo provides an advantage to some species and disadvantage to others.<sup>117</sup>

#### *\*\*Mitigation Strategies*

McNeely & Scherr (2003) provide six categories of recommendations for reducing the impact of agriculture on biodiversity: “(1) create biodiversity reserves that also benefit local farming communities; (2) develop habitat networks in non-farmed areas; (3) Reduce (or reverse) conversion of wild lands to agriculture by increasing farm productivity; (4) minimize agricultural pollution; (5) Modify management of soil, water, and vegetation resources and (6) Modify farming systems to mimic natural ecosystems.”<sup>118</sup> The authors rank intervention types (1), (2), (5) and (6) as having the greatest potential benefits to biodiversity in pastoral and ranching systems, and intervention types (4) and (5) as the most beneficial in rain-fed crop systems.<sup>119</sup> Specific strategies include:

- *Mitigate the environmental problems caused by livestock which indirectly reduce biodiversity:* decrease pressures on climate change, water resources, land conversion and desertification.<sup>120</sup>
- *Expand grazing in specifically designated areas* to maintain ecologically valuable landscapes to wildlife.<sup>121</sup>
- *Intensify crop feed production* to reduce pressures on natural land and habitat, while minimizing the externalities of that crop production.<sup>122</sup>
- *Establish and retain wind breaks, hedgerows and woodlots* within agricultural lands.<sup>123</sup>
- *Engage local farmers in ecosystem management planning* in order to benefit from local knowledge of traditional farming practices and currently-pressing environmental problems, as well as to increase farmer participation in impact mitigation strategies.<sup>124</sup>
- *Use extension professionals* to communicate locally-appropriate strategies to improve agriculture and biodiversity.<sup>125</sup>

#### **Water Resources**

## *General Livestock Impacts*

Livestock affects water resources and produces environmental impacts through two channels: (1) The quantity of often scarce water resources required to grow feed crops and sustain livestock animals, and (2) the wastewater created and other water resources degraded by livestock feeding, servicing and processing.<sup>126</sup> Water quality problems can stem from land degradation. Reactive nitrogen and other nutrients lost from soil into water bodies can cause nitrification and eutrophication.<sup>127</sup> Direct deposition of fecal material and runoff of applied fertilizers and wastes reduces water quality.<sup>128</sup>

Slaughterhouses which directly discharge wastes into water bodies can lower dissolved oxygen to toxic levels.<sup>129</sup>

The amount of water directly consumed by livestock is dwarfed by the water requirements of their feed crops: 50 to 100 times as much water is required to grow livestock feed crops as is needed to sustain the animals themselves.<sup>130</sup> However, in grazing and mixed farming systems in SSA where native vegetation and crop residues are a major feed component, little or no additional water is allocated to meet feed requirements.<sup>131</sup> In general, the more grain-intensive the livestock feed, the more water-intensive the livestock production.<sup>132</sup>

## *\*\*Buffalo-Specific Impacts*

In addition to requiring large volumes of water as production inputs, buffalo reduce water resource quality in several ways. The processing of one pound of red meat can produce wastewater so high in dissolved oxygen that it would need to be diluted into 200,000 liters of water in order to meet EU standards for wastewater effluent.<sup>133</sup>

The tanning of hides also produces wastewater containing chemical toxins such as chromium, which are harmful to humans and wildlife.<sup>134</sup> Between 6 and 15 liters of water inputs per kilogram of carcass are used during the slaughter and processing of buffalo.<sup>135</sup>

Like cattle, buffalo submerge themselves in available water to cool themselves when the air temperature is high.<sup>136</sup> The presence of water buffalo in freshwater areas was reported by local fisherman to drive fish away, and resulted in lower fish catches.<sup>137</sup>

In Australia, feral water buffalo have been reported to accelerate soil erosion, channel floodwaters, and remove vegetative cover.<sup>138</sup> Water buffalo grazing breaks up

floating vegetation mats, altering the hydrological flow of waterways and allowing for salt-water intrusions.

## *\*\*Mitigation Strategies*

### *Interventions to improve the efficiency of water used by buffalo:*

- *Increase transpiration of feed crops and decrease evaporation.*<sup>139,140</sup> Strategic choices of water-efficient feed crops, including agricultural crop residues, can increase the productive efficiency of livestock water use.<sup>141</sup> However, agricultural crop residues may have less nutritional value for livestock, and residue consumption by livestock produces methane emissions and reduces soil quality if the residues would otherwise be deposited on fields.<sup>142</sup>
- *Strategically provide drinking water to animals to minimize buffalo movement,* lessening water resource degradation and restricting them to suitable grazing areas.<sup>143</sup>
- *Designate conservation areas* where livestock grazing is only permitted during times of need.<sup>144</sup> Protection of vegetation against grazing pressures increases biomass production (which increases carbon dioxide absorption), reduces evaporation and runoff, and increases transpiration.<sup>145</sup>
- *Improve rainwater harvesting* to reduce livestock walking.
- *Leave small scattered trees* planted upland in pastures in order to reduce erosion while also providing shade to keep buffalo cool without submersing themselves in local water sources.<sup>146</sup>
- *Engage in agroforestry.* The use of fodder trees and forage legumes can create favorable microclimates which reduce erosion and improve transpiration, soil structure and soil fertility. Agroforestry also enables the production of livestock-consumable biomass from water resources.<sup>147</sup>

### *Interventions to mitigate water resource degradation:*

- *Improve planting methods* including raised beds, and minimized tillage in feed crop production.
- *Balance cattle feed* between degradable and non-degradable proteins to reduce nitrogen excretion.<sup>148</sup>

- *Contain and store manure* to minimize runoff into water bodies and to reapply nutrients within the farming system.<sup>149</sup>
- *Control grazing intensity and frequency* to improve vegetation cover, reduce soil erosion, and improve water quality.<sup>150</sup>
- *Leave small scattered trees* planted upland in pastures to provide shade and keep cattle cool without requiring them to submerge in local water sources.<sup>151</sup>
- *Employ grade stabilization* along stream banks and create hardened water access sites for cattle to reduce bank sediment erosion.<sup>152</sup>
- *Reduce the amount of time spent by cattle near water points* to reduce soil erosion and direct fecal loading.<sup>153</sup> Rotate feeding stations and portable water sources to reduce soil compaction from trampling.<sup>154</sup> Locate temporary cattle enclosures further than 60 meters from waterways.<sup>155</sup> If relocating farm infrastructure is impossible, planting of vegetation to trap sediment and other biological filtration methods can reduce waterway pollution.<sup>156</sup>
- *Establish conservation buffers* around riparian areas in order to reduce sediment loads and erosion by slowing water velocity, stabilizing banks with plant roots, and facilitating plant absorption of soluble materials.<sup>157</sup>
- *Modernize slaughterhouses* to reduce animal waste polluting local waters from carcass processing.<sup>158</sup>

### Methodology:

This literature review was conducted using databases and search engines including University of Washington Library, Google Scholar and Google, as well as the following websites: IFPRI, ILRI, WRI, IWMI, African Development Bank, World Bank, UNFAO, UNEP, Millennium Ecosystem Assessment and IPCC. Searches used combinations of the following terms: environment, environmental, environmental impacts, developing world, Sub-Saharan Africa, rain-fed agriculture, grazing, pastoral, emissions, biodiversity, water, water resources, water quality, soil, land, livestock, species comparison, cattle, cows, buffalo, water buffalo, chickens, poultry, beef, goats, bovine, natural resource use, feed conversion efficiency,

livestock water productivity, ecological footprint, life cycle assessment, climate change, global warming, air pollution smallholder, sustainability. The methodology also included searching for sources that were identified as central works and examining relevant lists of works cited. This literature review draws upon over 50 cited sources, and relied in equal parts on peer-reviewed publications and publications from major international organizations, especially FAO, ILRI and IFPRI.

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*Appendix 1: Comparison of Livestock Impacts (where available)*

<b>Environmental</b>	<b>Extent of Negative Environmental Impacts</b>	<b>Expert Rankings</b>	<b>Environmental Benefits</b>
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<b>Impact</b>		<b>by Livestock</b>	
<b>Greenhouse Gas Emissions</b>	<p><u>Cattle</u>: 46-58 kg/methane/head/yr from enteric fermentation for Indian/African dairy cows; 27-31 kg/methane/head/yr for other cattle. 5-6kg methane/head/year from manure.</p> <p><u>Goats</u>: 5kg methane/animal/yr from enteric fermentation. 0.11-0.22kg/methane/head/yr from manure decomposition.</p> <p><u>Chickens</u>: No methane emissions from enteric fermentation. 0.02kg/head/year from manure.</p> <p><u>Water Buffalo</u>: 55-77 kg/methane/head/yr from enteric fermentation. 4-5kg methane/head/year from manure.</p>	<p><i>Cattle</i> and/or <i>Buffalo</i> have greatest lifecycle greenhouse gas emissions, <i>chickens</i> have lowest emissions.</p>	<p>Livestock consumption of crop residues reduces alternative burning of biomass. <i>Cattle &amp; Buffalo</i> can replace draft and farm machinery emissions.</p>
<b>Manure Management and Nitrogen Retention</b>	<p><i>Cattle</i>: 0.34-0.63kg/head/year N excretion, 22-50% volatilization rate.</p> <p><i>Goats</i>: 1.37 kg/head/yr N excretion, 15-35% N volatilization rate.</p> <p><i>Chickens</i>: 0.6-1.1 kg/head/yr N excretion, 50-55% N volatilization rate.</p> <p><i>Water Buffalo</i>: 0.32kg/head/year N excretion, 30-45% volatilization rate.</p>	-	<p>Proper manure management fertilizes soils.</p>
<b>Feed Conversion</b>	<p><i>Cattle</i>: 7kg grain/1kg meat.</p> <p><i>Chickens</i>: 2 kg/grain/1kg meat or eggs.</p>	<p><i>Chickens</i> most efficient.</p>	-
<b>Land Degradation</b>	-	<p><i>Goat</i> grazing most damaging, followed closely by <i>cattle/water buffalo</i>; <i>chickens</i> least damaging. <i>Cattle</i> drive most land conversion.</p>	<p>Grazing removes fire-inducing biomass, disperses seeds. Manure fertilizes soil. Retention of grazing lands prevents conversion to more-damaging land uses.</p>
<b>Biodiversity</b>	-	-	<p>Grazing can provide habitat and increase species diversity in ecosystems adapted to frequent grazing. Livestock production reduces bush meat consumption.</p>
<b>Livestock-Water Productivity</b>	<p><i>Cattle</i>: 0.082kg meat/1000 L water.</p> <p><i>Goats</i>: 0.118kg meat/1000 L water.</p> <p><i>Chickens</i>: 0.22-0.51kg meat/1000 L water</p>	-	-
<b>Water Quality</b>	-	<p><i>Buffalo</i> spend most time in water bodies, <i>cattle</i> and <i>goat</i> grazing also causes water quality impairment.</p>	-

Endnotes

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  - <sup>11</sup> FAO (2009), p. 74
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  - <sup>14</sup> Hererro & Thornton (2009), p. 1
  - <sup>15</sup> Nicholson et al. (2001) p. 14
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  - <sup>32</sup> Thorpe (2009), p. 414
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  - <sup>34</sup> IPCC (2006), p.59, 67
  - <sup>35</sup> IPCC (2006), p.59, 67
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  - <sup>40</sup> Sheikh et al. (2006), p. 318
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  - <sup>42</sup> Goodland (2010), p. 9
  - <sup>43</sup> Reid et al. (2003), p.97
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  - <sup>48</sup> Gerber et al. (2010b). p. 53
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  - <sup>51</sup> Ehui & Pender (2005), p. 237
  - <sup>52</sup> Delgado et al. (2008), p.63
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<sup>68</sup> Thornton & Gerber (2010) p. 176  
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<sup>72</sup> Reid et al. (2004), p. 104  
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<sup>93</sup> Asner & Archer (2010) p. 78  
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