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2 Feed Resources vis-à-vis Livestock and Fish Productivity in a Changing Climate

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Abstract

Globally, livestock contributes 40% to agricultural gross domestic product (GDP), employs more than 1 billion people and creates livelihoods for more than 1 billion poor. From a nutritional standpoint, livestock contributes about 30% of the protein in human diets globally and more than 50% in developed countries. Aquaculture accounts for nearly 50% of global seafood production and employs more than 100 million people. As outlined in the livestock revolution scenario, consumption of animal-sourced food (ASF) will increase substantially, particularly in the so-called developing countries in response to urbanization and rising incomes, offering opportunities and income for smallholder producers and even the landless, thereby providing pathways out of poverty. It is important to recognize that the increasing demand for ASF pertains to ruminants (meat and milk), monogastrics (broilers, eggs and pork) and aquatic animals such as fish. To put it differently, much more animal feed will be needed for all domestic livestock and farmed aquatic animals in the future. Competition for feed among livestock and fish species will increase, in addition to competition with human food production and biomass needs for biofuels and soil health, unless we see significant levels of intensification of ASF production, and in ways that are environmentally sustainable. Animal source food production globally already faces increasing pressure because of negative environmental implications, particularly because of greenhouse gas emissions. As livestock and aquaculture are important sources of livelihood, it is necessary to find suitable solutions to convert these industries into economically viable enterprises, while reducing the ill effects of global warming. In relation to climate change, ASFs will have to play a dual role: one of mitigation and the other of adaptation.

The most evident and important effects of climate change on livestock production will be mediated through changes in feed resources. The main pathways in which climate change can affect the availability of feed resources for livestock – land-use and -systems changes, changes in the primary productivity of crops, forages and rangelands, changes in species composition and changes in the quality of plant material

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– will be discussed in the chapter. The chapter will propose an environmentally friendly development of livestock production systems, where increased production will be met by increased efficiency of production and not through increased animal numbers. For aquaculture, the focus will be on better sourcing of feedstuffs and on-farm feed management. Feeding strategies that increase the efficiency of production by producing more from fewer livestock animals and less feed will result in reduced greenhouse gas emissions. This will be demonstrated by analysing livestock populations in India and their respective level of productivity. Thus, in India in 2005/06, the daily milk yield of cross-bred, local cows and buffalo averaged 3.61 l, resulting in a ratio of feed metabolizable energy (ME) for maintenance and production of 2.2 to 1. By increasing daily milk production in a herd model (of a mixed cross-bred, local cow, buffalo population) from 3.61 to 15 l day^{-1}, energy expended for maintenance becomes 1:1.91. As a result, the same amount of milk can be produced by fewer livestock, leading to a reduction in emissions of methane of more than 1 million tonne (Mt) year^{-1}.

2.1 Introduction

2.1.1 Livestock: the good and the bad

Globally, livestock contributes 40% to agricultural gross domestic product (GDP), employs more than 1 billion people and creates livelihoods for more than 1 billion poor (Steinfeld *et al*., 2006). From a nutritional standpoint, livestock contributes about 30% of the protein in human diets globally, and more than 50% in developed countries. Moreover, livestock helps many farm households diversify livelihoods and reduce risks, particularly when crops fail. The relationships between livestock and the environment are complex, and appear to be viewed very differently in developed and developing country perspectives. The Food and Agriculture Organization report, *Livestock's Long Shadow*, focused on the effects of livestock on the environment (Steinfeld *et al*., 2006). The climate change impacts of livestock production (calculated in Steinfeld *et al*. (2006) at 18% of the total global greenhouse gas (GHG) emissions from human sources) have been widely highlighted, particularly those associated with rapidly expanding industrial livestock operations in Asia. Hall *et al*. (2011) estimate that 1% of GHG emissions, equivalent to 6–7% of agricultural GHG emissions, come from aquaculture. Global estimation also shows that livestock uses 30% of land, 70% of agricultural land and is an important agent of land degradation, deforestation, N and P in water supplies. Yet, in smallholder crop–livestock and agropastoral and pastoral livestock systems, livestock are one of a limited number of broad-based options to increase incomes and sustain the livelihoods of an estimated 1 billion people globally who have a limited environmental footprint. Livestock are particularly important for increasing the resilience of vulnerable poor people subject to climatic, market and disease shocks through diversifying risk and increasing assets. Given that almost all human activity is associated with GHG emissions, those from livestock and fish in these systems are relatively modest when compared to the contribution that livestock and farmed fish make to the livelihoods of this large number of people. The complex balancing act of resource use, GHG emissions and livelihoods is almost certain to get more rather than less complicated, because of the so-called livestock and blue revolutions.

As outlined in both the livestock revolution and recent fish production scenarios (Delgado *et al*., 1999; World Bank, 2013), the consumption of animal-sourced foods (ASFs) will rise in developing and emerging countries. Current and recommended future meat consumption patterns are summarized in Table 2.1. While the increasing demand for livestock products offers market opportunities and income for smallholder producers and even the landless, thereby providing pathways out of poverty (Kristjanson, 2009), livestock production globally faces increasing pressure because of negative environmental implications,

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Table 2.1. Current daily meat consumption and convergent meat consumption levels recommended for 2050. (Data modified from McMichael *et al.*, 2007.)

Country/category	Current consumption	Recommended consumption
Developed countries	224 g day^{-1}	↓
Latin America	147 g day^{-1}	
		90[a] g day^{-1} or 20 g day^{-1} animal protein[b]
Developing countries	47 g day^{-1}	↑
Africa	31 g day^{-1}	

Notes: [a]A maximum of 50% of red meat; [b]equals on a yearly basis either: (i) 45 kg of fish; (ii) 60 kg of eggs; (iii) 230 kg of milk.

particularly because of GHG emissions (Steinfeld *et al.*, 2006). Besides GHGs, the high water requirement in livestock production is a major concern. As livestock is an important source of livelihood, it is necessary to find suitable solutions to convert this industry into an economically viable enterprise, while reducing the ill effects of global warming. In relation to climate change, livestock will have to play a dual role: one of mitigation and the other of adaptation.

By taking the livestock population and its current level of productivity in India, this chapter proposes a possible option that can address the issues associated with livestock–livelihood and livestock and the environment.

2.2 Climate Change on Key Livestock Systems Components Other Than Feed

2.2.1 Livestock genetics and breeding

Traditionally, the selection of animals in tropical breeds has been an adaptive one, but in recent times, market pull has stimulated a rapidly changing demand for higher production that could not be met quickly enough by breed improvement of indigenous animals. Widespread cross-breeding of animals, mostly with 'improver' breeds from temperate regions crossed with local animals, has occurred, often with poor results. Little systematic study has been conducted on matching genetic resources to different farming and market chain systems from already adapted and higher-producing tropical breeds. However, given the even greater climatic variability and stresses anticipated, this is a logical response to the adaptive challenges that will be faced. The greatest role for using the adaptive traits of indigenous animal genetic resources will be in more marginal systems in which climatic and other shocks are more common. Indigenous breeds, which have co-evolved in these systems over millennia and have adapted to the prevalent climatic and disease environments, will be essential (Baker and Rege, 1994). These systems are under substantial pressure arising from the need for increased production as well as land-use changes. Under these circumstances, ensuring continuing availability of these adapted animal breeds to meet the needs of an uncertain future is crucial.

Current animal breeding systems are not sufficient to meet this need and the improvement of breeding programmes under different livestock production and marketing contexts is a critical area for new research. The preservation of existing animal genetic diversity as a global insurance measure against unanticipated change has not been as well appreciated as has that for plants, although a recent report on the state of the world's animal genetic resources (FAO, 2007) and the accompanying Interlaken Declaration have highlighted this important issue. When conservation through use is insufficient (as is the wide-spread situation with indiscriminate cross-breeding), *ex situ*, especially *in vitro*, conservation needs to be considered as an

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important component of a broad-based strategy to conserve critical adaptive genes and genetic traits.

2.2.2 Livestock (and human) health

The major impacts of climate change on livestock and human diseases have been focusing on vector-borne diseases. Increasing temperatures have supported the expansion of vector populations into cooler areas, either into higher-altitude systems (for example, malaria and tick-borne diseases in livestock) or into more temperate zones (for example, the spread of bluetongue disease in northern Europe). Changes in rainfall pattern can also influence an expansion of vectors during wetter years. This may lead to large outbreaks of disease, such as those seen in East Africa due to Rift Valley Fever virus, which is transmitted by a wide variety of biting insects. A good example is also the complexity of climate change influences with other factors associated with vector populations of tsetse flies in sub-Saharan Africa (McDermott *et al*., 2001). Helminth infections, particularly of small ruminants will be influenced greatly by changes in temperature and humidity. Climate changes could also influence disease distribution indirectly through changes in the distribution of livestock species. For example, areas becoming more arid would only be suitable for camels and small ruminants.

2.3 Feed Use and Its Projections

2.3.1 Current feed demand and use

Feed production is a key component in livestock production, not only because it is the key resource that fuels animal productivity but also because it is the key link between livestock, land and several regulating and provisioning ecosystem services such as water cycles, GHG emissions, carbon sequestration, maintenance of biodiversity, and others. The global use of feeds for livestock between 1992 and 2000 was estimated at 4.6–5.3 billion tonnes (Bt) of dry matter (DM) year^{-1} (Bouwman *et al*., 2005; Wirsenius *et al*., 2010; Herrero *et al*., 2013). Of this, grass comprises the majority of biomass consumed (2.3–2.4 Bt DM), followed by grains (0.5–1 Bt of concentrates), crop residues (0.5–1.2 Bt) and other feeds (cultivated fodders and legumes, occasional feeds, etc.). The larger ranges between grains and crop residues lie in different definitions of the feed components, with the lower bound for crop residues representing only stovers and the upper bound including some agroindustrial by-products like brans, oilseed cakes and others. The worldwide feed consumption by livestock as per animal type, system and feed type is presented in Table 2.2 and Fig. 2.1 (Herrero *et al*., 2013). Monogastrics dominate the use of grain globally and in most regions, with the exception of South Asia and the MENA region (Middle East and North Africa), where industrial monogastric production accounts for only 20–25% of production (Herrero *et al*., 2013). Meat animals, both cattle and small ruminants, consume the majority of fibrous feeds. In terms of regional differentiation, livestock in the developing world consumes most of the feed: grass (73%), crop residues (95%) and occasional feeds (90%), respectively (Herrero *et al*., 2013). This, coupled with the fast dynamics of livestock production growth in these regions, makes biomass dynamics a critical entry point in improving the sustainability of livestock enterprises in the future. Globally, mixed crop–livestock systems consume two-thirds of livestock fibrous feeds.

Herbivorous/omnivorous fish have traditionally been reared in pond systems dependent on autochthonous production (i.e. microorganisms, phyto- and zooplankton) enhanced by the application of limited quantities of on-farm crop and animal wastes that both provide a source of direct nutrition and boost autotrophic and heterotrophic production above natural levels (Brummett and Beveridge, 2015). However, through the increased use of feeds, production has been intensifying in order to generate more fish biomass per unit of land

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Table 2.2. Feed consumption at the world level per animal type, system and feed type (thousand tonnes). (From Herrero *et al.*, 2013.)

		Grazing	Occasional	Stover	Grains	All feed
Cattle		1,902,557	403,187	520,441	225,987	3,052,172
	LGA	237,689	15,256	5,878	1,114	259,937
	LGH	133,285	13,914	22	733	147,953
	LGT	65,000	9,731	106	6,829	81,667
	MXA	338,742	150,439	264,856	38,677	792,714
	MXH	306,850	115,326	133,867	22,831	578,874
	MXT	296,118	27,590	76,912	108,861	509,481
	Others	408,842	35,283	24,366	30,543	499,034
	Urban	116,030	35,647	14,434	16,400	182,510
Small ruminants		359,623	155,940	51,886	59,867	627,316
	LGA	114,538	9,713	1,278	8,153	133,682
	LGH	18,021	1,450		1,726	21,196
	LGT	14,763	24,393		7,047	46,203
	MXA	97,831	40,070	33,971	17,127	188,999
	MXH	34,935	15,356	11,504	5,013	66,808
	MXT	22,293	39,604	3,038	11,277	76,212
	Other	39,166	19,596	1,327	6,180	66,269
	Urban	18,076	5,758	767	3,345	27,946
Pigs					537,129	537,129
	Smallholders				67,983	67,983
	Industrial				469,146	469,146
Poultry					476,329	476,329
	Smallholders				76,144	76,144
	Industrial				400,185	400,185
Livestock total		2, 262,180	559,127	572,327	1,299,312	4,692,946

Notes: LG = livestock grazing; MX = mixed crop–livestock system; A = arid; H = humid; T = temperate/highland.

and water use, and today only an estimated 30% of farmed fish production does not use any feeds (Tacon *et al*., 2011). Temperature and sunlight, as well as nutrients, determine autochthonous production. Increases in temperature can be expected to affect productivity and fish growth and production up to a maximum for warm-water systems and species (e.g. catfish, tilapias and Indian major and Chinese carp) of 30°C and 25°C for common carp. Increases in rainfall may decrease autochthonous production through increased turbidity while decreases in rainfall might reduce pond volumes for production (Allison *et al*., 2009).

Two types of feed are used: supplementary feeds, which are generally based on refractory, long-chain, carbohydrate-based crop wastes, such as rice, and wheat bran and oil cakes, sourced on-farm or locally (FAO, 2013). Such feeds, which have minimal processing and result in a moist dough or

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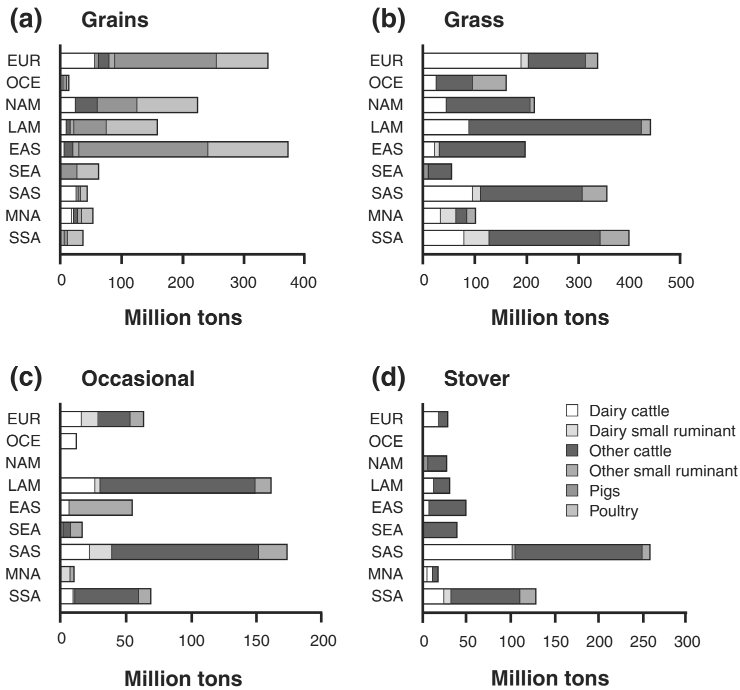

Fig. 2.1. Regional estimates of feed consumption by livestock species: (a) grains; (b) grazed grass; (c) occasional feeds; (d) stovers (million tonnes dry matter). EUR = Europe, OCE = Oceania, NAM = North America, LAM = Latin America, EAS = Eastern Asia, SEA = South East Asia, SAS = South Asia, MNA = Middle East and North Africa, SSA = Sub Saharan Africa. (From Herrero et al., 2013.)

simple moist or dried pellets, still dominate farmed fish production, especially of carp, tilapias and catfish in Asia. The impacts of climate change described above will affect crop production, and therefore quantity and quality (see following chapter). Nutritionally complete feeds, however, are becoming increasingly widely used. Such feeds were first developed for the trout and salmon industries and were based largely on fishmeal and fish oil, with crop-based feedstuffs added for energy and to bind the diet, the latter being of particular importance to maintain pellet integrity in water until consumed. For more omnivorous fish species, much less fish-based ingredients are required. Pelleted feeds are often manufactured by small, local feed mills, which often use low-quality feedstuffs and have a scant understanding of fish nutrition to produce diets that, although cheap, perform poorly. However, large multinational companies, such as CP Foods in Asia, increasingly dominate aquaculture feed markets, bringing with them research knowledge, use of superior feedstuffs and extrusion technologies and technical support to producers. Total industrial compound aqua feed production has increased at an average rate of 11% per annum, from 7.6 million tonnes (Mt) in 1995 to 29.2 Mt in 2008 (Tacon *et al*., 2011). While extruded feeds have advantages over conventional pelleted feeds in terms of feed integrity and digestibility that translate into decreased food conversion ratios, they are more energy-intensive to produce.

The main crops used in the production of aquaculture feeds are soybean, rapeseed, maize and wheat bran (cf. livestock: maize, soybean cake, bran and wheat) (Troell *et al*., 2014, unpublished results). While there is some overlap with both demand from livestock and for human consumption,

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aquaculture uses only 4% of the crop biomass used in livestock production (Troell *et al.*, 2014, unpublished results; Tacon *et al.*, 2011). While aquaculture can be expected to grow by at least 50% by 2030 (Hall *et al.*, 2011; World Bank, 2013; WRI, 2014), and while its dependency on feeds can be expected to grow by at least a similar amount, it very much depends on technology development and the markets and policy drivers as to what effects this will have on demand for feedstuffs and on the sector's impacts on climate change (WRI, 2014).

2.3.2 Projections of feed use to 2030

A number of studies have projected feed use to 2030 (Bouwman *et al.*, 2005; Wirsenius *et al.*, 2010; Havlik *et al.*, 2014; Troell *et al.*, 2014, unpublished results). Estimates of feed use by livestock to 2030 range from 6.5 to 8 billion tonnes (Bt) DM year^{-1}, depending mostly on assumptions about improvements in the quality of feed available or reductions in the demand for livestock products caused by human dietary transitions to diets with less meat (Fig. 2.2). Under business-as-usual conditions, the rate of growth of feed use to 2030 is projected to be between 2.9 and 3.3% year^{-1} (Bouwman *et al.*, 2005; Havlik *et al.*, 2014). Most of this growth is expected in tropical and subtropical areas that exhibit the highest growth rates in animal number and the highest increase in the demand for livestock products. For aquaculture, the estimates are in the order of 25 Mt of crops, growing to something like 35–45 Mt under various scenarios, within the next 30 years.

The dynamics of future feed use are dominated by large increases in grain use due to a faster increase in the consumption and production of pork and poultry, relative to ruminant products. Additionally, grassland expansion and/or intensification hold the key to future land use by ruminants (Herrero *et al.*, 2013; Havlik *et al.*, 2014). In the business-as-usual case, grasslands are

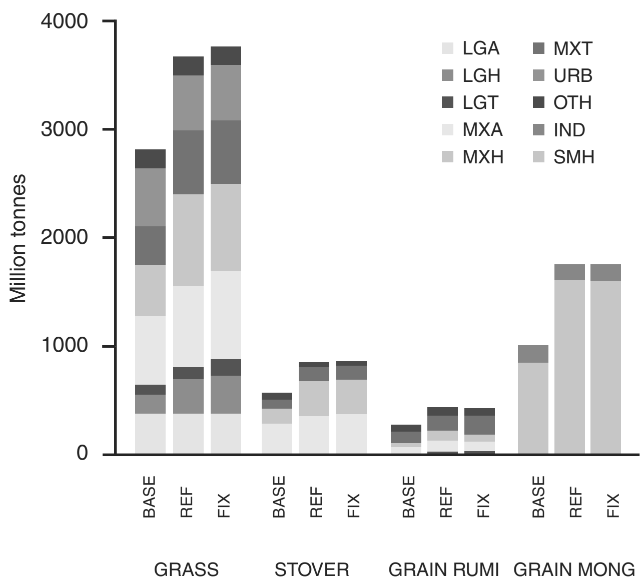

Fig. 2.2. Feed consumption in 2000 (BASE) and two contrasting scenarios (REF, FIX) to 2030. REF represents a scenario where systems transitions to more intensive mixed systems could occur to 2030, while FIX is a scenario where the proportions of production systems remain constant to 2030. LG = livestock grazing; MX = mixed crop–livestock system; A = arid; H = humid; T = temperate/highland; URB = urban; OTH = other; IND = industrial monogastrics; SMH = smallholder monogastrics; GRAIN RUMI = grain fed to ruminants; GRAIN MONG = grain fed to monogastrics. (From Havlik *et al.*, 2014.)

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projected to provide an additional 0.8–1.3 Bt DM for ruminant production, while in alternative scenarios (Wirsenius *et al*., 2010; Havlik *et al*., 2014), grassland expansion contracts as systems intensify with higher-quality feeds or human diets change. Crop residues keep on playing a significant role, especially in alternative scenarios, as their relative proportions in ruminant diets increase slightly. This suggests that if these resources are also targeted for improved nutritional value, they could play an increased strategic role in using livestock as a vehicle for improving livelihoods, increased resource-use efficiencies and human nutrition in the future. The forecast for global feed availability by 2030 as per production system, animal and feed type is illustrated in Table 2.3.

2.4 Effect of Climate Change on Feed Resources and Quality

Despite the importance of livestock and fish to the poor and the magnitude of the changes that are likely to happen, the impacts of climate change on livestock

Table 2.3. Global feed projections to 2030 by livestock production system (thousand tonnes). (From Havlík *et al*., 2014.)

Row labels	Grazing	Occasional	Stover	Grains	Grand total
Cattle	2,376,674	450,973	758,563	341,388	3,927,597
LGA	177,456	9,452	2,896	518	190,323
LGH	213,086	19,998	9	1,315	234,408
LGT	68,399	5,898	77	7,308	81,682
MXA	372,966	134,724	301,582	76,858	886,129
MXH	551,769	148,338	286,885	58,140	1,045,132
MXT	468,679	61,671	128,352	150,335	809,038
Other	408,508	35,265	24,329	30,534	498,636
Urban	115,810	35,627	14,433	16,379	182,249
Small ruminants	568,116	277,486	97,459	99,039	1,042,100
LGA	173,961	28,723	1,296	12,428	216,409
LGH	49,796	4,134		3,308	57,239
LGT	14,442	46,387		10,691	71,520
MXA	162,061	77,960	60,091	30,305	330,417
MXH	83,890	53,342	30,826	18,302	186,361
MXT	26,723	41,586	3,152	14,479	85,939
Other	39,166	19,596	1,327	6,180	66,269
Urban	18,076	5,758	767	3,345	27,946
Pigs				907,391	907,391
Other				67,980	67,980
Urban				839,411	839,411
Poultry				852,073	852,073
Other				76,140	76,140
Urban				775,932	775,932
Grand total	2,944,789	728,458	856,022	2,199,890	6,729,160

Notes: LG = livestock grazing; MX = mixed crop–livestock system; A = arid; H = humid; T = temperate/highland.

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systems, particularly in developing countries, is a neglected research area (Thornton *et al.*, 2009). The few existing predictions and impact assessments are qualitative, at large scale and lack comprehensiveness (Sirohi and Michaelowa, 2007; Nardone *et al.*, 2010). Most projections on climate change and its impacts focus on crop production (e.g. Sirohi and Michaelowa, 2007; Challinor and Wheeler, 2008; Thornton *et al.*, 2009). In view of increasing demand (note the preceding chapter) and the shrinking supply of livestock feed, such information gaps are worrisome.

Climate change is a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It is caused by factors such as biotic processes, variations in solar radiation received by earth, plate tectonics and volcanic eruptions. Certain human activities, including crop and livestock production, have also been identified as significant causes of recent climate change (IPCC, 2007). As illustrated earlier, the impacts of climate change on livestock are multidimensional. The most evident and important effects of climate change on livestock production are mediated through changes in feed resources. Figure 2.3 illustrates a simplified flow diagram exemplifying the main pathways in which climate change can affect the availability of feed resources for livestock and links climate change and livestock feed quality and productivity. It summarizes it into: (i) impacts on biomass productivity; (ii) impacts on the composition of pasture species; and (iii) impacts on the chemical composition of feed resources (plant, e.g. Thornton *et al.*, 2009). However, information on the relative importance of these impacts is not available.

Predicted impacts are most often associated with different but interactive factors such as increase in temperature, carbon dioxide (CO_2) fertilization and land-use/land-cover changes, shortage of fresh water and greater incidences of rainfall, and change in length of growing period (LGP)

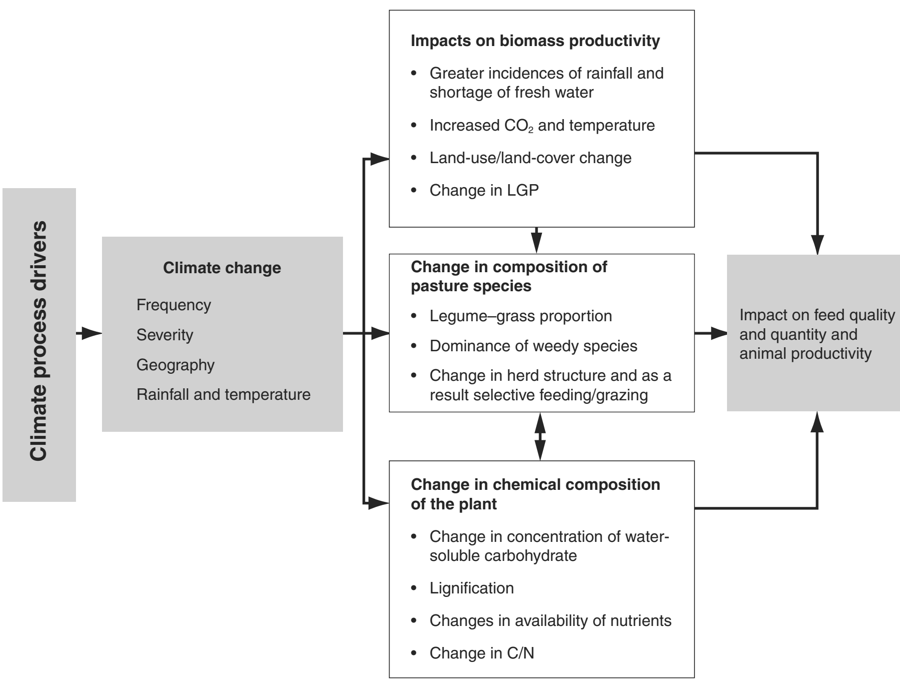

Fig. 2.3. Simplified flow diagram illustrating the main pathways in which climate change affects feed quality and productivity.

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(IPCC, 2007; Sirohi and Michaelowa, 2007; Challinor and Wheeler, 2008; Thornton *et al*., 2009).

Parthasarathy and Hall (2003) suggested that 40–70% of the livestock feed sources in India, depending on the dominant ecoregions, comes from crop residues. Projections indicate that these roles will be intensified (Herrero *et al*., 2013). Pasture and grazing land is only about 3.4% (Sirohi and Michaelowa, 2007) of the total area, and thus the contribution is negligible. In view of these facts, here we try to focus only on the impacts of climate change on crop productivity, to understand its implications for livestock feed quality and productivities.

Despite acknowledged spatial variability and uncertainty on predictions, many model outputs suggest that precipitation will increase at higher latitudes and decrease in tropical and subtropical regions (IPCC, 2007). Crop yields are projected to fall in the tropics and subtropics by 10–20% by 2050 due to a combination of warming and drying, but in some places yield losses could be more severe. Future projections of climate change using global and regional climate models, run by the Indian Institute of Tropical Meteorology (IITM), with different Intergovernmental Panel on Climate Change (IPCC) emission scenarios, indicate temperature changes of about 3–5°C and an increase of about 5–10% in summer monsoon rainfall (NATCOM, 2004). It is also projected that the number of rainy days may decrease by 20–30%, which would mean that the intensity of rainfall is expected to increase. There are no comprehensive studies on the yield losses of all crops as the result of climate change. For major food–feed crops such as rice, wheat, sorghum and millet, there are fragmented studies, many concluding reduced yields, but with different magnitudes and underlying assumptions.

For example, prediction with and without CO_2 fertilization suggests different pictures. In this regard, for major food–feed crops such as millet and sorghum, losses of about 10–15% of grain yield during the second half of the 21st century are projected. Khan *et al*. (2009) suggested a strong linear decline in wheat yield with the increase in January temperature. According to these authors, for every degree increase in mean temperature, grain yield of wheat decreased by 428 kg ha^{-1}. For rice, an increase of 1°C in temperature resulted in a 5, 8, 5 and 7% decrease in grain yield in north, west, east and southern regions, respectively. An increase of 2°C in temperature resulted in a 10–16% reduction in yield in different regions, while a 4°C rise led to a 21–30% reduction. On interaction between CO_2 fertilization and increased temperature, for example at 350 ppm in north India, there was a change of –5, –12, –21, –25 and –31% in grain yield of rice with an increase of 1, 2, 3, 4 and 5°C in temperature, respectively. In the same region, and at the same temperatures but at 550 ppm, these yield changes were 12, 7, 1, –5 and –11%, respectively. Thus, in eastern and northern regions, the beneficial effect of 450, 550 and 650 ppm CO_2 was nullified by an increase of 1.2–1.7, 3.2–3.5 and 4.8–5.0°C, respectively (Challinor and Wheeler, 2008; Khan *et al*., 2009). In contrast to this nullifying effect, Thornton *et al*. (2009) discussed that such nullification of the impacts of increased temperature on productivity by CO_2 fertilization was very optimistic (for C_3 crops), and they suggested that such effects could only be partial. This argument obviously can lead to an overall decrease in grain yield and livestock feed productivity. The question is to understand what this implies for livestock feed sourcing, particularly in view of both regional- and global-scale projections illustrating a sharp increase in demand (Ramachandra *et al*., 2007; Herrero *et al*., 2013).

In a projection to 2020, Ramachandra *et al*. (2007) illustrated that crop residues as dry fodder sources would remain an important source of feed, and suggested a deficit level of about 10–11%. But the work of Ramachandra *et al*. (2007) did not take the impacts of climate change into account. Put differently, when the impacts of climate change are added to the current undersupply, the existing gaps for dry fodder will be amplified. It is important to note that the ongoing competition for uses of crop residues as a source of household energy,

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soil and water management will worsen this adverse trend.

Although the pasturelands in India are increasingly shrinking, pocket-wise, they are important sources of feed. Permanent pasture and grazing land in India is about 3.4% of total agricultural land (Sirohi and Michaelowa, 2007). In addition to an expected reduction in biomass productivity, Sirohi and Michaelowa (2007) argue that additional changes of grassland in terms of composition of species (grass: legume species ratio) might be the result. The change in grassland composition could be in response to increasing temperature (resulting change in LGP) and also to a change in farmers' behaviour in adapting to certain livestock species (to capture opportunities and also to adapt to climate change), and thus selective feeding. For example, in the drylands of India in recent years, a significant increase in small ruminants has been noticed. Further controlled research as to how such a change can impact longer-term grassland composition needs to be confirmed empirically. The fact that legumes constitute important sources of crude protein (CP), such change in composition for pasture will impact the quality of livestock feed negatively.

As indicated in Roger *et al*. (2000) and Thornton *et al*. (2009), climate changes through increased CO_2 concentration will affect feed quality, particularly in terms of carbon/nitrogen (C/N). Higher C/N influences the microbial population, and thus digestibility of the feed. Also, increased temperature can result in lignification which leads to reduced digestibility and nutrient availability for livestock (Thornton *et al*., 2009).

Water scarcity has become globally significant over the period 1960–2000 or so, and is an accelerating condition for 1–2 billion people worldwide (MEA, 2005). The response of increased temperatures on water demand by livestock is well known. For *Bos indicus*, for example, water intake increases from about 3 kg kg^{-1} of DM intake at 10°C ambient temperature, to 5 kg at 30°C and to about 10 kg at 35°C (see Fig. 2.4; NRC, 1981).

However, about 100 times more water can be required for fodder production than for drinking water, resulting in low livestock water productivity. Empirical evidences across scales (both consumption and use efficiencies) vary significantly (Haileslassie *et al*., 2011). For example, in Gujarat, the heartland of the Indian white revolution, on

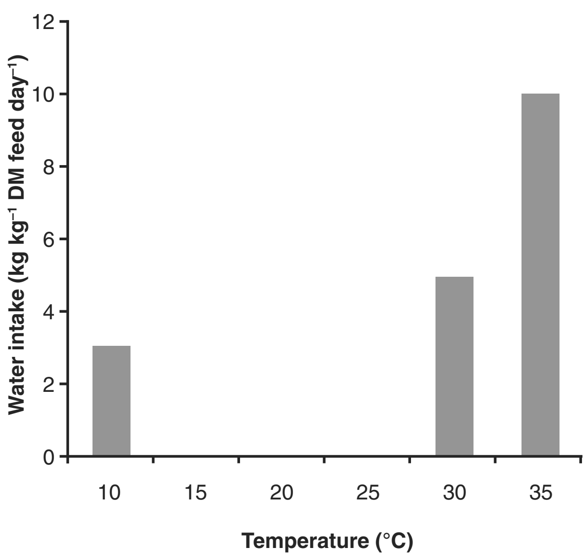

Fig. 2.4. Variation of livestock water intake as affected by temperature gradient and dry matter intake.

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average 3400 l water are required for the production of 1 kg of milk (see Table 2.4).

Indirect effects on feed resources can have a significant impact on livestock productivity, carrying capacity of rangelands, buffering ability of ecosystems and their sustainability, price of stovers and grains, trade in feeds, changes in feeding options, GHG emissions and grazing management. Generally, dependency on crop residues, reduced digestibility as the result of lignification and/or change in species composition will have a negative feedback on the mitigation (e.g. increased GHG emission).

2.5 Option to Address Mitigation and Adaptation

Options to address the complex issue of feed–livestock–livelihood–climate change can be viewed from different angles. For example, one option, as is apparent from Fig. 2.5, is change in food habit from an inefficient ASF to a more efficient one. In this case, beef is a far less efficient source of calories and protein than milk and other meats (Wirsenius *et al*., 2010). But livestock uses in tropical countries are multiple and cannot be narrowed down to only energy and protein and the key issue is then how to strike a balance.

A closer look at the energy usage and productivity of animals in most tropical countries suggests that with low-producing animals, most of the feed is used for maintaining the animal and not for the production of ASF. Blümmel *et al*. (2013) used dairy production and productivity in India in 2005/06 as an example and found that only about 32% of the feed metabolizable energy was used for milk production. If daily

Table 2.4. Some water requirements and allocations in dairy production. (Data modified from Singh *et al*. (2004), who used a life cycle analysis.)

Site	Water required (l)	Produce
Gujarat	3,400	1 kg of milk
	10,000	Fodder production per animal per day
Global	900	1 kg of milk

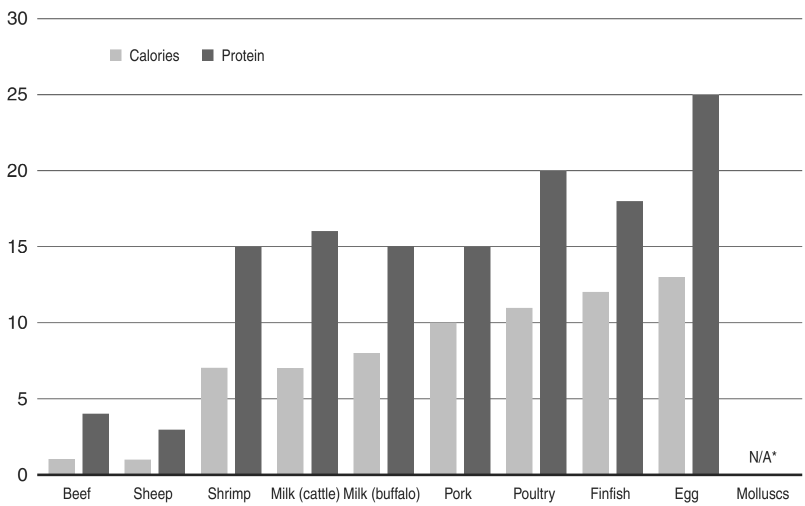

Fig. 2.5. Energy and protein production efficiencies of the different animal species (livestock species [% or "units of edible output per 100 units of feed or grass input]) Wirsenius *et al*. (2010). Note: 'edible output' refers to the calorie and protein content of bone-free carcass.

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milk yield per animal would increase from the 2005/06 across-herd (buffalo, cross-bred and indigenous cattle) average of 3.61 kg to 15 kg, then the total feed metabolizable energy requirement would be reduced by over 50% (Table 2.5), resulting from fewer animals being needed to produce the same amount of milk. In other words, more than 50% less feed biomass would be required to produce the same amount of ASF.

It is highly improbable that the so-called livestock revolution can materialize without significant intensification in the production of ASF. These considerations are exemplified in Table 2.6 based on the dairy scenario in India, which in 2005 had a dairy livestock population of 69.75 million producing about 82 Mt of milk. By 2020, the demand for milk is predicted to increase to about 172 Mt. If per animal milk yield were to increase at the compound annual growth rate (AGR), average daily milk yield would be 5.2 kg and about 20 million more dairy animals would be required to meet the demand for milk. Given the already severe feed shortage and the mounting concerns about the negative environmental effects from livestock (illustrated in the preceding section), this is clearly not a viable strategy. In contrast, increasing per animal productivity as conceptualized in Table 2.5 would result in a significant reduction in animal numbers and feed requirements per unit produced (Blümmel *et al*., 2013).

The importance of per animal productivity for total feed requirement relative to ASF production can also be demonstrated for pigs, assuming a growth development from 10 to 80 kg of live weight and daily live weight gains (LWG) of 100, 200, 300, 400 and 500 g. Data were calculated according to Kirchgessner (1997), assuming that total metabolizable energy (ME) requirement equals ME for maintenance (ME) plus ME

Table 2.5. Actual across-herd average daily milk yields (3.6 kg) and scenario-dependent (6–15 kg) metabolizable feed energy requirements to support total Indian milk production of 81.8 million tonnes (Mt) in 2005 and reduction in methane production relative to milk production from fewer animals. (Data modified from Blümmel *et al*., 2013.)

Milk (kg day^{-1})	Metabolizable energy required (MJ * 10^9)			Methane production (Tg)
	Maintenance	Production	Total	CH_4 from 81.8 Mt of milk
3.6	1247.6	573.9	1821.5	2.3
6	749.9	573.9	1323.8	1.7
9	499.9	573.9	1073.8	1.4
12	374.9	573.9	948.8	1.2
15	299.9	573.9	873.9	1.1

Table 2.6. Milk demand in India in 2005/06 and in 2020 and dairy population and feed demand under across-herd yields of 3.61 kg day^{-1} in 2005/06, an estimated compounded annual growth rate in 2020 of 5.24 kg day^{-1} and needed average daily milk yield of 6.76 kg day^{-1} if the milk demand in 2020 is to be provided by the dairy livestock population of 2005/06.

	(2005/06)	2020	2020 (fixed DLP)
Milk (million tonnes)	81.8	172.0	172.0
Yield (kg day^{-1})	3.61	5.24	6.76
Dairy livestock population (DLP; millions head)	69.75	89.92*	69.76
Feed metabolizable energy requirements (MJ * 10^9)			
Maintenance	1,247.6	1,608.2	1,247.6
Production	573.9	1,075.0	1,075.0
Total	1,821.5	2,683.2	23,266.6
Feed requirements (tonnes)	247,500,000	364,570,000	315,600,000

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for protein accretion (ME) plus ME for fat accretion (MEf). The following equations were used:

$$ME_m \text{ (kJ day}^{-1}\text{)} = 719 * \text{kg LW0.63} * 1.1.\text{ ME} \quad (2.1)$$

$$ME_p = 40.4 \text{ kJ g}^{-1} \text{ protein} \quad (2.2)$$

$$ME_f = 52.7 \text{ kJ g}^{-1} \text{ fat} \quad (2.3)$$

Protein and fat content in LWG were assumed to be 16.0% and 9.5% in LW up to 20 kg; 16.5 and 12.1% from LW 20–40 kg; 16.4 and 16.3% from LW 40–60 kg; and 15.9 and 20.9% from LW 60–80 kg, respectively (Kirchgessner, 1997).

Pigs that grow at 500 g day^{-1} would reach slaughter after 140 days, while pigs growing at 100 g daily would need 700 days. Such differences in fattening periods would obviously have severe implications for feed requirement for maintenance, and total feed requirement for the production of 70 kg of LW is much lower for faster-growing pigs (Fig. 2.6). Daily weight gains of 500 g would be approximately half of the achievable gains in highly intensified and specialized industrial state-of-the-art pig fattening enterprises, and still about 50% of the feed energy is used for maintenance purposes (Fig. 2.6). Contrarily, in dairy production, feed energy for maintenance and production would equal about 8 l day^{-1}, i.e. a moderate level of production (calculated from Table 2.4). Still, the feed input for 70 kg of live weight will decrease from about 7000 MJ ME to about 2200 MJ ME if pigs grow at a rate of 500 g day^{-1} rather than 100 g day^{-1}. In summary, if carefully planned and implemented, this approach will have both mitigation and adaptation impacts. Decreasing animal population and increasing per animal productivity will help in decreasing the total feed requirement in ruminants and monogastrics, with positive effects in terms of land and water resources and GHG emission.

The picture is less clear in aquaculture. According to recent projections in the *Fish to 2030* report (World Bank, 2013), capture fisheries production will remain fairly stable between 2010 and 2030. In contrast, global aquaculture production will maintain its

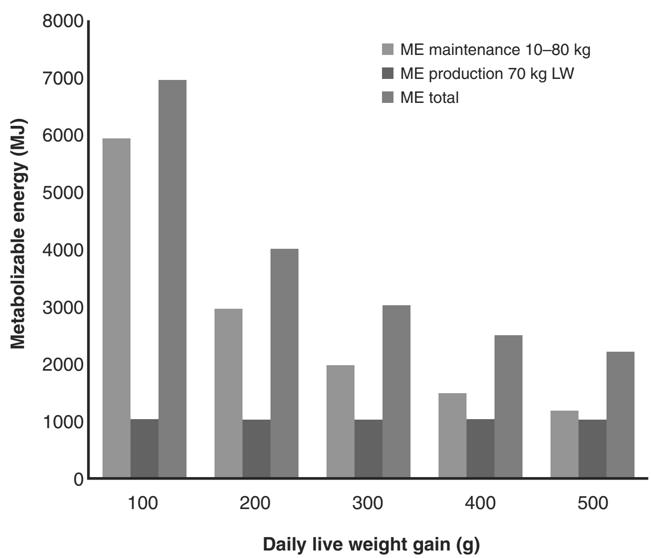

Fig. 2.6. Requirement of metabolizable feed energy (MJ) to produce 70 kg of live weight gain in pigs growing at daily rates of 100, 200, 300, 400 and 500 g.

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steady rise from historical levels, reaching the point where it equals global capture production by 2030. Global fish supply, from both capture and culture, is projected to rise to 187 Mt by 2030, as compared to 147 Mt in 2010. The rapid growth of aquaculture has raised questions concerning its environmental sustainability. The *Blue Frontiers* study (Hall *et al*., 2011) compared the global and regional demands of aquaculture for a range of biophysical resources across the entire suite of species and production systems in use today. The units of analysis were the elements of a six-dimensional matrix comprising 13 species groups, 18 countries, 3 production intensities, 4 production systems, 2 habitats and 5 feed types. This gave 75 positive matrix elements that accounted for 85% of the estimated total world aquaculture production in that year. The data from the 75 species production systems reviewed showed a positive relationship between overall production levels and impact.

A comparison of environmental efficiencies across countries gave a variable picture. A look at the drivers of impact, i.e. those attributes of the production system that contributed most to environmental impact, showed that the fish production system itself contributed most to eutrophication, but impacts on climate change and acidification were dependent on the nature of the national energy supply; a factor outside the control of the local operator. The study also noted that fish convert a greater proportion of the food they eat into body mass than do livestock and therefore the environmental demands per unit biomass or protein produced are lower (Hall *et al*., 2011). A number of key conclusions and recommendations are identified in Hall *et al*. (2011) that point the way towards improved productivity for aquaculture with reduced environmental impact.

First, feed represents a significant influence on the environmental impact of aquaculture development, and reducing the dependency on fishmeal and fish oil, while requiring new innovations in technologies and management, will have spectacular payoffs both in terms of profitability, food and nutrition security and reduced environmental impact. Second, aquaculture has, from an ecological efficiency and environmental impact perspective, benefits over other forms of animal source food production for human consumption. In view of this, where resources are stretched, the relative benefits of policies for fish farming versus other forms of livestock production should be considered. Third, reductions can be made to the sector's impact on both climate change and acidification by improving energy efficiency throughout the production and value chains, and for more intensive systems shifting to alternative energy sources. Fourth, aquaculture affects climate change and climate change will affect aquaculture, and to minimize the potential for climate change, energy consumption should be minimized and new aquaculture enterprises should not be located in regions that are already high in sequestered carbon, such as mangroves, sea grass or forest areas.

2.6 Conclusion

Global and regional trends in livestock and fish feed resources need to be seen in the context of contraction (western hemispheres and Latin and Central America (LCA)) and convergence (developing and emerging countries) in the consumption of animal-sourced food and the impact of climate change. Climate change will affect livestock and fish production mainly through its effects on feed production and resourcing. A big unknown in global feed requirements resides with a decrease in ASF consumption (i.e. contraction), as recommended by health, environmental and ethical agencies for the western hemispheres and LCA; feedstuffs requirements in those regions will likely contract too. Actual feed resource demand in the developing and emerging countries will depend heavily on the degree of intensification in the sense of increasing per animal productivity. Focusing on productive animals will address both the adaptive and mitigation measures of climate change related to feeding and feed sourcing, associated natural resource usage (for

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example, land and water) and GHG emission. Yet, despite the important role the sector is playing in the livelihood of smallholders in the tropical world, the livestock sector is an understudied area. For example, many studies addressing feed demand supply projections do not yet take the climate change scenario into consideration.

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