9

Rangeland and Livestock

Lead Author
Barry Baker [1]

Contributing Author
Ernesto F. Viglizzo, Argentina

9.1 Nature and scope of the problem

Rangeland and livestock ecosystems are complex, with myriad interactions among the biotic and abiotic components of the system as well as the economic and social components. Consequently, the effects of a changing climate will have direct (first order) and indirect (second or higher order) impacts at many different spatial and temporal scales. Examples of these impacts include changes in forage yield, changes in livestock productivity, changes in ecological processes, alterations in farm level profitability, changes in regional farm incomes, and possibly modification of regional and national food production and incomes. Therefore, understanding lower order impacts are crucial for anticipating and predicting higher order effects (Parry and Carter, 1989).

The goals of the rangeland and livestock assessment are to (1) identify rangeland production areas that are sociologically, economically, and ecologically vulnerable to changes in climate; (2) evaluate how climate affects management practices and ecological processes of rangeland and livestock systems; and (3) identify possible adaptation strategies to minimise adverse effects and, where possible, optimise positive benefits of climate change. The methods described in this chapter are meant to provide the means for accomplishing these goals.

---

[1] Ecosystems Research International, Fort Collins, Colorado, USA.

Rangelands, which can be defined as unimproved grasslands, savannahs, shrublands, hot and cold deserts, and tundra, cover approximately one-fifth of the world's land surface and provide food for approximately 50 percent of the world's ruminate livestock and countless numbers of wild herbivores (WRI, 1996). Billions of people around the world either directly or indirectly derive food or income from livestock that graze or browse on these lands.

Increases in atmospheric carbon dioxide (CO_2) can raise plant productivity and cause changes in temperature, precipitation, solar radiation, and wind patterns that could have important effects, either positive or negative, on animal and plant production in rangeland ecosystems. Consequently, climate driven changes in the sustainability and productivity of rangeland and livestock systems could have profound direct and indirect effects on human populations, local, regional, and national food supplies, and economic security for most nations in the world.

9.1.1 Impacts on livestock

The IPCC (1996) summarised research on the potential impacts of climate change for livestock and listed four possible effects: (1) changes in livestock feedgrain availability and price; (2) direct effects of climate on animal health, growth, and reproduction; (3) impacts on pasture and forage crops; and (4) changes in distribution of disease and parasites.

Although the primary focus of this chapter is concerned with rangeland and livestock systems, some mention should be given to the possible effects of climate change on more intensively managed livestock production schemes. A review of available research suggests that direct impacts may be minor for intensively managed livestock production systems such as confined poultry, swine, and beef operations (IPCC, 1996). These systems already have a great deal of built-in climate control through the use of shade, misting devices, and mechanical heat regulation. However, there are important indirect effects on these systems, for example, costs and availability of feedgrain, water quality and quantity, and cost, availability, and type of energy sources.

The well being and productivity of livestock in natural conditions depend on the animal's ability to cope with environmental challenges such as nutritional and thermal environments and exposure to disease and parasites. The direct effects from heat and water stress on grazing or browsing livestock are most likely to be manifested as decreases in feed intake, milk production, and rates of reproduction.

The indirect effects of climate driven changes on animal performance result from alteration in the animal's nutritional environment. Research suggests that changes in climate are most likely to influence the quality and quantity of forage produced (Walker, 1994; Van den Pol van Dasselaar and Lantinga, 1995; De-Xing Chen et al., 1996; Fuller and Prince, 1996; Topp and Doyle, 1996a; Thornley and Cannell, 1996). Consequently, these changes in forage may alter the productivity of grazing livestock (Baker et al., 1993; Eckert et al., 1995; Topp and Doyle, 1996b).

Climatic restrictions on vectors, environmental habitats, and disease causing agents are important for keeping many animal diseases in check (Stem et al., 1989). Alterations of temperature and precipitation regimes may result in a spread of disease and parasites into new regions or produce an increase in the incidence of disease. Changes in the incidence and spread of disease and parasites would reduce animal productivity and possibly increase animal mortality.

9.1.2 Impacts on rangelands

Climatic changes such as increased atmospheric concentration of CO_2, changes in temperature, and changes in precipitation patterns have the potential to affect rangeland ecosystems. An in-depth description and literature review of the current state of knowledge regarding the effects of these driving forces on plant and ecosystem physiology and biogeochemistry are beyond the scope of this chapter. Instead, a summary of direct and indirect impacts and feedbacks of climate change is provided here. Detailed reviews and studies regarding these processes can be found in IPCC (1996) and Breymeyer et al. (1996).

The direct effects of climate and climate change on rangeland ecosystem processes are fairly well described, have relatively short response times, and are somewhat easier to predict than the indirect effects. The direct effects of climate change on rangeland ecosystems from alterations in precipitation regimes, temperature, and atmospheric concentrations of CO_2 include (1) changes in decomposition rates; (2) changes in aboveground net primary production (ANPP); (3) shifts in C_3/C_4 species of grasslands; (4) changes in fluxes of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), nitric oxide (NO), and nitrous oxide (N_2O); (5) changes in evapotranspiration and runoff; and (6) changes in forage quality (Ojima et al., 1991; Breymeyer et al., 1996; IPCC, 1996).

The indirect effects are less well understood. Because of lags in the response time of the system and the complexity of the feedbacks that are involved, the impacts of climate change take longer to identify. Also human activities, including burning, cropping, and management of grazing animals, have the potential to modify indirect effects by either accelerating or slowing these processes. Thus predicting the direction and magnitude of the impact is more difficult. Examples of the indirect effects of climate change on rangeland ecosystems include (1) changes in the structure of vegetation communities; (2) changes in vegetation cover that could alter surface albedo, humidity, and ground level wind patterns; (3) changes in the C:N ratios or lignification of vegetation that alter litter quality and affect soil nutrients; (4) alterations in soil characteristics; (5) changes in biogeochemical cycles that lead to the invasion of exotic species of plants; and (6) possible influence on frequency of wildfires in some areas (Ojima et al., 1991; IPCC, 1996).

9.1.3 Socio-economic impacts

Climate induced changes on rangelands and livestock production would have effects on economies and societies at farm, national, and international levels. These impacts are likely to be seen as changes in income and prices, and hence changes in livelihood, employment, and investment. Analysing such impacts would require an economic model, more specifically a (recursive) applied (or computable) general equilibrium model. Such models have been applied to climate change impacts on agriculture, though not on livestock, and are discussed in Chapter 8, Agriculture.

Social systems in some parts of the world may be stressed beyond their ability to cope with any further changes in climate. In areas where livestock are forced to graze on marginal lands (either by social structure, economic conditions, or governmental regulations), further degradation or reductions in forage productivity could result in political unrest, famine, or other social disturbances.

9.1.4 Areas and extent of impacts

The rangeland and livestock sector is most likely to be vulnerable in countries in the poorer regions of the world and least capable of adapting to change in climate or other environmental perturbations (Antle, 1995). Many of the countries in these regions are experiencing high population growth that forces expansion of grazing into areas of marginal productivity, which places extreme pressures on an already stressed ecosystem (Parry et al., 1988).

The potential negative impacts of climate change on livestock production are likely to be greater in those areas of the world where production is already operating at the margins. Traditional pastoralist systems that are seen in many regions of the developing world are less likely to have the flexibility built into the system for adapting to extreme climatic events (such as changing the type or mix of grazing livestock, cross-breeding, relocating), whereas modern industrialised livestock production systems in the western regions of the United States, Canada, and parts of South America are more likely to make adjustments to mitigate many of the potential negative effects of climate change.

Changes in precipitation are especially important in regions where lack of rainfall is already a limiting factor (Parry et al., 1990). At a regional level, alterations in rainfall patterns are likely to have a greater ecological and socio-economic impact than the direct effects of small increases in mean annual temperature (IGBP, 1992). Although, in those areas of world where daytime temperatures are at the limits or approach the upper limits for livestock production, higher temperatures at night may cause heat stress in animals.

The negative effects of increases in concentrations of atmospheric CO_2 are most likely to be experienced in tropical and sub-tropical rangelands. The IPCC Working Group II (IPCC, 1996) listed the extent of known regional impacts of altered climate regimes and the relative degree of confidence in their prediction. They predicted with medium confidence that increased atmospheric concentrations of CO_2 are likely to alter the carbon and nitrogen ratios of some forage plants. The result of this phenomenon would be manifested in a decreased palatability and nutritional quality of the forage. This is most likely to occur in lower latitude rangelands where forage quality is already low.

The IPCC also predicted with a high degree of confidence that small changes in the frequency of extreme climatic events may have disproportionate effects on what managers and herders have to cope with in rangeland systems. Changes in climate are likely to produce alterations in the boundaries between rangelands and other biomes, such as deserts and forests, directly through shifts in species composition and indirectly through changes in wildfire regimes, opportunistic cultivation, or agricultural release of the less arid margins of the rangeland territory (IPCC, 1996). They predicted that these effects will be more common in temperate rangelands.

9.1.5 Identification of impacts and adaptations options

To keep the task of impact assessment manageable, the range of climatic impacts to be included in the assessment should be listed and prioritised within the goals of the assessment. Table 9.1 contains a list of the possible types climate driven impacts that are likely to occur in the rangeland and livestock sector.

Table 9.1 Likely impacts in rangeland and livestock sector.

Livestock impacts	Shifts in rangeland vegetation structure or boundaries Changes in forage quality and quantity Changes in length of growing season Changes in livestock productivity Changes in water quality and quantity.
Ecological impacts	Alteration in carbon storage capacity of the ecosystem Alterations in greenhouse gas emissions Disturbances in ecosystem functions (e.g., alterations in biogeochemical cycling, incidence of wild fires, etc.) Change in soil quality and productivity Changes in biodiversity Changes in habitat suitability for wildlife.
Socio-economic impacts	Changes in food production and security (locally, regionally, and nationally) Changes to incomes derived from livestock production, wildlife, and other rangeland outputs Changes in land use Changes in recreational use of rangelands Alteration in scenic quality.

As can be seen from Table 9.1, there are many potential cross-sectoral impacts to be considered in the assessment. The team designing the assessment for this section is strongly urged to co-ordinate their effort with the water resources (Chapter 6), agriculture (Chapter 8), energy (Chapter 11), forests (Chapter 12), and biodiversity (Chapter 13) sectors.

Once the impacts to be included in the assessment are identified, a list of indicator variables, those variables used to evaluate change in the system (see Table 9.2), and adaptation options should be identified. Some of the methods presented in the next section are better than others at producing outputs that can be used for adaptation assessments or incorporation into policy assessments. Therefore, a particular method or suite of methods should be chosen based on impacts and adaptation strategies to be used in the assessment.

9.2 An array of methods

This section presents an array of methods for conducting climate change impact assessments for rangeland and livestock systems.

9.2.1 Description of methods

9.2.1.1 Experimentation

A wealth of data and knowledge has been gleaned from experiments on the effects of environmental stresses on the physiology and production of plants and animals. Also there is a growing amount of information available on the effects of atmospheric concentrations of CO_2 on plant production (Gonzàlez-Meler et al., 1996; IPCC, 1996; Long et al., 1996; Shaver and Aber, 1996), plant quality and decomposition (Melillo, 1996), and soil carbon storage (Paustian et al., 1995; Tate et al., 1995). Because of the long time delays in response, complex interactions, and lack of feedbacks, experimentation has limited application with regard to impact assessment. But the data produced and understanding gained in the workings of individual components of the system are extremely useful for other assessment methods.

Even though the usefulness of experimentation is limited and may be considered impractical in the context of programs or projects with limited funding, like climate change country studies, the establishment of long-term field experiment sites is extremely valuable, and usually needs to be budgeted for separately. This type of research program could be considered as a future research priority should funding or collaborative arrangements with other national or international agencies become available. For example, since the establishment of the first six sites in the United States during the early 1980s, the National Science Foundation’s Long Term Ecological Research program has been conducting research on long-term ecological phenomena in the United States and developing a network of sites in other countries throughout Asia, Australia, South America, Africa, and Europe. These long-term field experimental sites represent a unique source of information on long-term ecological processes and are a principal component necessary for regional assessments of the effects of climate on those processes (Hall et al., 1995; Paustian et al., 1995).

Table 9.2 Possible climate induced changes, indictor variables, controlling climatic factors, rangeland and livestock, ecological, and socio-economic impacts.

Category	Indicator variables	Controlling climatic factors	Rangeland and livestock impacts	Ecological impacts	Socio-economic impacts
Below ground nutrient pools	Soil carbon, nitrogen, and phosphorus	Temperature and precipitation	Changes in forage resources, shifts in vegetation structure or boundaries	Changes soil quality and productivity, alteration in plant productivity, cover, and shifts in species.	No first order impacts but many second order impacts because of alterations in plant structure and function. Impacts listed in following rows.
Plant or forage quantity	Peak standing crop, annual production, length of growing season	CO_2, temperature, and patterns of precipitation	Reduced feed intake and livestock productivity, reduction in harvested forage	Changes in carbon storage, community structure, changes in water storage, alteration in biodiversity, and changes in habitat suitability.	Changes in land-use, and change income. Second order impacts such as changes in food production and security.
Plant or forage quality	Carbon to nitrogen ratio or digestibility	CO_2 and temperature	Changes in livestock production, such as milk production, growth rates, reproduction, etc.	Changes in carbon storage, greenhouse gas emission, soil quality and productivity, habitat suitability and biodiversity.	Changes in food production and security.
Plant adaptability or shifts in species	Water use efficiency	Temperature, precipitation, and CO_2	Changes in livestock production and utilisation, shift in type of herbivores	Changes in community structure and function, biodiversity, habitat suitability.	Changes to food production, incomes, land-use, and maybe scenic quality.
Livestock heat stress	Cow weight at weaning, body condition scores	Temperature, humidity, and night time cooling	Changes in mortality, milk production, decreased animal intake, and weight gain	Changes to ecosystem structure due to increased grazing should conditions be positive.	Alteration in food production, food security, and incomes.
Voluntary feed intake	Diet quality, intake of grazed forage, and forage to supplement ratios	Temperature	Changes in growth rates, milk production, reproduction, and mortality	Changes to ecosystem structure due to increased grazing should conditions be positive.	Alteration in food production, food security, and incomes.
Young nursing animal production	Mother’s milk production, weights at weaning, and growth rate	Temperature	Changes in growth rate and mortality	Changes to ecosystem structure due to increased grazing should conditions be positive.	Alteration in food production, food security, and incomes.

9.2.1.2 Screening techniques

The purpose of preliminary screening is to identify those areas where more detailed analysis may be needed or to develop some initial quantitative assessments of an area's vulnerability and response to climatic change. Regions of vulnerability may be spatially defined by administrative, geographic, or ecological boundaries. Methods used in a screening analysis include the construction and utilisation of simple indicators or indices, geographical analyses, the use of remotely sensed data, or a combination of the three methods.

Indicators or indices

Two basic characteristics can be used to define indicators (Hammond et al., 1995). First, they must quantify information so that the significance of the data is more readily apparent. Second, they must improve communication by simplifying information about complex phenomena.

In the development of indices, administrative or geographic boundaries can be used to delineate areas that are economically or sociologically dependent on livestock production from rangelands (Baker et al. 1993; Eckert et al., 1995). Clearly, areas that are economically dependent on rangelands for livestock production are susceptible to the positive as well as the negative effects of changes in climatic conditions.

Ecological boundaries can also be used to define areas that are ecologically at risk from changes in climate. These areas can be defined by their susceptibility to degradation, loss of biodiversity, desertification, and so on. Economic and demographic data can be combined with ecological data to develop a socio-ecological risk index (Baker and Hanson, 1993). However, the construction of this type of index is not an end in and of itself. Careful analyses must be conducted to determine the nature and degree of the risk. For example, rangelands at the northern or wetter edge of an ecological boundary may not be at risk or at much less risk than rangelands at the southern or drier edge of the boundary.

Geographic analysis

Another approach that can be used to determine and analyse areas that are sensitive to changes in climate is the use of GIS (Du Preez et al., 1990; Baker and Hanson, 1993; Baker et al., 1993). It allows for the integration and summarisation of environmental information using natural units such as watersheds, rangeland areas, and soil units. Indices can be included in a GIS to demonstrate spatially where the impacts of climate change such as degradation of rangeland resources are most likely to occur and where degradation would have economically significant societal impacts.

Satellite remote sensing enables scientists to make direct observations of the land surface at frequent and repetitive intervals, hence allowing for the mapping and monitoring of changes in land use and cover at a variety of spatial and temporal scales. Other applications of remotely sensed data include inventory of pasture and rangeland vegetation, changes in forage condition, monitoring soil erosion and soil moisture, and detection of episodic events on rangelands.

There is an extensive body of literature within many natural science disciplines that document the development and potential for satellite sensor data analysis techniques for use in climate change research. A partial and very abbreviated list of related papers on this topic is provided in Table 9.3.

Not all remotely sensed data come from satellites. Aerial photography is also a very useful method for collecting information regarding rangeland systems. The Systematic Reconnaissance Flight (SRF) is the best known and most widely used method. It employs a combination of photographs or video imagery with visual observations to estimate the numbers and spatial distribution of human settlements, livestock, wildlife, land use, and land cover types (Norton-Griffiths, 1988). The SRF method provides a rapid and relatively inexpensive means for gathering a systematic sample of remotely sensed imagery and field observations (Hassan and Hutchinson, 1992).

Table 9.3 A partial bibliography of the application of satellite sensor data for vegetation analysis and monitoring.

Author[1]	Title
Hobbs and Mooney, 1990	Remote sensing of biosphere functioning.
Wylie et al., 1991	Satellite and ground-based pasture production assessment in Niger: 1986-1988.
Prince, 1991	A model of regional primary production for use with coarse resolution satellite data.
Tucker et al., 1991	Expansion and contraction of the Sahara Desert from 1980 to 1990.
Ehrlich et at., 1994	Applications of NOAA AVHRR 1-km data for environmental monitoring.
Goward et al., 1995	Transient effects of climate change on vegetation dynamics: satellite observations.
Fuller and Prince, 1996	Rainfall and foliar dynamics in tropical Southern Africa: Potential impacts of global change on savannah vegetation.

[1] Published sources may be found in the reference list.

9.2.1.3 Expert judgement

There is no more simple or inexpensive method for rapid assessment of the state of knowledge of the effects of climate change on rangeland and livestock systems than asking the opinion of experts. Experts on animal science, range science, agricultural economics, soil science, climatology or meteorology, and social sciences may be solicited for their opinions on possible impacts.

The use of indigenous knowledge may be valuable for filling information gaps in data and understanding as well. There are three global centres, the US based Center for Indigenous Knowledge for Agriculture and Rural Development (CIKARD) at Iowa State University; LEAD in The Netherlands; and CIRAN; two regional centres in Nigeria and the Philippines, and several national centres in, Mexico, Indonesia, Ghana, Kenya, Sri Lanka, Brazil, Venezuela, South Africa, Burkina Faso, and Germany that provide training, data, and establish lines of communication between citizens and the development community. CIKARD is currently in the process of compiling a method for the use of indigenous knowledge in a training manual.

In many data poor areas, expert judgement from resource experts may be used as data by utilising the Delphi method. Clearly, the success of the Delphi and other methods of utilising expert judgement depends greatly on the proper selection of the group of experts, who should have access to the best available information and most recent research in their respective fields of study. The usefulness of expert opinion also depends on the scope and depth of the expert's experiences and understanding of the problem.

9.2.1.4 Analogue scenarios

Another way to examine the possible effects of climate change on rangeland and livestock production systems is to use an analogous scenario from either another place or another time. There are four types of analogies, historical event, historical trend, regional analogies of present climate, and regional analogies of future climate.

Little research has been conducted using analogue scenarios to examine the potential effects of climate change on rangeland and livestock systems. Easterling et al. (1992) constructed a historical analogue climate scenario from climate records during the Dust Bowl era (1930-1940) in the Great Plains of the United States to determine the effects of climate change on agricultural production in the Missouri, Iowa, Nebraska, and Kansas region. Although this study did not analyse the effects of climate change on rangeland livestock, the team did examine the indirect effects of a changing climate on feed sources for animal production. An overview of this study can be found in Chapter 4, Integration.

An example of an analogue scenario would be examining rangeland livestock production practices in a region that has a current climate similar to the projected change in climate, in the region under study. Alternatively, the impact of historical events such as protracted drought or monsoons on livestock production could also be incorporated into the analysis, as described above. In each of these examples, the analysis would provide a basis for creating a qualitative or even a semi-quantitative description of potential impacts.

9.2.1.5 Empirical-statistical models

An empirical-statistical model can be used to explain system dynamics by empirically analysing the relationships between some defined input and output variable such as a particular climate variable and forage yield on livestock production. This type of model is relatively simple to develop and can have a very high accuracy of prediction over the range of data for which it was developed. However, these models do have limitations. Statistical models are descriptive and not mechanistic in nature. Thus they provide only limited insight into the mechanisms underlying the particular patterns of interest. They are also unsuited for predicting responses to novel situations for which no data are available.

The statistical model lends itself quite nicely, however, to predicting first-order effects of climate change on forage and livestock production. Bergthorsson (1985) developed a model from climate and livestock data to compute the potential of livestock production in Iceland. The computational accuracy of the model was tested against historical data. He then used temperature deviations from historical records to determine the potential impacts of climate change, with regard to temperature, on livestock production. For another application of the empirical-statistical method, see Box 9.1.

9.2.1.6 Life zone, bioclimatic, or eco-classification models

Life zone, bioclimatic, or eco-classification models are actually another type of empirical-statistical model. These models range from very simple models such as the Holdridge Life Zone model (Holdridge, 1967) to the more complex models as presented in Prendergast and Hattersley (1985), Rizzo and Wiken (1992), Wang Futang and Zhao Zong-Ci (1995), and Li Xia (1995). This modelling approach is useful for examining impacts of climate on regional vegetation. However, because bioclimatic models are based on correlation they are subject to all of the limitations of empirical-statistical models as discussed above.

9.2.1.7 Processed based simulation models

Over the past 20 to 25 years many simulation models have been constructed to simulate rangelands and livestock production. These models can be divided into three major categories: biophysical models, decision support systems, and integrated models. In keeping the discussion within the context of the goals of this Chapter, the group of models under the heading of ecosystem or biophysical models can be further subdivided into rangeland process models and rangeland livestock ecosystem models. This last group also includes pastoral livestock production systems.

The intent of this discussion is not prescriptive in nature nor is the list of models presented all inclusive. Rather, the discussion is meant to provide an overview of the models and methods that have been used and cited in the literature for the assessment of climate change in rangeland and livestock production systems. More information regarding model requirements and source contacts is listed in table 9.10.

Box 9.1 Example: Adaptation to climate change in the Argentine Pampas.

The region and the problem: The Argentine Pampas is a wide plain with approximately 60 million hectares of land mainly suited for cattle rearing and crop production. Based on its rainfall and soil quality patterns, the region may be divided in humid, sub-humid, and semi-arid zones. During the last century, various crop and cattle production activities were combined in different ways in each zone in response to the permanent environmental constraints and the cyclical climate variability. However, land-use options were also sensitive to economic conditions and technological factors. In this case, the problem was to assess how the rural sector has adapted to varying climate conditions by adjusting land-use strategies and other technological tactics.

Methods: Following a scheme suggested by Steffen and Ingram (1995) to integrate information, geographical and historical data were displayed along three intersecting axes: space, time, and adaptation response (Viglizzo et al., 1995, Viglizzo et al. 1997). The last one was not quantifiable, but it was necessary to identify different land use options that arose when a multilevel approach was utilised. Therefore, to understand the adaptive response of land-use to climate change, geographical data sets were analysed by scaling down along the space axis from the whole region to agro-ecological zones and specific sites. Similarly, historical sets of data were manipulated following a scale-dependent analysis which involved the last century as well as shorter periods of no more than three decades. Considering that rainfall was the climate variable which provided the greatest statistical variability both in space and time, a broad transect was displayed in the study region to cut across a wide rainfall gradient. Different sites were analysed along different periods of time. Thus different geographical and historical scales were combined in a multilevel approach. Long-term data sets on land use were compared with long-term data on climate (rainfall), economic (price of products), and technological (yield trend) factors. Comparisons were made within the transect for the whole region, the main agro-ecological zones (humid, sub-humid and semi-arid), and specific sites (political districts). Because price and production level of different farming activities were not comparable in absolute terms, relative indices were utilised for statistical analysis. Simple linear and quadratic regression analysis were used to associate the climate, economic, and technological factors with land-use change.

Adaptation assessment: The formal hypothesis was that climate might be the main force explaining changes in land use at the wider geographical space and the longer term, but factors other than climate (e.g., price and yield) would be explaining most of the land-use variance at the lower scales of time (few decades) and space (specific sites). But the results suggested that the hypothesis was partially wrong. Land-use variability tended to respond to climate variability only in the long term, but not to the variability of climate across the whole region. Thus the adaptive response of land use to climate change appeared to be a site-specific and a time-dependent function, mainly in the humid environments. As the environmental conditions turn drier in the western zones, the technology to improve water utilisation in soil appears to have more weight than land use in the adaptation process.

Policy options: Considering that the adaptation to climate change seems to be a site-specific and a time-dependent function, adaptive policies in the Pampas should be oriented to long-term strategies on specific sites instead of a generalised strategy for the whole region. Given that climate can drive both the relocation and translocation of the farming activities, a better climate scenario may show a negative impact on soil conservation, mainly in the fragile lands of the semi-arid zone, due to the uncontrolled expansion of crops at the expense of pastures and natural areas. A dramatic agro-ecological collapse of this kind occurred in the region during the 1930s and the 1940s. Since the natural reaction of farmers is to grow more annual crops when rainfall increases, a long-term land preservation strategy should be encouraged to counteract the potential undesirable effects of improved climate conditions.

The importance of this kind of historical assessments is that they can help to understand the autonomous adaptive behaviour of farmers to different climate conditions. This human dimension of the adaptive response would complement other options that can be assessed through the use of GIS, mathematical modelling, expert systems, and decision-support tools.

Sources: Steffen and Ingram (1995); Viglizzo et al. (1995); Viglizzo et al. (1997).

Where possible, the use of validated simulation models developed in or near the region of interest is highly recommended. These models are more likely to use data that are available for the region and incorporate system processes that are unique to the area of interest.

Biophysical models

Biophysical simulation models mechanistically simulate ecological and physiological processes. Because these models are process driven, they can be applied to many different environments and can also be used to test the sensitivity and stability of the system to a range of changes in climatic conditions. Box 9.2 is an example of the application of the process-based vegetation model BIOME to an analysis of rangelands in Southern Africa.

Box 9.2 Example: Rangelands and climate change in Southern Africa.

Hulme (1996) discusses the potential impacts of climate change on the 12 countries of the Southern African Development Community (SADC). Substantial attention is paid to rangelands, as pastoralism and ecotourism are major income earners in these countries.

Three climate scenarios were evaluated, one with reduced precipitation, one with unchanged precipitation, and one with increased precipitation. The scenarios are based on different GCMs. All three have higher temperatures. The climate scenarios were used as input to a generic model of potential vegetation (BIOME). Two of the three scenarios show a tendency towards more arid vegetation. Increased temperatures outweigh the enhanced water use efficiency due to higher ambient concentrations of carbon dioxide. Only the scenario with increased precipitation shows a modest tendency towards more moist vegetation.

The distribution of 44 wildlife species was assessed using regression models developed specifically for this project. The models consider only direct climatic influences on species distribution. For all three scenarios, an increase in species diversity was found, possibly furthering opportunities for tourism. The models also indicate that species are likely to move to different locations than where they can now be found. A similar exercise was undertaken for tsetse flies, mosquitoes and ticks. The spread of tsetse flies – a limiting factor to cattle – was found to decrease under all three scenarios.

The impact of these changes on livestock and pastoralists was assessed based on expert judgement. Two of the three scenarios were concluded to worsen production and development potentials for the regions as a whole, and perhaps substantially so in certain areas. The wet scenario was found to lead to little change or perhaps a slight improvement. Climate change thus seems to enhance current problems of population growth, weather variability, and soil degradation.

However, these models are very data intensive, and their major disadvantage is that complete data sets for parameterising and validating them rarely exist. Also, the models tend to be extremely complex, and a certain level of training and expertise is required to use the model effectively. Lastly, many of the models that have been used in this approach are point models, which require making simplifying assumptions when results are aggregated to the regional level.

Rangeland ecosystem

Currently, there are four well recognised models that have been used under a variety of environmental conditions and geographical locations to simulate the potential effects of climate change, including the effects of atmospheric concentrations of CO_2, on rangeland or pasture ecosystems (Table 9.4). The models either do not have an animal component or the herbivore model has been simplified, thus limiting livestock management options and the analysis of indirect effects of impacts on animal productivity.

Rangeland and livestock

The three models presented in Table 9.5 all contain a pasture or grassland model at the same level of detail as the animal model. As above, these models also simulate the effects of atmospheric concentrations of CO_2 and climate change impacts on the rangelands. The direct effects of climate change on animal production are simulated only by SPUR2. The indirect effects of climate change, reduction in performance due to changes in forage quality and quantity, are simulated by all three models. Only the Hurley pasture model simulates or considers carbon as contributed by methane.

One of the major limitations to all of the animal models listed in Table 9.5 is that they were developed in countries that have a livestock management system vastly different than the nomadic pastoralist systems often found elsewhere in the world. Therefore, adapting these models to this type of situation may be a daunting if not impossible task.

Decision support systems

Decision support system (DSS) models allow the user to examine the potential effects of management decisions in a given system based on a set of decision rules that have been formulated in the model. One such DSS, GRASSMAN, has been used to evaluate the effects of climate on livestock and pasture production as well as to predict changes in emissions and productivity (McKeon et al., 1993; Howden et al., 1994). GRASSMAN is an agricultural decision support model that allows users to investigate the effect and interactions between tree clearing, livestock and pasture management, and climate on pasture condition, animal performance, and paddock financial returns (Scanlan and McKeon, 1990). The model has been modified to include sources, sinks, and storage of greenhouse gases (CO_2, CH_4, N_2O, CO, and NO) in tropical and sub-tropical savannah woodlands of northern Australia (Howden et al., 1994).

Table 9.4 Rangeland ecosystem models that have been used for climate change impact assessment.

Model	Objective	Management options	Country of origin	Published international application	Advantages/ Disadvantages	Citation
CCGRASS	Evaluate the long-term effects of management and various environmental condition of soil carbon sequestration	Effects of grazing and mowing incorporated from experimental data.	The Netherlands	Unknown at the time of publishing	Well suited for management and climate interaction on soil and plant dynamics. Does not include the effects of herbivores.	Van den Pol van Dasselaar and Lantinga, 1995
CENTURY	Simulate C, N, P, and S dynamics for the plant-soil system for grassland and agricultural production	Seasonal effects of burning and grazing simulated.	United States	Africa, Asia, Europe, North America, and South America	Well suited for studying the long term effects of climate change on biogeochemical cycling; Seems to be very transportable to different regions of the world. Only simplified herbivore routine	Parton et al., 1987. This model has been widely used and cited. Recent review of model in Breymeyer et al., 1996
GEM	Explore the interactions of elevated CO_2 and changes in climate on grassland production, decomposition, and nutrient cycling.	Effects of grazing not simulated as the model is written.	United States	Not at the time of publishing (Personal communication, W. Hunt, NREL, 1997)	Well suited for studying the effects of climate on biogeochemical cycling. Model suited for temperate grasslands. Only simplified herbivore model	Hunt et al., 1991; De-Xing Chen et al., 1996
GRASS	Simulate shoot number, C, and N budget, energy balance, and water budget.	Original model design to assess impact of grazing on African grassland systems	Kenya and United States	Africa and North America	Well suited to African savannahs and grazing. Improved below ground model. Very physiologically based.	Coughenour, 1984 and Breymeyer et al., 1996

Table 9.5 Rangeland livestock production models that have been used for climate change impact assessment.

Model	Objectives	Management	Animal model	Country of origin	Published international applications	Advantages/Disadvantages[a]	Citation
Hurley Pasture Model	Simulate the fluxes of C, N, and water in linked soil, plant, and animal systems	Grazing is simulated	Mature, non-lactating sheep	England and Scotland	Unknown at the time of publishing	Allows for the study of soil-grass-animal interactions. The only model reviewed that has a sheep model. Like all the other models, many parameters are needed.	Thornley and Cannell, 1997
SPUR2	Simulate C and N dynamics for plant-soil system, simulate beef cattle production, and simulates plant herbivore interactions	Simulates simple to complex grazing management schemes. Multi-site or pastures	Contains 2 beef cattle models. A complex life cycle individual cow-calf model and a simple single yearling beef cattle model.	The United States	Asia, North America, and South America	Allows for the simulation of multiple sites, rotational type grazing, and simulates herd dynamics. However, herd model is complicated. Not suited for tropical or phosphorous limited soils.	Hanson et al., 1992
Topp and Doyle Model	Simulate changes above and below ground plant production, simulate grazing and dairy cow production.	Application of fertiliser, mowing, and grazing	Dairy cow production model that simulates growth, milk production, and grazing	Scotland	Unknown at the time of publishing	Allows for the simulation of dairy type cattle. Grass model is well suited for temperate conditions. Unsure of model performance in tropical conditions.	Topp and Doyle, 1996a&b

[a] The authors recommend that the steward of the model be consulted before deciding on the suitability of a particular model.

Integrated models

Integrated models can be considered to be a special case of process-based models in that they usually incorporate some type of process based simulation model with other methods such as GIS or databases or economic models. The objectives of these models are usually to attempt to model regional biophysical and socio-economic processes and interactions simultaneously (Rosenberg, 1993). The site or regional impacts can then be aggregated, where appropriate to regional or global impacts. Examples of this method included the integration of a site specific grassland ecosystem model, CENTURY, and a GIS (Burke et al., 1990); two regional models, CLIMPACTS (New Zealand focus) the US effort VEMAP (Kenny et al., 1995; Kittel et al., 1995); and a global model TEM (Melillo et al., 1993). The International Geosphere-Biosphere Programme's terrestrial transect program provides an excellent example of how many methods may be combined to examine climate driven impacts on terrestrial ecosystems. The transects are a set of integrated global change studies consisting of distributed observational studies and manipulative experiments coupled with modelling and synthesis activities organised along existing gradients of underlying global change parameters, such as temperature, precipitation, and land-use. The transects are 1000 kilometres long and are wide enough to encompass the dimensions of remote sensing images. They will be used to determine changes in terrestrial biogeochemical cycling, study the effects of global change on ecosystem composition and structure, and serve as a platform for studying the impacts of global change on various aspects of terrestrial ecosystems, such as production systems, soil processes, and ecological complexity. The initial set of transects are located in four key regions: (1) the humid tropics of the Amazon basin, central Africa, and Southeast Asia; (2) the semi-arid tropics in savannahs of west Africa, Kalahari (southern Africa), and northern Australia; and (3) the mid-latitude semi-arid grasslands of the US Great Plains, the Patagonia of Argentina; and north-eastern China; and (4) the high latitude boreal forest-tundra of Alaska, Canada, Scandinavia, and Siberia (IGBP, 1995).

9.2.1.8 Economic models

Several types of models can be used to evaluate the economic implications of the direct effects (first order impacts) of climate change on rangeland and livestock production systems for local and regional economies. Some of these models use outputs that are collected from the methods describe above as inputs for stand-alone economic models, and others are linked or integrated into biophysical simulation models. Chapter 8 describes relevant economic models in detail.

9.2.2 Selection of the method

Selection of the appropriate method to be used in the analysis is an extremely important step in conducting a meaningful impact analysis. The first and most important step in this process is defining a clear and concise statement of the problem and setting quantifiable goals and objectives for the assessment. Other issues that need to be considered are:

- Defining the scale, scope, and time horizon of the assessment;
- Assessing the availability, resolution, and quality of the data;
- Assessing the availability of human, technological, and financial resources.

It is important to think about method selection as an iterative process that is based on limiting factors. For example, goals and objectives may be set that require data that are unavailable or the institutional infrastructure may be unable to support computer intensive analyses.

Selection of the appropriate method may also be determined in context of the temporal and spatial resolution of results and time frame for conducting the analysis. The matrix presented in Table 9.6 combines these criteria with a ranking of data and resource needs presented above. Where a range of scores are provided, it is assumed that techniques may range from the very simple to the extremely complex.

9.3 Scenarios

Discussions of socio-economic and climate change scenario development are covered in detail in Chapters 2 and 3, respectively. Regardless of what future climates have in store for the world, establishing climatological and socio-economic baselines is essential for detecting and measuring change.

9.3.1 Climatological baseline

Rangeland ecosystems are event driven systems in that the amount and timing of precipitation, fire, and grazing, as well as other activities, have the capacity to alter the structure and function of the ecosystem. Extreme climatic events such as prolonged droughts or monsoons also have the potential to alter the trajectory of these systems. Therefore, baseline climate data should be from as long a period as possible to capture the frequency of extreme events. The usual climate variables needed for rangeland livestock production systems include temperature, precipitation, solar radiation, wind run, and in some cases humidity. The resolution of the data, maximums and minimums, daily, monthly, seasonal, or yearly averages, will depend on the method or model employed.

Table 9.6 Summary of methods.

Method	Temporal scale of results	Spatial scale of results	Time to conduct analysis	Data needs	Skill or training required[a]	Technological resources	Financial resources $ -Low; $$-Moderate; $$$-High
Experimental	Season to decades	Site	Months to years	Needs little data. The data are generated.	Specialised training in the discipline of study.	Depends on the complexity of the study. Farming Systems oriented research to long term ecological studies.	Dependent on the scope of the project. Can vary from farming systems research to long-term ecological studies. $ to $$$
Screening techniques (including GIS & remote sensing)	Snapshot at a particular time	Site to national	Several week to months. If monitoring changes in systems then possibly years.	Simple screening processes can be accomplished with little data. The purpose is to identify not only risk but also gaps in knowledge and data.	Training required in area of study. GIS and remote sensing techniques require specialised training.	Complexity of the analysis will determine. Simple map, tabular data, personal computers. Even satellite data may be utilised on PC's if technically expertise is available.	Dependent on the complexity of the analysis, techniques being utilised and if equipment is needed. $ to $$
Expert judgement	Years to decades	Site to region	Days, weeks, or a few months	Very little data needed.	Requires wide experience in field of study and good understanding of processes involved.	Little technology is needed.	Depends on the number of consultants being employed and fees being paid for local and international consultants. $ to $$
Analogue	Decades	Site to national	Weeks to months. Depends on the availability of data	Data dependent. The quality and quantity of data must be sufficient to construct a meaningful analogy.	Training required in area of data analysis.	Very little technical resources are needed. Most can be accomplished on a personal computer.	Depends on data availability, personnel, and if additional equipment is needed for the analysis. $$
Empirical-statistical	Season to decades	Site to national	Weeks to months. Dependent on the availability of data.	Requires enough data to construct a meaningful statistical model. For example, data of several decades would be required to capture normal fluctuations in climate data.	Requires specialised training in statistical analyses.	Very little technical resources are needed. Most can be accomplished on a personal computer. Sophistication of necessary software is model dependent.	Depends on data availability, personnel, and if additional equipment is needed for the analysis. $$

9.3.2 Socio-economic baseline

The socio-economic baseline describes the present state of non-climatic factors that affect rangeland livestock production systems. Information needed to establish this baseline may include the following variables: vegetation cover (type and extent); soil characteristics (depth, texture, properties, etc.); estimations of soil organic matter, topography, and mean atmospheric concentration of CO_2 or other trace gases; and other non-climatic environmental variables. Socio-economic factors include land use, water use, management practices (e.g., grazing management schemes), economic factors (e.g., contribution to GNP, price of market outputs such as meat, milk, hide, wool, etc.), food demand, social variables (employment, settlements), structure or land tenure. Socio-economic factors are not likely to remain static; therefore, it is important that baseline conditions of the most important and relevant factors are considered in the assessment.

9.4 Autonomous adaptation

Adaptations may be classified as either autonomous, which usually refers to adjustments made within the system, or planned, which refers to adjustments that are external to the system such as adjustments that are initiated or prompted by public policy (Smit, 1993; Carter et al., 1994). Clearly, rangelands and the people who derive their livelihood from these systems have some degree of inherent adaptability. The degree to which these systems can adapt and remain productive for their defined use depends on the magnitude, timing, frequency, and duration of the disturbance.

Autonomous adaptation in rangeland livestock production systems can be defined in terms of ecological processes and human management decisions. From an ecological standpoint the limit of the system’s ability to adapt depends on the rate of change of the disturbance relative to the inherent rate of change in the system and to changes that have occurred during the evolution of the system. The sustainability of the system as a productive source of food for livestock and wildlife is directly related to how human management practices adjust to the disturbance as well.

In terms of human adaptation, the nature and processes of adaptation to climate are poorly understood and rarely directly investigated (Smithers and Smit, 1997). Although the process and nature of adaptation may be elusive given the current state of knowledge, evidence does exist, through the persistence of agricultural practices, that cattle farmers make autonomous changes, both tactically and strategically, to offset the effects of disruptions in the system (Table 9.7).

Table 9.7 Possible types of climate induced autonomous adaptations in rangeland livestock production systems.

Rangeland ecosystems	Shifts in biological diversity Shifts in species composition Shifts in species distribution
Livestock farmers	Change in grazing management (timing, duration, and location) Change in mix of grazers or browsers Change in supplemental feeding Change in location of watering points Change in breeding management Changes in rangeland management practices Change in operation production strategies Change in market strategies

The selection of impact method will determine the type of adaptation analysis that can be performed. Some of the methods will allow for conducting the assessment directly whereas in other cases, the adaptation assessment will have to conducted by using output generated from the impact assessment (Table 9.8).

Table 9.8 Suitability and scale of impact method for adaptation assessment.

Impact analysis method	Suitability for adaptation assessment	Scale of assessment
Expert judgement	Information used to conduct separate assessment	Farm level to national (possibly global)
Analogue	Output used to conduct separate assessment	Regional to national
Empirical-statistical	Output used to conduct separate assessment	Farm level to national
Life zone or bioclimatic model	Output used to conduct separate assessment	Regional to global
Biophysical models, decision support systems, integrated models	Assessment may be conducted within the context of the model	Farm level to global
Economic models	Assessment may be conducted within the context of the model	Farm level to global

In the discussion on the usefulness of experimentation for impact assessment, the statement was made that this method had limited application. However, if improvements are to be made on the estimates of potential impacts of climate change on agriculture, there is a need to know more about the processes in which ranchers perceive and respond to changes in climate (Smit et al., 1996). Perhaps an empirical analysis of autonomous adaptation, such as the method used by Smit et al. (1996), should be included into the impact and adaptation assessment or conducted as a corollary.

9.5 Planned adaptation

Smit et al. (1996) state that a distinction can be made between effects that are direct, short-term changes made in response to climate change, and responses and adaptations that are purposeful and conscious decisions made in reaction to the effects, which alter the nature of farming and regional agricultural systems. The focus of this section is on those strategic adaptations that would change the face of rangeland livestock production for a given region. Adaptations such as these are usually a result of governmental or public policy actions. (However, some of the measures mentioned here could be classified as autonomous agriculturist adaptations as well.) The following lists were compiled from recommendations made by IPCC WG II (1996).

Adaptations that facilitate production under a changing climate. The actions would be undertake by individual ranchers, but incentives, information, and assistance may be provided by governmental agencies.

- use vegetative barriers or snow fences to catch snow and increase soil moisture;
- use windbreaks to protect soil from erosion;
- reduce stocking rates;
- use feed conservation techniques and fodder banks;
- improve nutritional plane by using protein, vitamin, and mineral supplements;
- change in mix of grazing or browsing animals;
- alter animal distribution by the use of mineral blocks, watering points, and fences;
- start weed management program;
- restore degraded areas;
- increase native rangeland vegetation or plant adapted species.

Adaptations that are undertaken by government and are purposeful and strategic, although, they can be either short or long in duration.

- modify price supports and other governmental programs to encourage cattle farmers to respond quickly to climate change such as commodity co-operatives and marketing boards, stabilisation programs and subsidies, and tariffs and other trade barriers;
- develop large-scale watershed projects;

- encourage production in the most efficient area by discouraging the use of marginal lands and protecting areas that are degraded;
- if shifts in location occur, establish new farm to market links if necessary; purchase rights of way before land appreciates;
- prepare for veterinary animal health services for the spread of diseases and parasites;
- develop breeding programs;
- develop agroforestry systems;
- if production is declining, allow for more importation;
- if climate change seriously undermines the viability of the animal production sector, develop support measures to fulfil other social objectives such as food security and preservation of the rural community, induce a movement out of agriculture through macroeconomic policies to assure that employment will be available outside of agriculture, develop policies and institutions that facilitate movement between sectors, create positive incentives for people to leave agriculture, stable economic growth, and provide education.

All adaptive responses to climate change have associated pros and cons that will be experienced biophysically, socially or culturally, and economically. The IPCC WG II on rangelands developed a matrix of possible practices to mitigate the impacts on climate change in rangeland production systems. A modified version of the matrix is presented in Table 9.9.

Table 9.9 Pros and cons of selected adaptation strategies.

Strategy	Biophysical	Social or cultural	Economic	Comment
Reduce stocking rates	Increase in plant cover, soil organic matter, and improve productivity on unhealthy rangelands	Country dependent and the value of animals as a social resource	Depends on the value of livestock products to local and national economies	May require changes in regional or national food production policies
Change the mix of grazing or browsing animals	Potential shift in plant species composition	Country dependent and the cultural value of specific types of animals	Depends on the value of livestock products	In general would produce positive effect through more efficient use of resources
Change animal distribution via mineral supplement blocks	Depends on minerals present in the rangeland	Not appropriate where animals are herded	Cost of purchase and distribution	Generally positive but not applicable to herding systems
Change animal distribution by water points	Developed water source may not be sustainable	May affect territory and property boundaries	Motorised sources too costly	Negative impacts if used to increase stocking rate
Use fences	Benefit to control domestic animals	Country dependent and livestock/wildlife system	Varies depending on country, source, and kind of material used for construction	Potential to interfere with wildlife migration
Use feed supplements	May reduce extensive grazing	Possible where animals are herded	Cost are often large but may increase production may offset cost	Potentially difficult to distribute to local areas
Increase native vegetation or plant adapted species	Benefit in retention of native species for gene conservation	Local people may rely on native species for medicines, etc.	Depends on the value of livestock and wildlife products, and the value of herbal medicine	Potential unknown benefits from native species; adapted species survive over the long term
Use herbicides	Cost if non-target species affected water pollution, damage to food chain	Same as biophysical plus possible removal of firewood sources	Varies depending on country and source of herbicide	Costs or benefits depend on meeting management goals
Implement agroforestry systems	Possible benefit with increased plant cover, diversity, and productivity	Potential benefit with change in grass/browse forage mix for livestock and wildlife	Cost of planting and maintaining	Increases carbon storage in trees; benefit in diversity and productivity if adapted species used
Develop large-scale watersheds	Potential for large land disturbances. Benefit to human and animal populations because of regulated and regular water supply. Harm to aquatic ecosystems	Potential for improved food production for both plants and animals	Costs of dam, etc.; benefit of hydroelectric power	Potential for increased human and animal populations because of increased water availability

Source: IPCC (1996)

9.6 Summary and implications

A variety of methods and modelling approaches have been presented in this chapter to assess the impacts of climate change on rangeland and livestock production systems. The choice of method to be used depends on the goals and objectives of the assessment, the quality and quantity of data available, and the availability of human, technological, and financial resources for the assessment. The scope of the analysis should be limited to those areas where impacts are likely to be the greatest and where the most meaningful analysis can be performed.

Often in climate change impact assessments more time and capital is spent investigating first order biophysical responses to climate driven impacts. The authors wish to stress the importance of spreading resources evenly among the assessment of second order responses to impacts and conducting thorough and meaningful adaptation assessments. Only by carefully assessment and reporting of these higher order effects can the importance of the potential impacts be conveyed to policy makers.

A spatial or geographical dimension is a feature common to most of the outputs or variables that indicate change in the impact analysis. Consequently, a quick and powerful way to display the results of the analysis is through the use of maps. These maps may be created by sophisticated computer GIS software or by hand. Other more conventional methods such as clear and concise charts or table are also useful for presentation of results.

What lies in the future for rangeland and livestock impact analyses? Many studies have been conducted on the potential effects of climate change on rangeland ecosystems. Most of this work has been directed toward examining climate driven impacts on ecological processes in rangelands. As a result, several models have been developed and validated for predicting changes in rangeland ecosystem processes.

However, by comparison, little work has been done to assess the effects of climate change on livestock production in rangeland ecosystems. The majority of the studies that have included livestock have been conducted in developed countries. Consequently, the models used in these studies tend to reflect the conditions and assumptions that exist in these more intensively managed production schemes. There is a definite need for the development of a robust model or suite of models that can be used to examine climate impacts on livestock and rangelands over a wide range of environments and management practices. These models should be developed in such a manner that output variables would be meaningful and useful as inputs to economic, socio-economic, and adaptation assessment analyses. The development of such methods will improve our ability to assess the future of the people whose livelihoods depend on the sustainability of rangelands.

Table 9.10 Documentation and source for grassland and grassland/livestock models.

Model name	CCGRASS Carbon Cycle of Grasslands
Model type	Mechanistic simulation model
Model purpose	To simulate the carbon cycle of grassland soils. Simulates the effect of atmospheric concentrations of CO_2 on biogeochemical processes
Citation information	Van den Pol van Dasselaar and Lantinga, 1995
Model developer	A. Van den Pol van Dasselaar
Model validated	Yes
Model input data requirements	Site specific data (above and below ground C, N application, mowing and grazing regimes) and climate data
Model output data	Carbon fluxes
Temporal scale	annual to several decades
Spatial scale	Site
Programming language	
Computer requirements	
Agency	Wageningen Agricultural University
Office location	Wageningen, The Netherlands
Office name	Dept. of Theoretical Production Ecology
Contact	A. Van den Pol van Dasselaar
Title	
Address	P.O. Box 430, NL-6700 AK Wageningen, The Netherlands
Telephone	
Fax	
E-mail	

Model name	Century
Model type	Predictive, simulation, process, deterministic
Model purpose	Analysis of soil organic matter dynamics in response to changes in management and climate
Citation information	Parton, et. al., 1987
Model developer	W.J. Parton et al. Agricultural Research Service and CSU support through NREL
Model validated	Yes
Model input data requirements	Driving variables: monthly mean max. and min. air temperatures, mean precipitation. State variables: soil texture, soil depth, vegetation types, management system type (e.g., grasslands, agroecosystems, forest), CO_2 levels, and C14 enrichment.
Model output data	Carbon, nitrogen, and phosphorous fluxes, net primary production, seasonal organic matter
Temporal scale	One month to thousands of years
Spatial scale	point model (1 square meter)
Programming language	FORTRAN 77, possibly recoding to C, DOS, and UNIX versions
Computer requirements	Information available from Bill Parton
Agency	Colorado State University
Office location	Fort Collins, CO, USA
Office name	Natural Resource Ecology Laboratory
Name	Bill Parton
Title	Senior Ecologist
Address	NREL, Colorado State University, Fort Collins, CO 80523 USA
Telephone	970-491-1987

Table 9.10 Documentation and source for grassland and grassland/livestock models - continued.

Model name	GEM and GEM2 Grassland Ecosystem Model
Model type	Predictive, simulation, process, deterministic
Model purpose	Interprets the results of field experiments on two different grassland ecosystems (native shortgrass prairie C4 and old stand of introduced perennial C3). Explores interactions of elevated CO_2, and elevation of temperature on grassland production, decomposition, and nutrient cycling.
Citation information	Hunt et al., 1991 (GEM); De-Xing et al., 1996 (GEM2)
Model developer	H.W. Hunt
Model validated	Yes
Model input data requirements	Driving variables: daily precipitation, weekly max. and min. air temperatures, wind speed, relative humidity, monthly mean soil temperatures. State variables: soil and inorganic ammonium nitrate data. Other data requirements for other situations, e.g., growth parameters
Model output data	State variables versus time (can be short-term weekly, or long-term). Main focus is seasonal
Temporal scale	
Spatial scale	Point model
Programming language	FORTRAN 77 6600 lines of code
Computer requirements	Sun SPARC1
Agency	Colorado State University
Office location	Fort Collins, Colorado, USA
Office name	Natural Resource Ecology Laboratory
Name	H. William Hunt
Title	

Model name	GRASS
Model type	Ecophysiologically processed based simulation model
Model purpose	Simulates physiological and morphological traits of plants, tillering and C and N budgets, light penetration, and soil water and heat budgets. Originally developed to simulate the effects of grazing on African grasslands. Effects of atmospheric CO_2 simulated
Citation information	Coughenour, 1984
Model developer	M.B. Coughenour
Model validated	Yes
Model input data requirements	driven daily weather data and initial conditions for state variables
Model output data	C and N fluxes, net primary production, seasonal organic matter
Temporal scale	time step of two hours for diurnal processes and two days for other plant growth processes. One month to decades
Spatial scale	Point or site model
Programming language	FORTRAN
Computer requirements	Personal computer
Agency	Colorado State University
Office location	Fort Collins, CO USA
Office name	Natural Resource Ecology Laboratory
Name	Michael Coughenour
Title	Senior Research Scientist
Address	NREL, Colorado State University, Fort Collins, CO 80523 USA
Telephone	970-491-5572
Fax	970-491-1965

Table 9.10 Documentation and source for grassland and grassland/livestock models - continued.

Model name	Hurley Pasture Model
Model type	A generic ecophysiologically processed based simulation model
Model purpose	To simulate the fluxes of carbon, nitrogen, and water in a grazed soil-pasture-atmosphere system, coupling the C an N fluxes, and modulating the fluxes by the plant and soil water status.
Citation information	Thornley and Cannell, 1997
Model developer	J.H.M. Thornley
Model validated	yes
Model input data requirements	Latitude, N input, windspeed, relative humidity, photosynthetically active radiation, air temp, soil temp, precip., stocking rate for sheep. [Plant submodel: 21 state variables and 60 parameters; Soil and Litter submodel: 15 state variables and 68 parameters; Animal submodel: 2 state variables and 9 parameters; Water submodel: 3 state variables and 40 parameters]
Model output data	C and N fluxes and state variables versus time:
Temporal scale	yearly to decades
Spatial scale	site
Programming language	unknown at time of publishing
Computer requirements	unknown at time of publishing
Agency	Institute of Terrestrial Ecology
Office location	
Office name	
Name	Dr. J.H.M. Thornley
Title	
Address	Bush Estate, Penicuik, Midlothian, EH26 0QB, UK

Model name	SPUR — Simulating Production and Utilization of Rangelands (version 2.0)
Model type	Predictive, simulation, process, deterministic
Model purpose	To determine and analyse management scenarios as they affect rangeland sustainability. Examines the effect of climate change on livestock production and grassland productivity.
Citation Information	Hanson et al., 1992
Model developer	Jon Hanson
Model validated	Yes
Model input data requirements	Driving variables: daily precipitation, max. and min. air temperatures, wind run and solar radiation. State variables: soil and plant data, CO_2 levels, animal performance data. See simulation set-up handbook
Model output data	State variables versus time plant and soil carbon and nitrogen, animal production data
Temporal scale	Daily time step; 1 to 80 years
Spatial scale	Point model applied up to 36 sites
Programming language	FORTRAN 77 (enhanced) 20,000 lines of code
Computer requirements	minimum requirements 486 CPU and 8 MB RAM
Agency	Agricultural Research Service
Office location	Fort Collins, Colorado USA
Office name	Great Plain Systems Research Unit
Name	Jon Hanson
Title	Supervisory Range Scientist
Address	USDA, ARS, NPA P.O. Box E , Fort Collins, CO 80522 USA

Table 9.10 Documentation and source for grassland and grassland/livestock models - continued.

Model name	Topp and Doyle Model
Model type	Predictive, simulation, process, deterministic
Model purpose	Simulate pure grass and grass-white clover swards. Examine the effects of changes in temperature and precipitation regimes and CO_2 on herbage production. Simulate grazing by dairy cattle. Examine the effects that changes in temperature and precipitation regimes and CO_2 may have on milk production and silage conservation.
Citation information	Topp and Doyle (1996a &b)
Model developer	Cairistiona Topp and Christopher Doyle
Model validated	yes
Model input data requirements	Five driving variables, mean daily temperature, photosynthetically active radiation, atmospheric [CO_2], available moisture, and available nitrogen. Initial conditions for 5 plant model state variables. For the animal model there are 8 state variables.
Model output data	State variables versus time plant and animal production data
Temporal scale	Daily
Spatial scale	Site
Programming language	Unknown at the time of publishing
Computer requirements	Unknown at the time of publishing
Agency	The Scottish Agricultural College
Office location	
Office name	
Name	Cairistiona Topp and Christopher Doyle
Title	
Address	Auchincruive, Ayr KA6 5HW, UK

References

Antle, J.M. 1995. Climate change and agriculture in developing countries. *American Journal of Agricultural Economics* 77, 741-746.

Baker, B.B., and J.D. Hanson. 1993. Simulating the effects of climate change on beef cattle production: A methodology for determining simulation sites. In *Proceedings of 46th Annual Meetings, Society Range Management.* pp. 9-10.

Baker, B.B., J.D. Hanson, R.M. Bourdon, and J.B. Eckert. 1993. The potential effects of climate change on ecosystem processes and cattle production on U.S. rangelands. *Climatic Change* 25, 97-117.

Bergthorsson, P. 1985. Sensitivity of Icelandic agriculture to climatic variation. *Climatic Change* 7, 111-127.

Breymeyer, A.I., D.O. Hall, J.M. Melillo, and G.I. Ågren (eds). 1996. *Global Change: Effects on Coniferous Forests and Grasslands.* Scientific Committee on Problems of the Environment 56, John Wiley & Sons, Chichester, United Kingdom.

Burke, I.C., D.S. Schimel, C.M. Yonker, W.J. Parton, L.A. Joyce., and W.K. Lauenroth. 1990. Regional modeling of grassland biogeochemistry using GIS. *Landscape Ecology* 4, 44-54.

Carter, T.R., M.L. Parry, S. Nishioka, and H. Harasawa. 1994. *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations.* University College, London, and Center for Global Environmental Research, Tsukuba, Japan.

Coughenour, M.B. 1984. A mechanistic simulation analysis of water use, leaf angles, and grazing in east African graminoids. *Ecological Modelling* 26, 203-230.

De-Xing Chen, H.W. Hunt, and J.A. Morgan. 1996. Responses of a C_3 and C_4 perennial grass to CO_2 enrichment and climate change: Comparison between model predictions and experimental data. *Ecological Modelling* 87, 11-27.

Du Preez, J.H., W.H. Giesecke, and P.J. Hattingh. 1990. Heat stress in dairy cattle and other livestock under southern African conditions. I. Temperature-humidity index mean values during the four main seasons. *Onderstepoort Journal of Veterinary Research* 57, 77-89.

Easterling, W.E., N.J. Rosenberg, M.S. McKenney, and C.A. Jones. 1992. An introduction to the methodology, the region of study, and a historical analog of climate change. *Agricultural and Forest Meteorology* 59, 3-15.

Eckert, J.B., B.B. Baker, and J.D. Hanson. 1995. The impact of global warming on local incomes from range livestock systems. *Agricultural Systems* 48, 87-100.

Gonzàlez-Meler, M.A., B.G. Drake, and J. Azcón-Bieto. 1996. Rising atmospheric carbon dioxide and plant respiration. In *Global Change: Effects on Coniferous Forests and Grasslands,* A.I. Breymeyer, D.O. Hall, J.M. Mellilo, and G.I. Ågren (eds), Scientific Committee on Problems of the Environment 56, John Wiley & Sons, Chichester, United Kingdom, pp. 161-181.

Hall, D.O., D.S. Ojima, W.J. Parton, and J.M.O. Scurlock. 1995. Response of temperate and tropical grasslands to CO_2 and climate change. *Journal of Biogeography* 22, 537-547.

Hammond, A., A. Adriaanse, E. Rodenberg, D. Bryant, and R. Woodward. 1995. *Environmental Indications: A Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development.* World Resources Institute, New York.

Hanson, J.D., B.B. Baker, and R.M. Bourdon. 1992. *SPUR2 Documentation and User's Guide*. U.S. Department of Agriculture, ARS, Great Plains Systems Research Technical Report-1, Fort Collins, Colorado, USA.

Hassan, H.M. and C. Hutchinson (eds). 1992. *Natural Resource and Environmental Information for Decision Making.* The World Bank, New York.

Holdridge, L.R. 1967. *Life Zone Ecology.* Tropical Science Centre, San Jose, California, USA.

Howden, S.M., D.H. White, G.M. McKeon, J.C. Scanlan, and J.O. Carter. 1994. Methods for exploring management options to reduce greenhouse gas emissions from tropical systems. *Climatic Change* 27, 49-70.

Hulme, M. (ed). 1996. *Climate Change and Southern Africa: An Exploration of Some Potential Impacts and Implications in the SADC Region.* Climate Research Unit, University of East Anglia, Norwich, United Kingdom, and WWF International, Gland, Switzerland.

Hunt, H.W., M.J. Trlica, E.F. Redente, J.C. Moore, J.K. Detling, T.G.F. Kittle, D.E. Walter, M.C. Fowler, D.A. Klein, and E.T. Elliot. 1991. Simulation model for the effects of climate change on temperature grassland ecosystems. *Ecological Modelling* 53, 205-246.

IGBP. 1992. *Global Change. Reducing the Uncertainties.* International Geosphere-Biosphere Programme, Stockholm, Sweden.

IGBP. 1995. *The IGBP Terrestrial Transects: Science Plan*. Global Change Report No. 36. International Geosphere-Biosphere Programme, Stockholm, Sweden.

IPCC. 1996. *Climate Change 1995. Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution f Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change.* R.T. Watson, M.C. Zinyowera, R.H. Moss (eds). Cambridge University Press, Cambridge.

Kenny, G.J., R.A. Warrick, N.D. Mitchell, A.B. Mullan, and M.J. Salinger. 1995. CLIMPACTS: an integrated model for assessment of the effects of climate change on the New Zealand environment. *Journal of Biogeography* 22, 883-895.

Kittel, T.G.F., N.A. Rosenbloom, T.H. Painter, D.S. Schimel, and VEMAP Modelling Participants. 1995. The VEMAP integrated database for modelling United States ecosystem/vegetation sensitivity to climate change. *Journal of Biogeography* 22, 857-862.

Li Xia. 1995. Modelling the response of vegetation in North-East China transect to global change. *Journal of Biogeography* 22, 515-522.

Linstone, H. and M. Turoff (eds). 1975. *The Delphi Method: Techniques and Applications.* Addison-Wesley Publishing Company, Reading, Massachusetts, USA.

Long, S.P., C.P. Osborne, and S.W. Humphries. 1996. Photosynthesis, rising atmospheric carbon dioxide concentration and climate change. In *Global Change: Effects on Coniferous Forests and Grasslands,* A.I. Breymeyer, D.O. Hall, J.M. Mellilo, and G.I. Ågren (eds), Scientific Committee on Problems of the Environment 56, John Wiley & Sons, Chichester, United Kingdom, pp. 122-159.

McKeon, G.M., S.M. Howden, N.O.J. Able, and J.M. King. 1993. Climate change: adapting tropical and sub-tropical grasslands. In *Proceeding of the XVIIth International Grassland Congress,* Palmerston North, New Zealand, pp. 1181-1190.

Melillo, J.M. 1996. Elevated carbon dioxide, litter quality, and decomposition. In *Global Change: Effects on Coniferous Forests and Grasslands,* A.I. Breymeyer, D.O. Hall, J.M. Mellilo, and G.I. Ågren (eds), Scientific Committee on Problems of the Environment 56, John Wiley & Sons, Chichester, pp. 199-206.

Melillo, J.M., A.D. McGuire, D.W. Kicklighter, B. Moore, III, C.J. Vörösmarty, and A.L. Schloss. 1993. Global climate change and terrestrial net primary production. *Nature* 363, 234-240.

Norton-Griffiths, M. 1988. Aerial point sampling for landuse surveys. *Journal of Biogeography* 15, 149-156.

Ojima, D.S., T.G.F. Kittel, T. Rosswall, and B.H. Walker. 1991. Critical issues for understanding global change effects on terrestrial ecosystems. *Ecological Applications* 3, 316-325.

Parry, M.L., and T.R. Carter. 1989. An assessment of the effects of climate change on agriculture. *Climatic Change* 15, 95-116.

Parry, M.L., T.R. Carter, and N.T. Konijn (eds). 1988. *The Impact of Climatic Variations on Agriculture Volume 2: Assessments in Semi-Arid Regions.* Kluwer, Dordrecht, The Netherlands.

Parry, M.L., J.H. Porter, and T.R. Carter. 1990. Agriculture: Climate change and its implications. *TREE* 5(9), 318-322.

Parton, W.J., D.S. Schimel, C.V. Cole, and D.S. Ojima. 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Science American Journal* 51, 1173-1179.

Paustian, K., E.T. Elliot, H.P. Collins, C.V. Cole, and E.A. Paul. 1995. Use of a network of long-term experiments for analysis of soil carbon dynamics and global change: The North American model. *Australian Journal of Experimental Agriculture* 35, 929-39.

Prendergast, B.J. and P.W. Hattersley. 1985. Distribution and cytology of Australian Neurachne and its allies (Poaceae), a group containing C3, C4, and C3-C4 intermediate species. *Australian Journal of Botany* 33, 317-336.

Rizzo, B. and E. Wiken. 1992. Assessing the sensitivity of Canada’s ecosystems to climate change. *Climatic Change* 21, 37-55.

Rosenberg, N.J. (ed). 1993. Towards an integrated impact assessment of climate change: The MINK study. *Climatic Change* (Special Issue) 24, 1-173.

Scanlan, J.C. and G.M. McKeon. 1990. *GRASSMAN.* Queensland Department of Primary Industries, Brisbane, Queensland, Australia.

Shaver, G.R. and J.D. Aber. 1996. Carbon and nutrient allocation in terrestrial ecosystems. In *Global Change: Effects on Coniferous Forests and Grasslands,* A.I. Breymeyer, D.O. Hall, J.M. Mellilo, and G.I. Ågren (eds). Scientific Committee on Problems of the Environment 56, John Wiley & Sons, Chichester, United Kingdom, pp. 183-198.

Smit, B.D. 1993. *Adaptation to Climatic Variability and Change: Report of the Task Force on Climatic Adaptation.* Canadian Climate Program Board Department of Geography, University of Guelph, Occasional Paper No. 19. Environment Canada, Downsview, Ontario.

Smit, B., D. McNabb, and J. Smithers. 1996. Agricultural adaptations to climatic variation. *Climatic Change* 33, 7-29.

Smithers, J. and B. Smit. 1997. Human adaptation to climatic variability and change. *Global Environmental Change* 7(2), 129-146.

Steffen, W.L. and J.S. Ingram. 1995. Global change and terrestrial ecosystems: an initial integration. *Journal of Biogeography* 22, 165-174.

Stem, E., G.A. Mertz, J.D. Stryker, and M. Huppi. 1989. Changing animal disease patterns induced by the greenhouse effect. In *The Potential Effects of Global Change on the*

United States: Appendix C — Agriculture, Volume 2. J. Smith and D.A. Tirpack (eds). US Environmental Protection Agency, Washington, D.C., pp. 11-1 to 11-38.

Tate, K.R., A. Parshotam, and D.J. Ross. 1995. Soil carbon storage and turnover in temperate forests and grasslands — a New Zealand perspective. *Journal of Biogeography* 22, 695-700.

Thornley, J.H.M. and M.G.R. Cannell. 1997. Temperate grassland responses to climatic change: An analysis using the Hurley Pasture Model. *Annals of Botany* 80, 205-221.

Topp, C.F.E. and C.J. Doyle. 1996a. Simulating the impact of global warming on milk and forage production in Scotland: 1. The effects on dry matter yield of grass and grass-white clover stands. *Agricultural Systems* 52 (2/3), 213-242.

Topp, C.F.E. and C.J. Doyle. 1996b. Simulating the impact of global warming on milk and forage production in Scotland: 2. The effects on milk yields and grazing management of dairy herds. *Agricultural Systems* 52 (2/3), 243-270.

Van den Pol van Dasselaar, A. and E.A. Lantinga. 1995. Modelling the carbon cycle of grassland in the Netherlands under various management strategies and environmental conditions. *Netherlands Journal of Agricultural Science* 43, 183-194.

Viglizzo, E.F., Z.E. Roberto, M.C. Filippín, and A.J. Pordomingo. 1995. Climatic variability and agroecological change in the Central Pampas of Argentina. *Agriculture, Ecosystems, and Environment* 55, 7-16.

Viglizzo, E.F., Z.E. Roberto, F. Lértora, E. López Gay, and J. Bernardos. In press. Climate and land-use change in field-crop ecosystems of Argentina. *Agriculture, Ecosystems, and Environment.*

Walker, B. 1994. Global change strategy options in the extensive agricultural regions of the world. *Climatic Change* 27, 39-47.

Wang Futang and Zhao Zong-Ci. 1995. Impact of climate change on natural vegetation in China and its implication for agriculture. *Journal of Biogeography* 22, 657-664.

WRI. 1996. *World Resources, 1996-1997.* World Resources Institute, Oxford University Press, New York and Oxford.