EVALUATION OF THE EFFECTS OF CLIMATE CHANGE ON FORAGE AND LIVESTOCK PRODUCTION AND ASSESSMENT OF…

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EVALUATION OF THE EFFECTS OF CLIMATE CHANGE ON FORAGE AND LIVESTOCK PRODUCTION AND ASSESSMENT OF ADAPTATION STRATEGIES ON THE CANADIAN PRAIRIES

A report to the Prairie Adaptation Research Collaborative

Canadian Climate Change Action Fund

By

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ABSTRACT

An understanding of adaptation of plant and animal systems in response to changes in climate will help to reduce the risk involved in livestock production. Climate change will affect a large array of systems. Forage and livestock production will not be excluded from the impact of climate change. The purpose of this study was to understand the concept of adaptation and to integrate adaptive management strategies within the beef industry. A case study was undertaken at three locations to determine the impact of climate change as predicted by the CGCM1 model on livestock production. Three adaptation strategies were devised namely an early turnout date, intensive early season grazing and an extended grazing season. These were applied to simulation for the years 2051-2090. The results should only be considered as only an example of the possible responses to climate change.

A climate change scenario was created using the Canadian Climate Change model (GCM1) and integrated into the GrassGro Decision Support System (DSS). Three adaptation strategies were tested in comparison to a baseline simulation (1961-1990) for 2 pasture associations, Russian wildrye/alfalfa (RWR/ALF) and Crested Wheatgrass (CWG) at three locations Melfort, Saskatoon, Swift Current, Saskatchewan. Climate change predictions were simulated for the years 2051-2080. The effects of climate change on livestock production were complex and results were variable for each site. The effects were more prominent at Saskatoon than Melfort and Swift Current, reflecting strong regional specificity and variability.

The adaptation strategies were more successful for RWR/ALF than for CWG pasture at Melfort and Swift Current while CWG appeared to be more successful at Saskatoon. Indeed, the results suggest that productivity of beef cattle grazing RWR/ALF pastures at Melfort and Swift Current could be enhanced with climate change. However, Russian wild ryegrass is slow and difficult to establish. Therefore one of the recommendations from this report calls for a greater research effort into the establishment problems of this grass.

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Introduction

Ecosystems and climate are complex functioning systems. In each, several interactions take place that produce various types of outcomes. The type of outcome is influenced by phenomena and time and space scale relationships. Ultimately, an "outcome" reflects the amount of disturbance/change to the system caused by an interaction. It is this change within the system that requires adaptation.

The term "adaptation" has been incorporated into several conceptual theories. Two such theories are:

1.) Adaptation for climate change; and
2.) Adaptation for ecosystem management

This report will first compare and contrast the basic concepts, definitions, and applications of adaptation within these two theories. It will then provide the results of a case study on the adaptation of livestock production to climate change.

What is adaptation?

The dictionary meaning of "adapt" includes fitting some purpose by altering or modifying. "Adaptation" is defined as both the process of adapting and the condition of being adapted. In other words, "adaptation" is an internally generated response of a system to external forces.

Within the context of climate change, "Adaptation" has been generally described as the degree to which adjustments are possible in the practices or structures within a system in response to actual or projected changes in climate (Watson et al., 1996). Moreover, adaptation may be spontaneous or planned.

However, in 2001 a more focused definition of the term adaptation was developed. Specifically, the IPCC Working Group II (Third Assessment), 2001 created 6 sub-definitions to describe the different forms of adaptation that occur within the context of climate change. These are:

1.) Anticipatory Adaptation;
2.) Autonomous Adaptation;
3.) Planned Adaptation;
4.) Private Adaptation;
5.) Public Adaptation; and
6.) Reactive Adaptation.

Anticipatory Adaptation refers to adaptation that takes place before climate changes occur. This form of adaptation anticipates potential changes in climate and prepares accordingly. Alternatively, Reactive Adaptation takes place following the observation and analysis of changes in climate.

Autonomous Adaptation is a spontaneous adaptation that does not constitute a conscious response to climate stimuli. It is triggered by both ecological changes in natural systems and market or welfare changes in human systems. This contrasts with Planned Adaptation, which results from a deliberate policy decision. Planned Adaptation is based on an awareness that conditions have changed or are about to change. Action is taken to ensure that a desired state is achieved, maintained, or revisited.

Private Adaptation is initiated and implemented by individuals, household, or private companies for the purpose of serving some self-interest. Alternatively, Public Adaptation is initiated and implemented by a public body and directed at serving a collective public need.

Adaptation and Climate Change

a) General principles

A primary characteristic of climate is variability. Within the context of climate change, variability becomes significantly more important, especially with respect to adaptation. As discussed above, adaptation is an adjustment to change within a system. Another way of stating this is to say that adaptation is an adjustment to variability within a particular system. Thus, adaptation to climate change necessarily includes adaptation to variability.

The interest in adaptation to variability within climate change is not limited to changes in long-term mean climate variables (Cater et al., 1994). As Smit et al, 2000 suggest, the impact of climate change can be modified by adaptations of various kinds. Climatic conditions are inherently variable from year-to-year, decade-to-decade, century-to-century and beyond. A change in mean climatic conditions is actually experienced through various changes in the nature and frequency of particular yearly conditions. Such changes include changes in extremes, and it is to the aggregation of these short-term variabilities that adaptations are ultimately made.

However, in order to avoid “maladaptation”, it is necessary for adaptation to take place at the same rate as variation in the factors affecting climate change. “Maladaptation” is defined as any change in natural or human systems that inadvertently increase vulnerability to climatic stimuli, and adaptation that does not succeed in reducing vulnerability but increases it instead (Bryant et al 2000).

Unfortunately, harmonization between variability and adaptation is not found in the present context of climate change. Specifically, as Kelly and Adger (2000) show, variability within climate change is occurring at a much faster rate than adaptation. (See Figure 1)

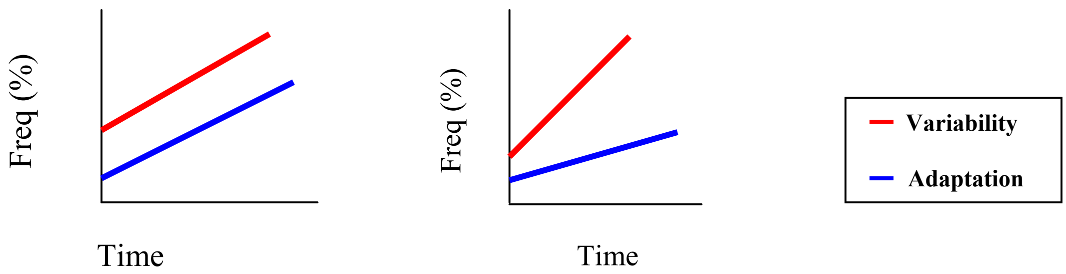


Figure 1. The relationship between Variability and Adaptation. The ideal relationship between the two is shown on the left and the actual response is represented by the graph on the right.

As the above figures illustrate, a discrepancy between variability and adaptation significantly increases the likelihood of maladaptation. Out of the 6 types of adaptation defined above, Anticipatory and Planned Adaptation appear to be the most effective ways of bridging the gap between adaptation and variability. Specifically, it will be necessary to, at least some extent, be able to predict variations within climate so that we are prepared to adapt at or near to the time in which the variation takes place.

The other types of adaptation are ineffective in this respect. For example, both Private and Public Adaptation involve a certain element of bureaucracy. In order for the adaptation to occur in these cases it must be approved and implemented at various levels of the bureaucracy. This is a slow process that can inhibit a particular adaptation's ability to keep up with changes that are occurring.

b) Time Scale in Relation to Adaptation to Climate

Anticipatory or planned adaptation methods are typically affected by external factors (Smith et al.,1996, Kelly, 2000). For example, there is little point in individual farmers planning adaptation to climate changes fifty years in the future if they are unable to adapt to economic factors such as declining terms of trade or rising costs of new seed types in the present context. This illustrates the need to maintain some focus on the more short-term forms of adaptation.

However, too much focus on short-term forms of adaptation may also result in negative outcomes. Specifically, short-term adaptive methods, including reactive forms of adaptation may be inappropriately equipped to manage medium and long-term changes in the climate. For example, farmers who adapt only to very short-term signals in the present may be jeopardizing farming conditions in the future (Risbey et al., 1994).

Adaptation and Ecosystem Management

In ecology, adaptation refers to the change/adjustment necessary for an organism or species to become fitted to its environment (Lawrence, 1996).

a) Organism Interaction with Environment

Organisms that inhabit the most extreme areas and transition zones of a particular niche are more susceptible to extinction because of the increased number of complications they experience attempting to adapt. Typically, organisms will adapt spontaneously to changes in the ecosystem. In other words, the type of adaptation that occurs in relation to an organism's interaction with its environment is Autonomous Adaptation.

However, much like under the climate change model for adaptation, where changes in the ecosystem occur at an increased rate, an organism may not be able to adapt at the same rate. For example, plant systems that rely on external elements (such as other organisms, pollinators, or mechanisms of seed dispersal) to complete a life-cycle, may be affected by climate change to the extent that they are no longer synchronized with these elements (Bond, 1995). This could result in reductions of plant populations.

Effects of this nature have been observed in several areas. Plant communities are subject to change due to a range of natural and anthropogenic factors. From an ecological perspective, landscape sensitivity to changes in the type of vegetation cover is intimately related to habitat change (See Figure 2) (Milne and Hartly 2001). Even in the absence of any human interference, natural processes such as ecological succession, catastrophic events (drought, fire) and climate change, will alter the appearance of the land cover over a range of time-scales (Gray et al., 1987).

With respect to the future effects of anthropogenic interference on rangelands, it has been suggested that climate change may be trivial relative to past and present impacts of human activities. These activities include livestock grazing (Le Houerou, 1996). Adaptation to grazing involves the ability to survive and reproduce under conditions of defoliation, trampling and nutrient recycling by herbivores. Autonomous Adaptation strategies that allow survival of individual plant species within a pasture include avoidance/minimization of herbivory and tolerance/recovery from herbivory (Caldwell *et al.,* 1998).

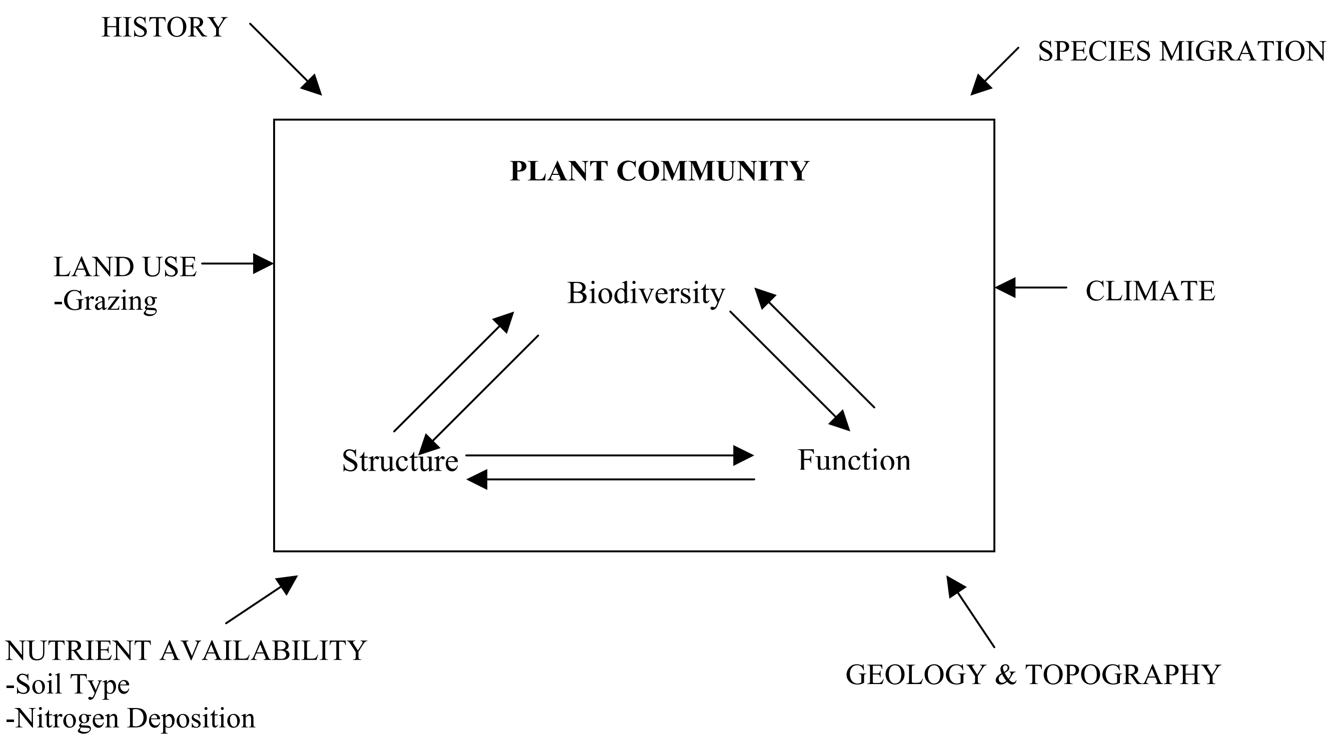


Figure 2. The Natural and anthropogenic influences on plant ecosystems (modified from Milne and Hartly 2001).

Falkner and Casler (2000) support the findings of Le Houerou and suggest that grazing herbivores are a major factor in the evolution of pasture plant species. Plant populations subjected to grazing are more likely to develop Autonomous Adaptations to grazing compared to those populations that have not been. Ultimately, while this may not be entirely true for all rangelands, it highlights the difficulty of separating the impacts of climate change from the impacts of many of the other pressures that are acting and will continue to act on the system (See Figure 2).

Furthermore, certain groups of organisms do not necessarily adapt at the same rate as other groups. As Walker & Steffen (1997) state, rangeland ecosystems have become fragmented over time due to the addition of such things as roads, croplands, and human developments. Moreover, they suggest that as rangeland ecosystems continue to fragment, the rate at which the fragmentation occurs will exceed that at which new assemblages form. As a result, ecosystems are not likely to react as a unit in response to climate change. Rather, individual groups within the ecosystem, such as C3 and C4 grasses, will disassociate and reassemble in new combinations.

b) Ecosystem Management

The scientific community has had some difficulty defining “ecosystem management”. The term has been used loosely and without defined consensus (Grumbine, 1997). However, a primary theme within all of the literature is the importance of including “adaptive management” techniques in the overall implementation of an ecosystem management model.

Several common points are made within the literature in relation to the inclusion of adaptive management techniques

1. The adaptation to climate change is a dependent variable. Specifically, no one knows how quickly the climate is changing and if natural environments can adapt on various time scales;
2. Adaptive management translates into a predictive tool that can be used for site-specific management;
3. Policy makers tend to perceive adaptive management as a tool in which the effects of broad impacts of policy emphasize the need to develop large-scale models (Halbert, 1993).

4. Scientists tend to follow interpretations made by Hollings (1978) and Halbert (1993) in that adaptive management assumes: “Scientific knowledge is provisional and focuses on management as a learning process, or continuous experiment where incorporating the results of previous actions allows managers to remain flexible and adapt to uncertainty” (Grumbine, 1994). To take an ecosystem approach means that people shift their focus from parts to wholes incorporating plants, animals, streams, esthetics and yield to the three dimensional landscapes that produce these valuable things (Rowe, 1992).
5. Ultimately, adaptive management is the process of coupling science and social values to promote the sustainable management of natural systems (Haney & Power, 1996).

Collectively, these common principles create a working definition of the term “Adaptive Management”. Specifically, Adaptive Management may be defined as a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs (Vallentine, 2001). It is a management approach that recognizes every action in an ecosystem affects a complex system of processes and that actions must be viewed for the whole ecosystem. Pattern persistence is the focus of management at all scales. Patterns are non-linear because the processes that create them occur at different scales and in a non-linear fashion. Ecosystem management realizes ecosystems are dynamic in time and space.

Adaptive management tends to rely on more of a Reactive Adaptation approach than the Climate Change Model of Adaptation. Adaptive management focuses on control devices that allow for learning through experience. By learning through experience feedback mechanisms are incorporated and either allow information to accumulate automatically or deliberately probe the environment to gather new information.

Additionally, adaptive management incorporates informational feedback loops into the management processing order to accelerate the rate at which environmental decision makers learn from experience (McLain and Lee, 1996).

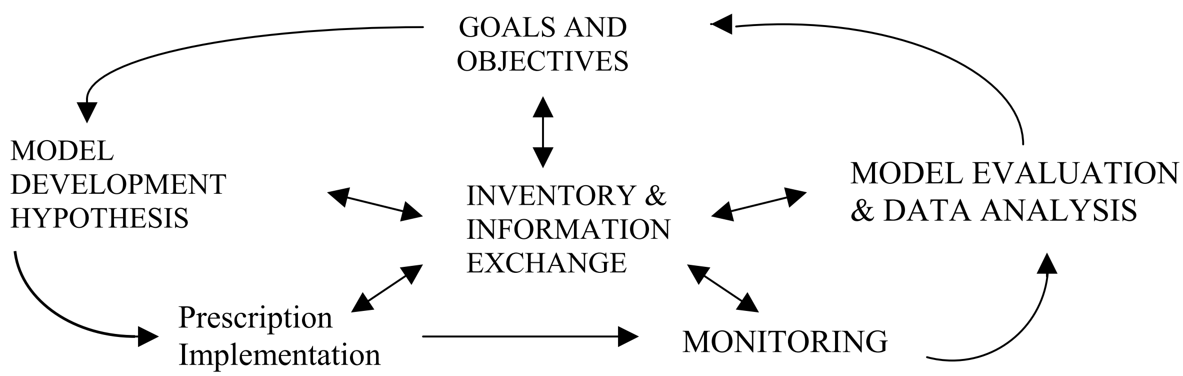


Figure 3. Adaptive management as it relates to ecological processes.

Adaptive management begins with inventory and information exchange, which is a continuous process throughout the entire cycle.

i. Inventory and Information Exchange

Adaptive management begins with the collection and compilation of existing information for each ecosystem. Inventory may include biotic surveys, literature searches, market analyses, and the preparation of appropriate databases and maps. Collection and interpretation of the information provides a baseline against which to measure change, but also helps to identify management options, barriers, opportunities, and goals.

ii. Goals and Objectives

Following the compilation and analysis of preliminary information, clear goals and objectives need to be established for each ecosystem being managed. Goals must be defined because they influence the way we organize information and perceive the problems and potential associated with ecosystem management.

iii. Model Development

Models are theories involving the way something may function in relation to various parameters. Models help with the understanding of complex interactions between various components in the ecosystem and allow for the measure of particular situations over time with out degradation to the actual natural system. Models can guide decisions by providing a response mechanism to gauge the relative impact of various factors surrounding different situations over time.

The use of models helps to highlight several potential solutions to ecosystem management, and the relative costs and benefits of each solution without actually impacting the area of concern or study. Walters (1986) argues that we need to "embrace" the uncertainty because uncertainty forces us to look for new and creative ways to manage natural resources. The uncertainties may include major extremes in weather such as hail, dust storms, floods and high temperatures but may also involve sporadic influxes of disease and infestations of insects. Finally, models allow for a more realistic interpretation of our understanding of complex systems.

iv. Management Implementation

Management Implementation provides the greatest difficulties with respect to model development and use (Grumbine, 1997). Specifically, implementation requires the co-operation of the scientific community with various levels of government and other interested groups. Grumbine (1997) notes that the power imbalance that exists between these groups does not foster co-operative behavior. Co-operation has not been consistent in the past and has inhibited the implementation of ecosystem management models.

Ideally, Grumbine (1997) suggests that any issues with respect to co-operation are to be discussed up front in order to avoid conflicts during implementation and beyond. Furthermore, co-operation requires that the implementation of management practices allows components of the model to be tested from an unbiased perspective (Walters and Holling 1990).

v. Monitoring

Monitoring is necessary as it provides a means to obtain data that will allow the manager to continuously refine management practices based on careful record keeping.

This routine may be referred to as adaptive management. Careful record keeping allows the manager to examine and adjust the system in ways that will further benefit the land. While monitoring the area it is particularly important to identify the cause of the problem, not the symptom, and to correct the plan accordingly. More often than not the cause of the problem is human oriented (e.g. improper management). Baselines must be established to give a reference factor for comparison. In the study reported here, the baseline is represented by the conditions that are present duringa 30-year baseline simulation (1961-1990).

Following implementation of management practices, the responses of ecological and socioeconomic variables are measured and recorded. This information is used to validate components of the model. Models also help in understanding the relationship between animal and plant interactions.

A model should provide some information with respect to how quickly an indicator (e.g. species that decreases with grazing) will respond to a disturbance (grazing and change in climate). In this way, undesirable changes can be caught before they become irreversible. Monitoring efforts should include indicators of long-term trends.

Adaptation Management Techniques Used for Climate Change Adaptation

While both Climate Change and Ecosystem Management adaptation strategies make use of the 6 main sub-categories of adaptation, each has its own focus. The Climate Change Model places an emphasis on Anticipatory and Planning Adaptation methods. On the other hand, the Ecosystem Management Model focuses on Autonomous and Reactive forms of Adaptation (See Figure 4).

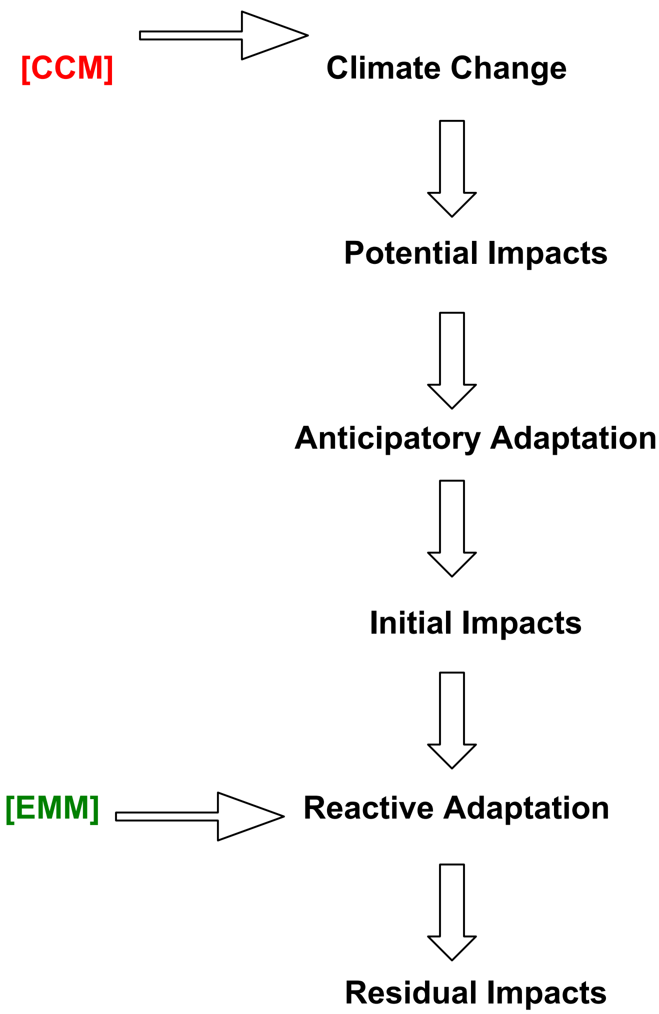


Figure 4. Flowchart of Climate Change and Impact in relation to the implementation of the two models. "CCM" notes the point in which the Climate Change model takes effect and "EMM" notes the point that the Ecosystem Management model begins

Further, both models place importance on adaptation in the short-term. However, the most significant difference between the two models is the degree of this importance. The Climate Model ultimately has a long-term focus, but recognizes that short-term forms of adaptation are necessary in order to achieve long-term success. Alternatively, the Ecosystem Management Model focuses primarily on changes and economic success of the short-term, with little consideration given to long-term objectives. This creates vulnerability in the long-term.

The Cost of Adaptation

Adaptation is unlikely to come without cost. Tol et al. (1998) concluded that adaptation costs (as opposed to net costs of damages) are not reported in most impact studies, especially in agriculture. Yet transition costs, such as retraining farmers in new practices, and equilibrium costs, such as developing additional irrigation, and the costs of developing new technology may be considerable (Antle, 1996). The absence of a benefit-cost analysis for adaptation is a key deficiency within the literature (Parry et al., 1999).

Case Study: Adaptation of Livestock to Climate Change

a) Introduction

Livestock production is Industry is a major industry on the Canadian prairies. As a result there must be concern in relation to the potential effects that climate change may have on the industry.

Hahn and Morgan (1999) suggest that large changes in climate will exponentially increase the costs of doing business within the livestock industry. Some studies suggest that during cooler seasons, climate change may be beneficial to the industry. However, such results are not well documented and the benefits are likely to be less than any negative consequences produced by increases in hot weather (Hahn *et al.*, 1992).

Management strategies are key to the adaptation of the livestock industry to climate change. A variety of management adaptations are available for livestock productions systems. For example, Hahn and Mader (1997) outline a series of proactive management counter-measures that may be taken during heat waves (e.g. shade and/or sprinklers) to reduce excessive heat loads.

Past changes in climate in Canada provide a starting point for measuring how climate change may effect livestock production. The 2001 IPCC Assessment Report on the impacts, adaptations, and vulnerability of climate change states that in the past, livestock have successfully adapted to changes in climate. This may indicate that livestock producers are likely to adjust to climate change successfully.

However, signs of negative effects are also evident under an analysis of the past. For example, the drought conditions of 1988 caused poor germination and growing conditions. As a result, livestock production was adversely impacted due to the effect on feed, the existence of dust storms, and the lack of suitable pastureland. Cattle ranchers attempted to adapt to these conditions by moving their herds to more fertile areas where feed and pasture were more plentiful (Conner, 1994). Despite these management strategies, Saskatchewan showed net farm income losses of 78% during this time (Brklacich et al 1997), causing about 10% of farmers to leave the industry (Phillips, 1990).

Ultimately, the full extent of the impact the 1988 drought had on the industry cannot be measured due to several financial support programs that were put in place to counteract the financial impact on producers. For example, a combination of crop insurance and special drought assistance paid out more than $1.3 billion to Prairie farmers. Provincial support programs acted as a supplement to this amount (Cambell and Smith, 2000).

For individual producers, uncertainties associated with potential climate change imply additional risks related to how and when to adapt current production practices (Lewandrowski and Schimmelpfennig, 1999). Confidence in the ability of livestock producers to adapt their herds to the physiological stresses of climate change is difficult to judge. The IPCC (2001) states there is a major methodological weakness based on the lack of simulations of livestock adaptation to climate change. Therefore, there is a need for a simulation of the effect of climate change on livestock production for the purpose of identifying appropriate adaptation strategies.

In the case study reported in this paper, different adaptation strategies were tested using the GrassGro decision support tool (DST). Simulations were run using a climate change scenario based on the CGCM1 climate change model to 2080 to determine the effects of climate change on beef cattle production.

b) Objectives

- To determine the effects of climate change on livestock production based on simulations using the CGCM1 global climate model.

- To devise three different management strategies to implement in simulation.
- To determine the effects of different management strategies on the outcome of the climate change on livestock production.

c) Methods

i. Model Description

The experiment will be carried out using computer-based simulations of the different climate scenarios. The main method is based on a data and input model. Climate data, economics, plant species, soil types are parameters that can be set up in the program. GrassGro is a computer software program developed at CSIRO Division of Plant Industry in Australia and adapted to Canada (Cohen et al. 1995). It combines the Grazfeed animal intake and nutrition models (Freer et al., 1997), Soil moisture and pasture growth modes (Moore et al., 1997) with a set of management rules and a simple gross margin calculator. Data for the evaluation of climate change effects on forage and range steer production were obtained from two sources. The baseline gridded prairie climate database (GRIP CD) (1960-1989) (Environment Canada and Agriculture and Agri-Food Canada 1996) and the future climate data were adapted from Canadian daily climate data (Environment Canada 1998) using the CGCM1 model.

ii. Simulation runs

GrassGro was used to simulate time slices of 30-yr intervals of livestock production. The baseline simulation was from 1961-1990; the future simulation was from 2051-2080. The soil was parameterized as an Asquith loamy soil association. Three locations in Saskatchewan were used for the simulation, Saskatoon, Melfort and Swift current. The locations were chosen to be on a transect from SW to NE across the three major soil types of brown, dark brown and black. The parameters of the simulations for livestock production at each location were set for 2 tame grasses. The grasses were crested wheatgrass (*Agropyron cristatum*) and Russian wild ryegrass (*Psathyrostachys juncea*). Total plant production was determined by averaging the growth for the 30-yr time slices for each group of species at each site. Hereford, Angus cross steers was used as a standard breed for all simulation runs. The herd size was determined by the stocking rate suitable for each site. Climate data for the 30yr baseline nominal run were generated using the actual weather data collected and entered in to the Metacess model in GrassGro (Clark *et al.,* 2000).

Effects of predicted climate change for the four scenarios were subsequently run and compared to the baseline. The climate-change scenario used was the Canadian Center of Climate (CCC) (Boer *et al.* 2000). All the details of the simulations and management strategies are listed in appendix 1.

iii. Indicator Variables

Indicator variables are model-derived graphs and values, which are predicted by the simulation. For the purpose of this study, indicator variables were: live weight gains, condition scores, stock-feed budgets, intakes and protein intakes. Increased weights in the fall indicate benefits to production due to increasing forage productivity. Livestock gain per acre and per animal should be maintained or increased.

iv. Adaptation strategies

An adaptation strategy can be introduced to reduce the effects of climate change, for example grazing at an earlier date. Forage was seen to start growing earlier due to warmer temperatures and more precipitation in the spring. To take advantage of the earlier growth a grazing date of April 15 to Sept 15 was chosen in order to keep the same 5-month grazing period as the baseline. This was the first adaptation strategy that was used on the sites.

The second adaptation strategy for the sites was to use an Intensive-early stocking (IES) grazing system. This type of grazing strategy is defined as a grazing method involving increased stocking density, often at about twice the normal level, during the first half of the growing season followed by nongrazing through the remainder of the growing season. The stocking rate and length of the grazing season varied between locations and was set according to the forage availability budget at each location. This strategy (if implemented properly) opens the possibilities for a variety of strategies depending on the conditions of the particular year based on economics and climate. Cattle can be sent early to feedlots, and depending on the cost of supplements can be supplemented to be finished at pasture.

The final strategy was a longer grazing period with a lower stocking rate (April 15-Oct 30, 1.4 steers/ha). This strategy was used at all three locations.

v. Animal performance

Animal production generally decreased with the climate change scenarios. Forage intakes varied between sites based on forage availability. Forage intakes for the baseline simulations were developed to represent an optimal management stocking-rate for each site and thus are from the medium stocking rate. Once the optimal stocking rate was found, the adaptation strategies were applied to the simulations.

d) Results

GrassGro simulations were conducted using moderate stocking rates and a set turnout date for the baseline simulations. For "management" adaptation strategies for livestock simulations testing high moderate and low stocking rates as well as early and nominal turnout dates were compared. Based on the results of the trials, the most feasible options were chosen and represented in graphs. (See appendix 1 for a complete description of the trials run and the results from those simulations are in tabular form).

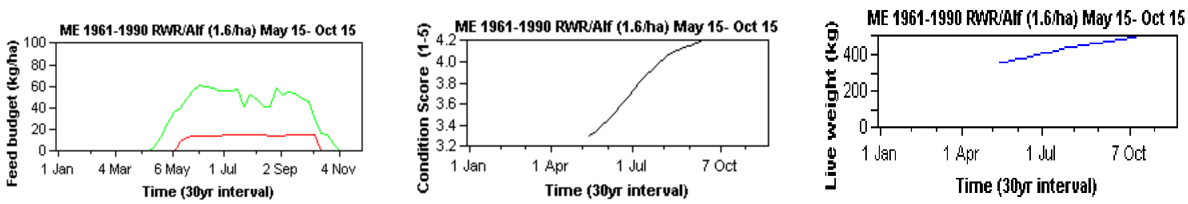
In an earlier study on the sensitivity of plant production in the realm of climate change, precipitation and forage production in summer were shown to decrease as predicted by the CCC. Mean annual temperature was increased by 4.6°C. These changes are great enough to cause substantial decreases in animal performance.

The results of the present simulations provide an indication of how the climate change will affect animal performance and what would happen if different adaptation strategies were implemented.

i. Melfort Russian Wild Ryegrass and Alfalfa pasture (RWR/ALF)

Baseline simulations at Melfort for steers grazing RWR/ALF pasture are shown in Figure 4. The stocking rate was set at 1.6 steers/ha. The site was grazed from May 15 to Oct 15, 1961-1990. Feed budgets indicate an ample supply of pasture for the (Figure 5a).

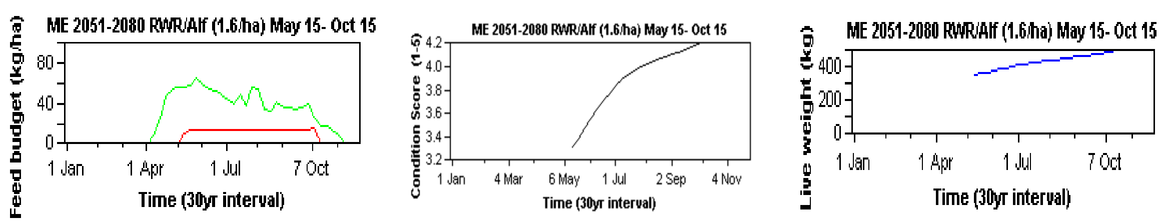
The average final body condition score (Scale of 1-5 of) of the steers for the area in the baseline was 4.3 (Figure 5b). Average final live weight for the baseline was 496 kg (Figure 5c).



(a) (b) (c)

Figure 5. Baseline simulation at Melfort for steers grazing Russian wildrye/alfalfa pasture at a stocking rate of 1.6 steers/ha May 15- Oct 15 1961-1990. (a: feed budget; b: condition score; c: turn-off live weight).

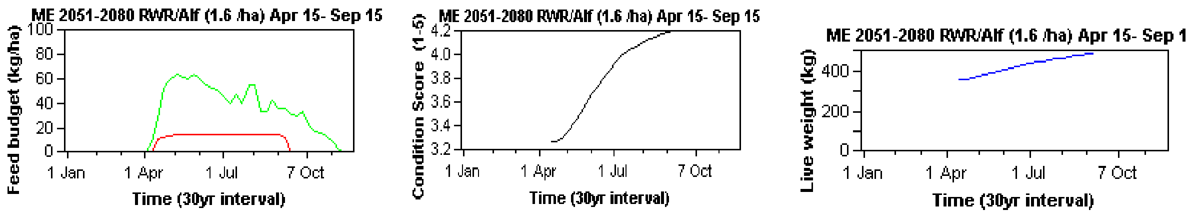
Simulations at Melfort for steers grazing Russian wildrye/alfalfa pasture at a stocking rate of 1.6 steers/ha May 15- Oct 15 2051-2080 are shown in Figure 6 and indicate little change in steer production (Figure 6b,c) but some reduction in the rate of pasture growth (green line Figure 6a).



(a) (b) (c)

Figure 6. Simulation at Melfort for steers grazing Russian wildrye/alfalfa pasture at a stocking rate of 1.6 steers/ha May 15- Oct 15 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

Adaptation strategy #1 at Melfort used the same stocking rate of 1.6 steers/ha was run for the years 2051-2080 with an earlier date on and off pasture (Figure 7). In all simulations, forage production decreased from baseline values. However, the decrease in forage did not adversely affect animal live weights. This was also reflected in the constant condition score (range 4.3-4.0) and the close proximity of live weights to the baseline data. This may indicate that adaptation strategies may just have to be monitored at this site.



(a) (b) (c)

Figure 7. Adaptation strategy #1 at Melfort for steers grazing Russian wildrye/alfalfa pasture at a stocking rate of 1.6 steers/ha May 15- Oct 15, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

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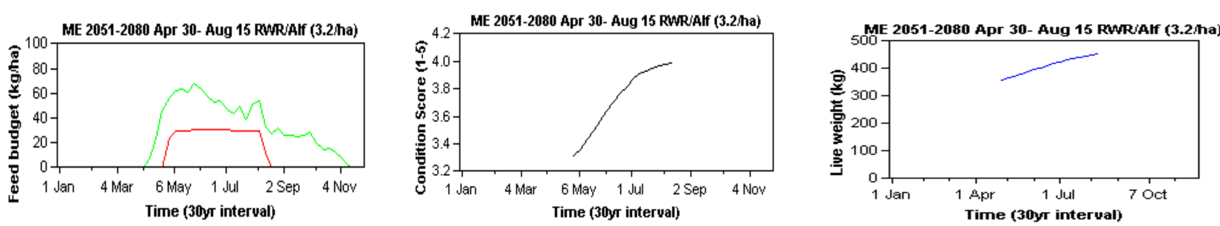
Adaptation strategy #1 indicated a small decrease in average final live weights (489 kg) in comparison to baseline data (496 kg) (Figure 7c). However, the condition score was unchanged (Figure 7b).

Figure 8 shows the results of adaptation strategy #2 when the stocking rate was doubled to 3.2 steers/ha and the grazing period was shortened to April 30-August 15.

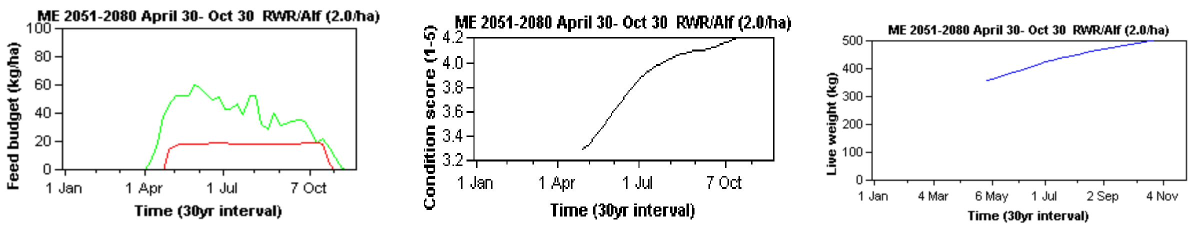


(a) (b) (c)

Figure 8. Adaptation strategy #2 at Melfort for steers grazing Russian wildrye/alfalfa pasture at a stocking rate of 3.2 steers/ha Apr 30- Aug 15, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

Adaptation strategy #2 indicated that final condition score would decrease slightly to 4.0 and final live weight would also decrease to 454kg (Figure 8b,c). This represents a significant reduction in productivity per animal but a substantial increase in productivity per ha because of the increased stocking rate.

Results for adaptation strategy #3 are shown in Figure 9. This strategy increased the length of the grazing period (April 30-October 30) and reduced the stocking rate to 2.0 steers/ha, which was still above that of the baseline simulation.



(a) (b) (c)

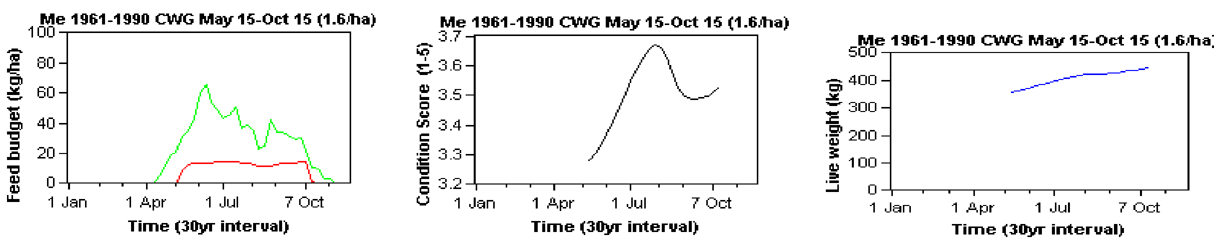
Figure 9. Adaptation strategy #3 at Melfort for steers grazing Russian wildrye/alfalfa pasture at a stocking rate of 2.0 steers/ha Apr 30- Oct 30, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

Adaptation strategy #3 resulted in an increase in final live weight (503kg) from the baseline data and no change in condition score.

All strategies at Melfort indicated little change from baseline data for condition score only small variations in average final live weights. However, adaptation #3 provided the greatest productivity per animal while adaptation strategy #2 provided the greatest productivity per hectare.

ii. Melfort Crested Wheatgrass pasture (CWG)

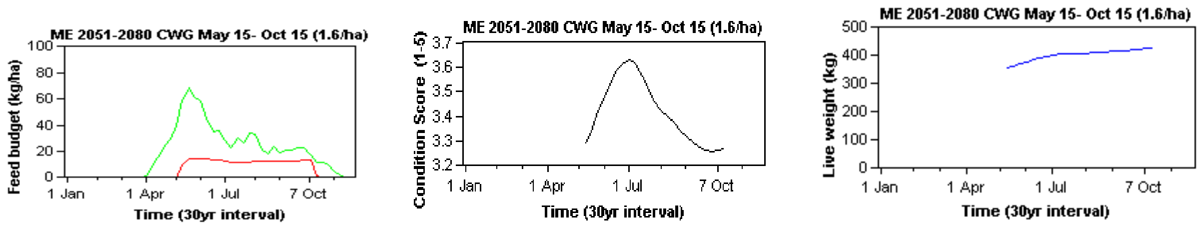
Baseline simulation simulations for steers grazing CWG at Melfort are shown in Figure 10. The stocking rate was set at 1.6 steers/ha, the same as for the RWG/ALF pasture. The site was grazed from May 15 to Oct 15, 1961-1990. The feed budget indicated that there was ample supply of green pasture for the steers at that stocking rate (Figure 10a). The average condition score was 3.5 (Figure 10b) and average final live weight was 446 kg (Figure 10c). Both represent a reduced level of productivity in comparison to RWG/ALF pasture.



(a) (b) (c)

Figure 10. Baseline simulation at Melfort for steers grazing crested wheatgrass pasture at a stocking rate of 1.6 steers/ha May 15- Oct 15 1961-1990. (a: feed budget; b: condition score; c: turn-off live weight).

Results of simulations for CWG 2051-2080 are presented in Figure 11.

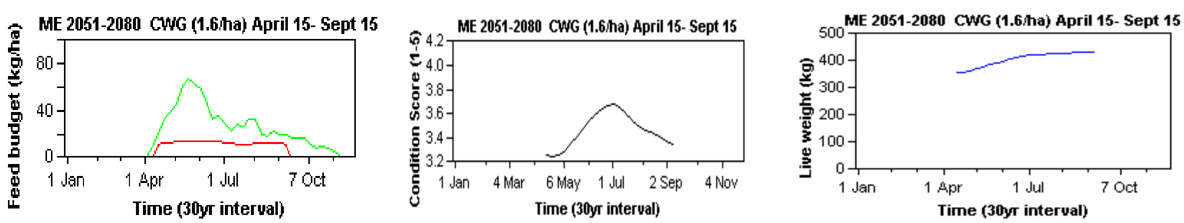


(a) (b) (c)

Figure 11. Simulation at Melfort for steers grazing crested wheatgrass pasture at a stocking rate of 1.6 steers/ha May 15- Oct 15 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

Simulations for CWG 2051-2080 indicated a 16 kg decrease in final live weight from baseline data to 430kg (Figure 11c) and the decline in condition occurred earlier and was much more severe in comparison to baseline data.

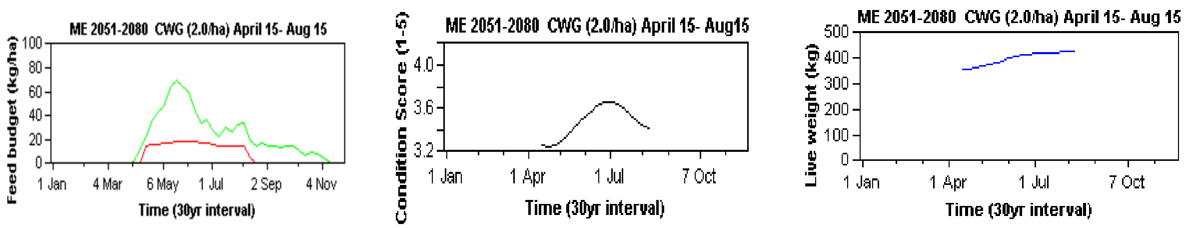
Results for adaptation strategy #1 (stocking rate 1.6 steers/ha; early grazing) for 2051-2080 are shown in Figure 12. Condition scores decreased from early to mid July (Figure 12b). This decline occurred earlier than baseline data. Average final live weight of steers (435 kg) was also less than baseline data but was 5 kg greater than that of a non-adaptation strategy (Figure 12c).



(a) (b) (c)

Figure 12. Adaptation strategy #1 at Melfort for steers grazing crested wheatgrass pasture at a stocking rate of 1.6 steers/ha May 15- Oct 15, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

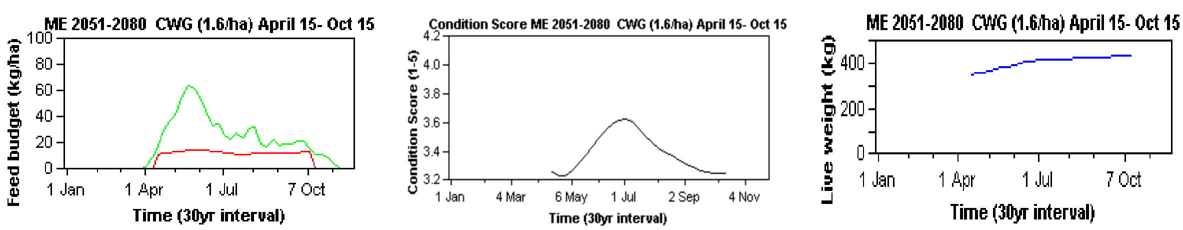
Results from strategy #2 are shown in Figure 13. This strategy resulted in the lowest average final live weight (427 kg) of all the simulations at the Melfort site, but it resulted in an increase in productivity/ha when compared to strategy 1 because of the increased stocking rate from 1.6 to 2.0 steers/ha. Condition score showed the same downward trend beyond July as all the simulations for CWG at Melfort.



(a) (b) (c)

Figure 13. Adaptation strategy #2 at Melfort for steers grazing crested wheatgrass pasture at a stocking rate of 2.0 steers/ha Apr15- Aug 15, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

Results for adaptation strategy #3, which used a longer grazing season (April 15- October 15) and 1.6 steers/ha) are shown in Figure 14. The final average live weight (440 kg) and condition score (3.3) provided no advantage over a non-adaptation strategy (Figure 14b,c).



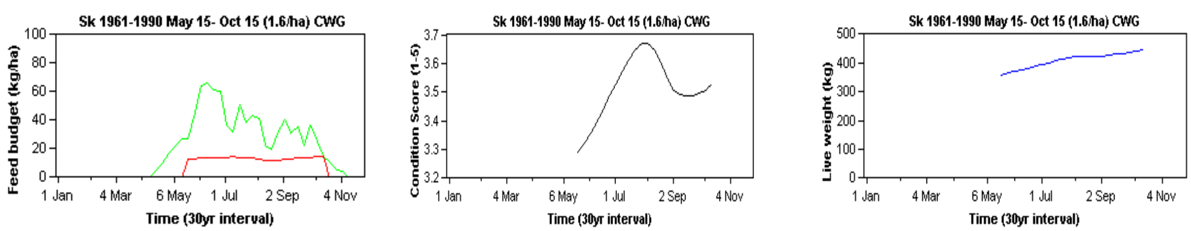
(a) (b) (c)

Figure 14. Adaptation strategy #3 at Melfort for steers grazing crested wheatgrass pasture at a stocking rate of 1.6 steers/ha Apr 15- Oct 15, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

Crested Wheatgrass (CWG) as a forage is shown to be more variable in its ability to maintain conditions scores of the steers. Unlike RWR, CWG shows a decrease in condition scores in late summer. This drop in condition score can be attributed to the characteristic traits of CWG having low protein and digestibility late in the season. Also, this grass tends to become wolfy (mature unwanted plants) if not stocked adequately in spring and early summer. The final condition score for the baseline data is considerably lower than for RWR/ALF (3.5) and this is reflected in the average final live weight (446kg) in comparison to RWR/ALF (496 kg).

iii. Saskatoon Crested Wheatgrass pasture (CWG)

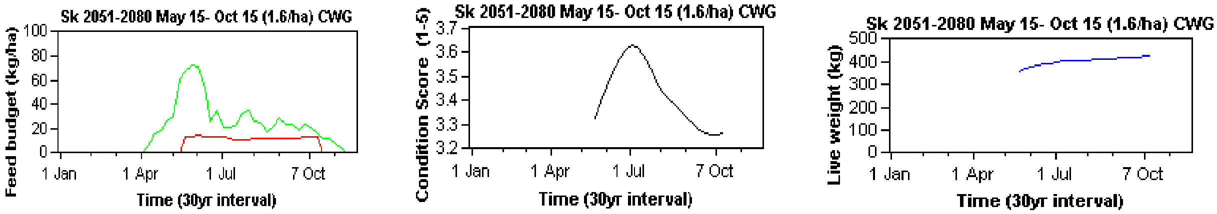
Baseline simulation simulations for steers grazing CWG at Saskatoon are shown in Figure 15. The stocking rate was set at 1.6 steers/ha. The site was grazed from May 15 to Oct 15, 1961-1990. Figure 15a indicates that the pasture supply adequately met the demands of the steers. The average condition score for the baseline data was 3.5 (Figure 15b) and average final live weight was 446 kg (Figure 15c).



(a) (b) (c)

Figure 15. Baseline simulation at Saskatoon for steers grazing crested wheatgrass pasture at a stocking rate of 1.6 steers/ha May 15- Oct 15 1961-1990. (a: feed budget; b: condition score; c: turn-off live weight).

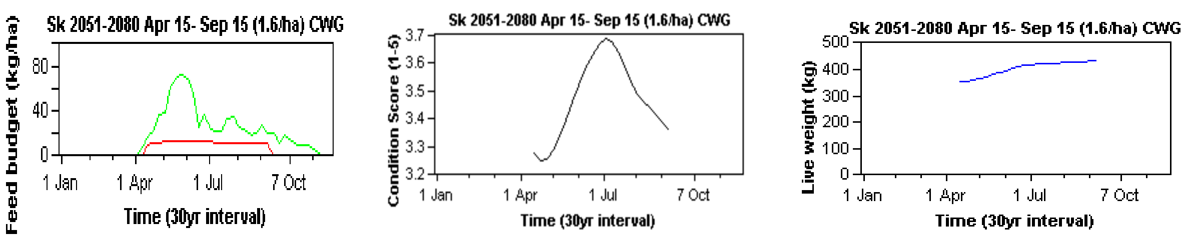
Simulation for 2051-2080 indicated that the final condition score decreased to 3.3 and average final live weight decreased by 16kg from 446 to 430kg (Figure 16).



(a) (b) (c)

Figure 16. Simulation at Saskatoon for steers grazing crested wheatgrass pasture at a stocking rate of 1.6 steers/ha May 15 - Oct 15 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

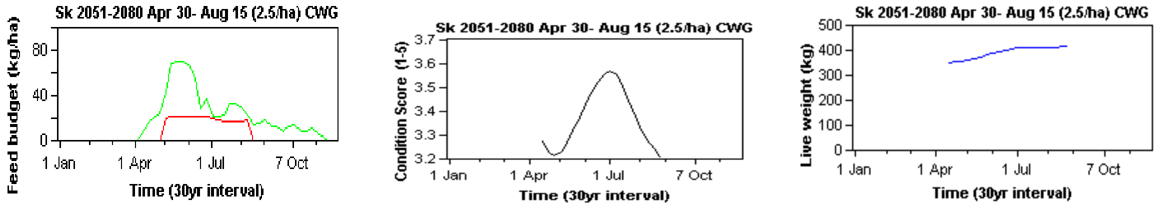
Adaptation strategy #1 (grazing Apr 15-Sep 15, 2051-2080) provided a small increase in average final live weights (434kg) compared with no adaptation (430kg) and final condition score was relatively unchanged (Figure 17).



(a) (b) (c)

Figure 17. Adaptation strategy #1 at Saskatoon for steers grazing crested wheatgrass pasture at a stocking rate of 1.6 steers/ha May 15 - Oct 15, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

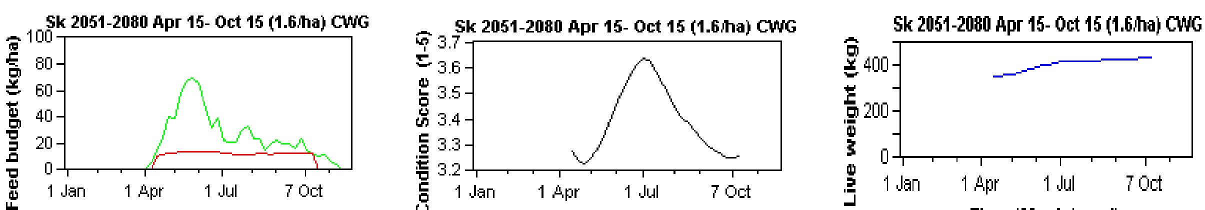
Adaptation strategy #2 (intensive early season grazing) resulted in a final condition score of 3.2 and live weight of 418kg (Figure 18). Although this represents a decrease in productivity per steer in comparison to no adaptation, it represents an increase in productivity per ha because of the increased stocking rate from 1.6 to 2.5 steers/ha.



(a) (b) (c)

Figure 18. Adaptation strategy #2 at Saskatoon for steers grazing crested wheatgrass pasture at a stocking rate of 2.5 steers/ha Apr 30- Aug 15, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

Adaptation strategy #3 (longer grazing period) increased final live weights (440kg) compared with strategies #1 and #2 and no adaptation strategy but it was still slightly less than baseline data (Figure 19). However, because the optimum stocking rate for this strategy was 1.6 steers/ha, productivity/ha was reduced when compared to strategy #2. Overall, all the simulations indicate that productivity at Saskatoon will be highly variable and greatly influenced by the adaptation strategy that is adopted.

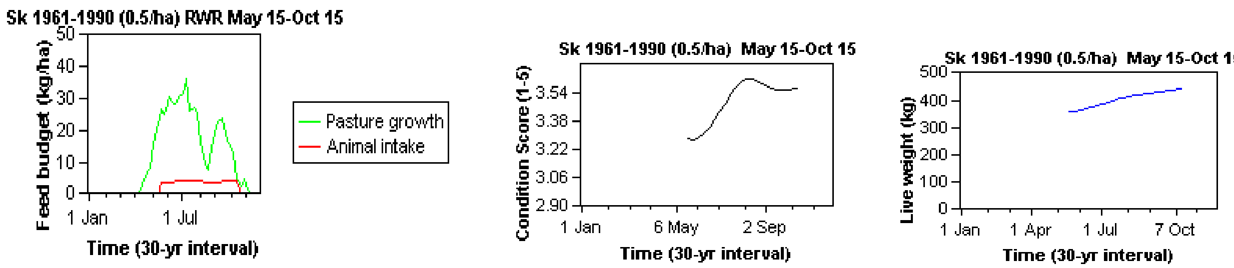


(a) (b) (c)

Figure 19. Adaptation strategy #3 at Saskatoon for steers grazing crested wheatgrass pasture at a stocking rate of 1.6 steers/ha Apr 15- Oct 15, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

iv. Saskatoon Russian Wild Rye/Alfalfa pasture(RWR/ALF)

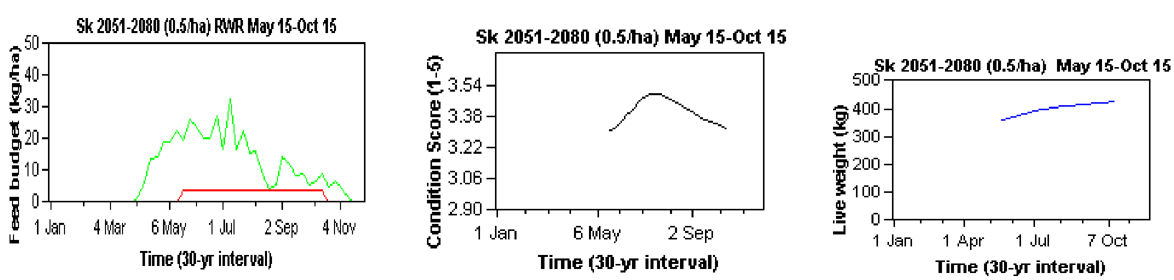
Baseline simulations1961-1990 at Saskatoon for steers grazing RWR/ALF pasture are shown in Figure 20. The stocking rate was set at 0.5 steers/ha. The pasture was grazed from May 15 to Oct 15. The pasture budget indicated an adequate balance of pasture growth to intake throughout the grazing period at the allocated stocking rate (Figure 20a). The average final condition score for 1961-1990 was 3.6 (Figure 20b) and average final live weight was 445 kg (Figure 20c).



(a) (b) (c)

Figure 20. Baseline simulation at Saskatoon for steers grazing Russian wildrye/alfalfa pasture at a stocking rate of 0.5 steers/ha May 15- Oct 15 1961-1990. (a: feed budget; b: condition score; c: turn-off live weight).

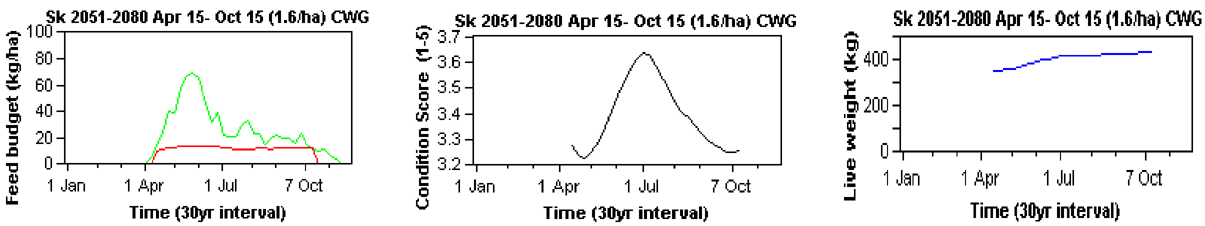
Simulations for 2051-2080 with no adaptive strategy indicated that the average final live weights and condition scores decreased significantly to 409 kg and 3.2 respectively Figure 21b,c).



(a) (b) (c)

Figure 21. Simulation at Saskatoon for steers grazing Russian wildrye/alfalfa pasture at a stocking rate of 0.5 steers/ha May 15- Oct 15 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

Adaptation strategy #1 increased average final live weights to 429 kg from 409 kg for no adaptation strategy (Figure 22c). Condition score peaked in mid-July at 3.4 then gradually decreased to 3.3 at the end of the grazing period (Figure 22b).

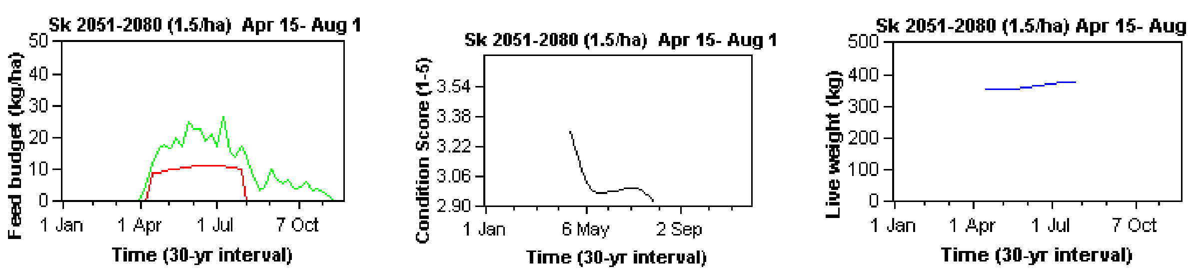


(a) (b) (c)

Figure 22. Adaptation strategy #1 at Saskatoon for steers grazing Russian wildrye/alfalfa pasture at a stocking rate of 1.6 steers/ha Apr 15- Oct 15, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

Not only did strategy #1 increase the turn-off weights if the steers but it also allowed for an increased stocking rate indicating that this was a beneficial strategy.

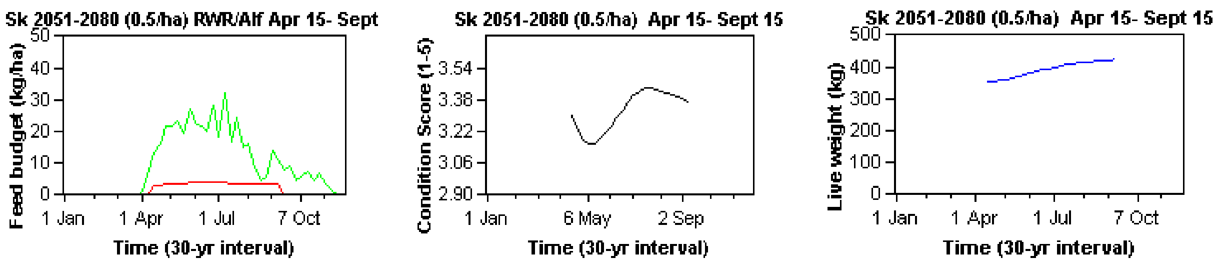
It was hypothesized that adaptation strategy #2 would alleviate the effects of summer drought and maximize forage in the spring. However, this strategy deceased condition scores to 3.0 and final average live weights (372kg) indicated little change during the grazing season (Figure 23).



(a) (b) (c)

Figure 23. Adaptation strategy #2 at Saskatoon for steers grazing Russian wildrye/alfalfa pasture at a stocking rate of 3.2 steers/ha Apr 15 - Aug 1, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

Adaptation strategy #3 (early turnout/extended grazing) was also less effective than strategy #1 with an average final live weight of 424 kg (Figure 24).



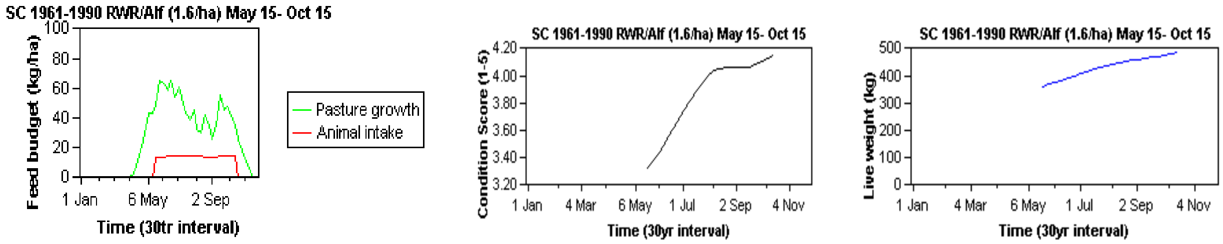
(a) (b) (c)

Figure 24. Adaptation strategy #3 at Saskaton for steers grazing Russian wildrye/alfalfa pasture at a stocking rate of 0.5 steers/ha Apr 30- Oct 30, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

The RWR/ALF pasture at Saskatoon was less productive than crested wheatgrass. One indication of poor performance was the decrease in the stocking rate from 1.6/ha on Crested Wheatgrass to 0.5/ha on Russian Wildrye/alfalfa. The condition scores and average live weights for the baseline simulations were comparable at these stocking rates (445kg, 3.6) and (446kg, 3.5) for RWR/Alf and CWG respectively. There is a large production advantage to CWG at Saskatoon because of the higher stocking rate potential.

v. Swift Current Russian Wild Rye/alfalfa pasture (RWR/ALF)

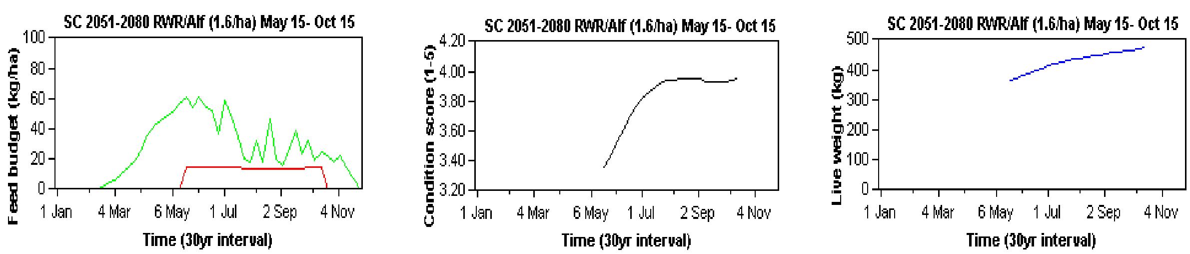
The stocking rate at Swift Current for baseline simulation (1961-1990) was set at 1.6 steers/ha and the grazing period was from May 15 to Oct 15. The Feed budget indicated adequate supply of RWR/ALF for this simulation (Figure 25a). The average baseline final condition score was 4.15 and the average final live weight was 486 kg (Figure 25b,c)



(a) (b) (c)

Figure 25. Baseline simulation at Swift Current for steers grazing Russian wildrye/alfalfa pasture at a stocking rate of 1.6 steers/ha May 15- Oct 15 1961-1990. (a: feed budget; b: condition score; c: turn-off live weight).

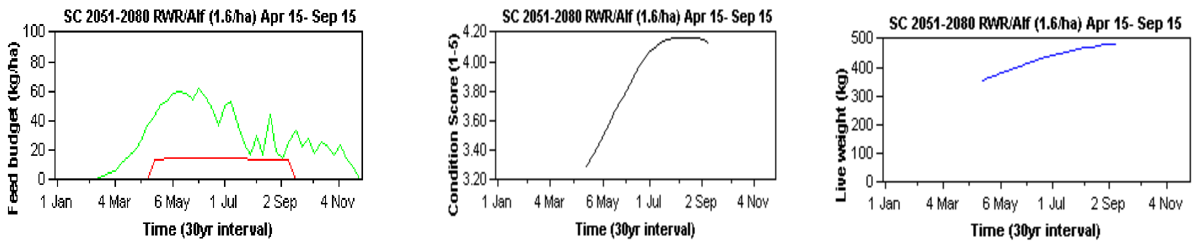
The same stocking rate of 1.6 steers/ha was used for simulations for 2051-2080 (Figure 26). There was a significant decrease in forage production compared with 1961-1990 and animal intake was closer to the maximum capacity of the pasture (Figure 26a). This was reflected in decreased final condition score (3.95) and live weight (475 kg) (Figure 26 b,c).



(a) (b) (c)

Figure 26. Simulation at Swift Current for steers grazing Russian wildrye/alfalfa pasture at a stocking rate of 1.6 steers/ha May 15- Oct 15 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

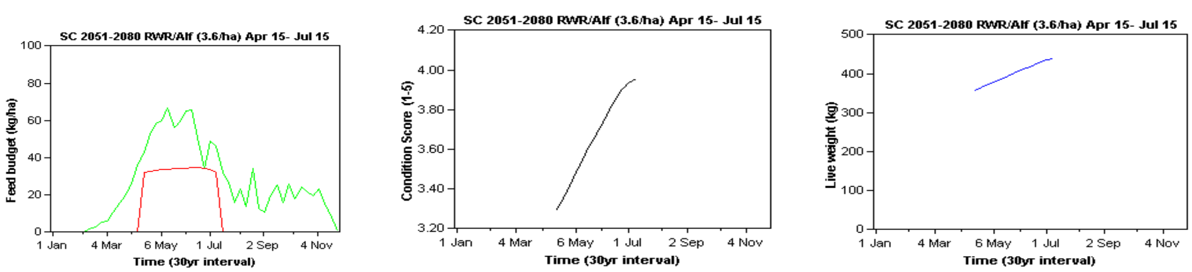
Adaptation strategy #1 increased condition score and average final live weight (4.13 and 483 kg respectively) relative to no adaptation but both were slight lower in comparison to the data for 1961-1990 (4.15 and 486kg respectively). These results are shown in Figure 27.



(a) (b) (c)

Figure 27. Adaptation strategy #1 at Swift Current for steers grazing Russian wildrye/alfalfa pasture at a stocking rate of 1.6 steers/ha Apr 15 - Sep 15, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

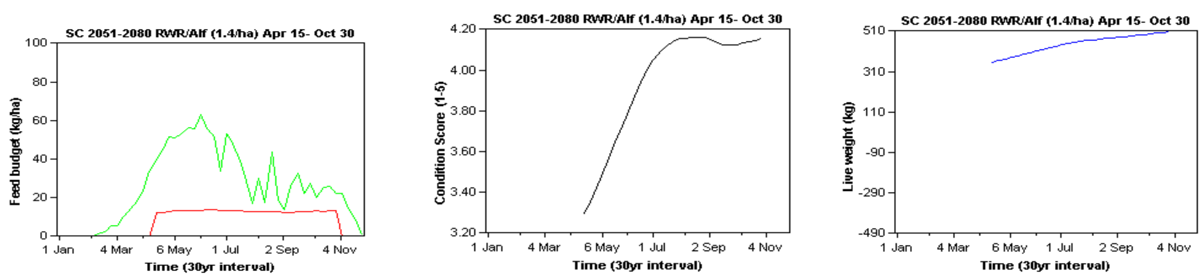
Adaptation strategy #2 (intensive early grazing) resulted an almost linear increase in live weights during the grazing season to 440 kg and condition score to 3.93 (Figure 28). Although these weights are less than those for 1961-1990 and 2051-2080 with no adaptation strategy, the increased stocking rate stocking rate (1.6 to 3.6 steers/ha) was able to make more efficient use of the available forage and productivity/ha was greatly increased. However, the length of the grazing season was shortened by 2 months relative to strategy #1.



(a) (b) (c)

Figure 28. Adaptation strategy #2 at Swift Current for steers grazing Russian wildrye/alfalfa pasture at a stocking rate of 3.6 steers/ha Apr 15 - Jul 15, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

Adaptation strategy #3 (longer grazing period), resulted in the heaviest final live weight (508 kg) and condition score (4.16) although there was a small decrease in stocking rate (1.4 steers/ha) relative to baseline and a large reduction in stocking rate relative to strategy #2. These results are shown in Figure 29.

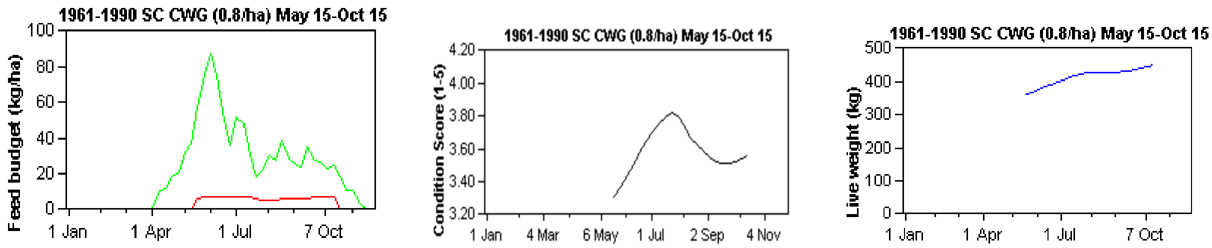


(a) (b) (c)

Figure 29. Adaptation strategy #3 at Swift Current for steers grazing Russian wildrye/alfalfa pasture at a stocking rate of 1.4 steers/ha Apr 30- Oct 30, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

vi. Swift Current Crested wheatgrass pasture (CWG)

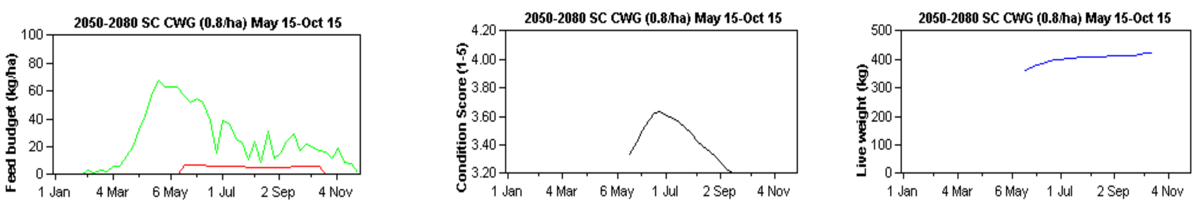
Data for 1961-1990 at a stocking rate of 0.8 steers/ha for crested wheatgrass pasture indicated an average final live weight of 449 kg and condition score of 3.56 (Figure 30). This was considerably lower than the 486 kg and 4.15 for the RWR/ALF pasture (Figure 25).



(a) (b) (c)

Figure 30. Baseline simulation at Swift Current for steers grazing crested wheatgrass pasture at a stocking rate of 0.8 steers/ha May 15- Oct 15 1961-1990. (a: feed budget; b: condition score; c: turn-off live weight).

All simulations for 2051-2080 for CWG at Swift Current resulted in live weights and condition scores that were less than the baseline data for 1961-1990 (Figures 31-34).



(a) (b) (c)

Figure 31. Simulation at Swift Current for steers grazing crested wheatgrass pasture at a stocking rate of 0.8 steers/ha May 15- Oct 15 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

Strategy #1 (early grazing) provided the best adaptation strategy (final condition score 3.45 and live weight 441 kg) with respect to per animal production (Figure 32).

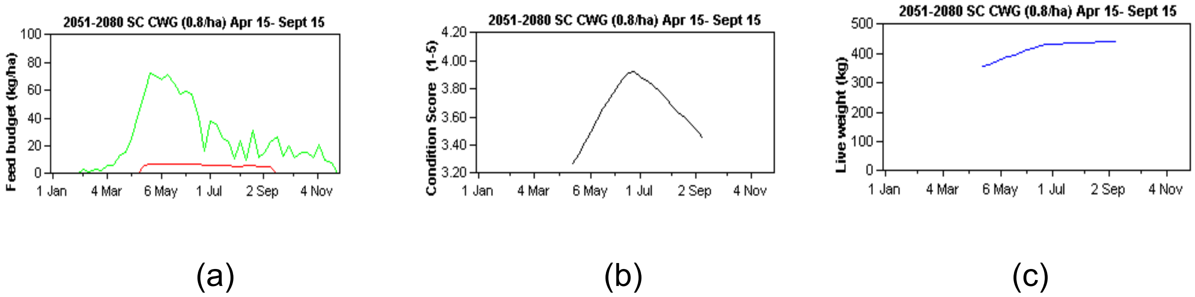


Figure 32. Adaptation strategy #1 at Swift Current for steers grazing crested wheatgrass pasture at a stocking rate of 0.8 steers/ha Apr 15 - Sep 15, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

However, Strategy #2 (intensive early season grazing) provided the highest condition score (3.77). Although the final average live weights were low (429 kg), the greatly increased stocking rate (2.5 from 0.8 steers/ha) enabled the most efficient utilization of the pasture and the best productivity/ha (Figure 33).

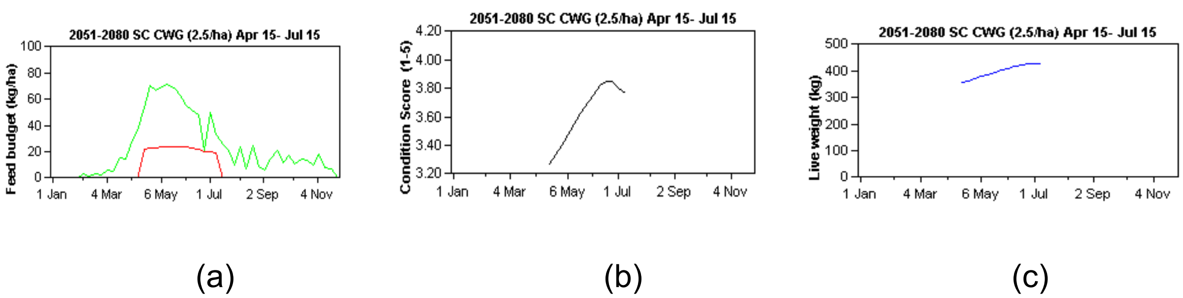
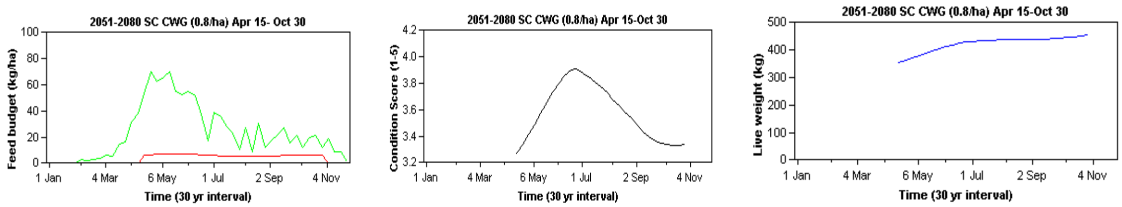


Figure 33. Adaptation strategy #2 at Swift Current for steers grazing crested wheatgrass pasture at a stocking rate of 2.5 steers/ha Apr 15 - Jul 15, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

Adaptation strategy #3 provided very little change in liveweights beyond the end of June and a steep decline in steer body condition (Figure 34) as a result of declining pasture quality (digestibility and protein content; data not shown).



(a) (b) (c)

Figure 34. Adaptation strategy #3 at Swift Current for steers grazing crested wheatgrass pasture at a stocking rate of 0.8 steers/ha Apr 15- Oct 30, 2051-2080. (a: feed budget; b: condition score; c: turn-off live weight).

d) Discussion

This project studied three possible adaptation strategies to climate change at three locations and two pasture types. The three locations were chosen to represent the three major soil associations in Saskatchewan (brown, dark brown and black). The two pasture associations were chosen because crested wheatgrass is the most commonly seeded tame grass in the province and has good early growth characteristics in spring but senesces early and loses quality rapidly in at high temperatures in summer. In contrast, Russian wild ryegrass has a longer growth period and maintains quality better than other grasses during the summer and fall. Alfalfa was chosen as the most commonly used legume in western Canada. It has long growing period and maintains quality throughout its growth cycle making it a good companion for Russian wild ryegrass. There is, however, a major problem with Russian wild ryegrass in that it is slow and difficult to establish. GrassGro does not simulate the establishment phase of perennial species although it does do this for annual species.

It is important to note that all predictions made in this report with respect to the effects of climate change on beef production can only be as accurate as the precision with which the CGCM1 climate model can predict future climate change. In addition, the CGCM1 model estimates climate change in 30-year segments but GrassGro requires a daily time step so we have had to adapt the data to assume a steady change over each 30-year segment.

Figure 35 presents a summarized comparison of final liveweights of steers grazing the Russian wild ryegrass and crested wheatgrass pastures at Melfort, Saskatoon and Swift Current for 1961-1990 (baseline) and 2051-2090 for no adaptation (future) and the 3 adaptation strategies (#1 - early turn-out, #2 - high intensity short duration grazing and #3 - low intensity long season grazing). It must be emphasized that the comparisons in Figure 35 have been made at different stocking rates. Similar stocking rates were possible at Melfort and Swift Current for the RWR/ALF pastures but final liveweights of steers were greater at Melfort. Stocking rates for the CWG pasture at Melfort were twice those at Swift Current with little difference in final liveweight. Similar stocking rates were possible at Saskatoon and Melfort for the CWG pasture and final liveweights were also similar. However, the stocking rate at Saskatoon for the RWR/ALF pasture was only $^{1}/_{3}$ that at Melfort and Swift Current and final live weights were also less at Saskatoon than the other 2 locations.

The results for Swift Current were not expected. It had been anticipated that climate change would cause similar results at Saskatoon and Swift Current. These results can be explained by the greater variability in rainfall patterns at Saskatoon and the lower rainfall during May and June (Figure 36). In addition, the GCM1 model indicated that summer temperatures would increase more at Saskatoon than the other 2 locations and GrassGro indicated that available plant moisture would be lower and evapotranspiration rate would be higher at Saskatoon.

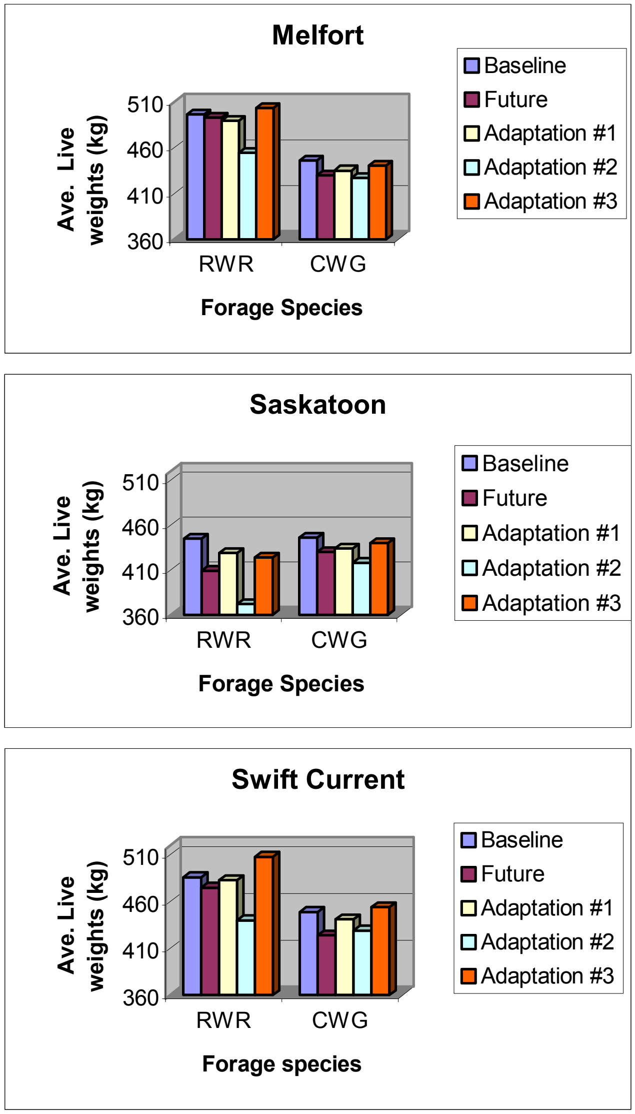


Figure 35. Summary of adaptation strategies for Melfort, Saskatoon and Swift Current using the CGCM1 Climate model.

The data reported here indicate that the best adaptation strategy for grazing Russian wild ryegrass/alfalfa pasture at Melfort and Swift Current would be adaptation strategy #3 if the aim of the operator is to turn off heavy backgrounded cattle. This strategy will allow cattle to be put out to pasture earlier in the spring and taken off pasture later in the fall. However, strategy #2 (high intensity short duration grazing) may be the preferred strategy for backgrounding steers since 60 and 150% more steers could be backgrounded to a slightly lower weight at Melfort and Swift Current respectively on the same area of pasture.

These lighter steers may be preferred to heavy backgrounded steers by feedlots for finishing. Traditionally, feedlots pay more/unit weight for light compared with heavy backgrounded steers. The economic gross margin for strategy #2 would therefore probably be greater. However, Strategy #3 would almost certainly be preferred for breeding cattle in the cow/calf sector of the beef industry where cattle are carried through the winter each year. Not only will this strategy increase the length of the grazing season at both of these locations, which will reduce the winter feeding costs, but it will also allow heavier turn-off weights in comparison to data for 1961-1990 (Figure 35) which could also reduce the winter feeding costs since heavy cows would require only maintenance feeding as compared to production feeding for light cows.

The best strategy for RWR/ALF pasture at Saskatoon for backgrounding steers would be strategy #1; put cattle out to pasture earlier in the spring (April 15) and remove them from the pasture in mid-fall (October 15). This provides the highest turn-off weights, the highest stocking rates and the longest grazing season. Although the condition scores of the steers decreased beyond the end of June these steers would be ideal for a feedlot to purchase for final finishing. This would also be the best strategy for the cow/calf sector because it would allow the longest grazing season and thus the shortest winter feeding period. However, the condition score for cows coming off pasture would need to be as good as that of the steers otherwise additional winter feeding costs would be incurred.

The best adaptation strategy at all 3 locations for crested wheatgrass in the cow/calf sector may be strategy #3, that is graze earlier in spring and continue later is fall. However, all strategies studied, except for strategy #3 at Swift Current, resulted in reduced liveweights at turn-off from crested wheatgrass compared with the baseline data of 1961-1990. However, strategy #2 would enable small increases in stocking rate to be implemented and this may increase the economic gross margin in a backgrounding operation. However, crested wheatgrass will probably be more suited to the cow/calf sector than backgrounding steers.

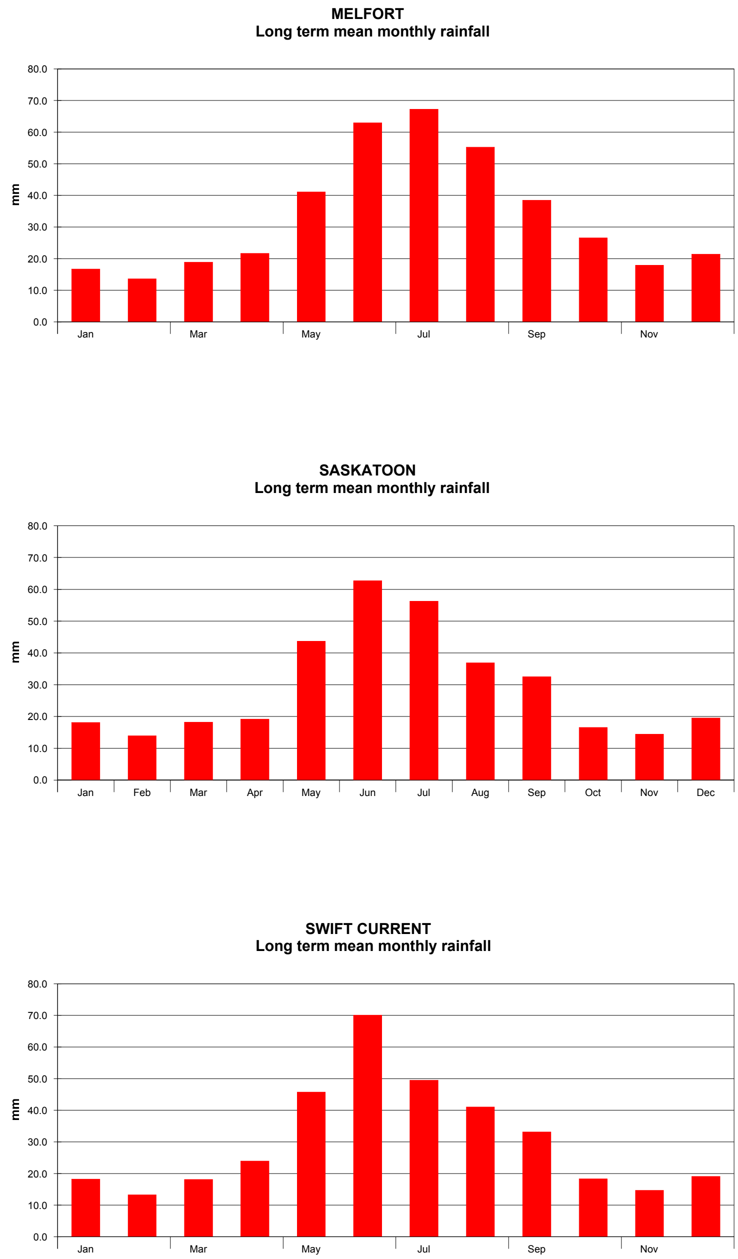


Figure 36. Long term mean monthly rainfall for Melfort, Saskatoon and Swift Current (1960-1990).

Based on the phenology and growth habit of crested wheatgrass, Romo (1994) suggested that concentrating high densities of livestock is a good method of obtaining the full benefits of this forage. Utilizing the lush, nutritious, early spring growth of crested wheatgrass can substantially improve average daily gains. Yearling steers were reported to gain 1.36 kg daily during the first 28 days of spring growth but only 0.9 kg daily during the second 28-days growth period (Rhodes et al., 1986). Although the gains of steers during late grazing were not as high as those reported for early grazing (Romo 1994), the need to extend the grazing season under practical management must also be considered (adaptation strategy #3). If crested wheatgrass is the only pasture available, strategy #2 may be best suited for backgrounding steers but is not practical for reproductive livestock (Launchbaugh et al., 1978) because of the reduced length of the grazing season. Baker (1994) predicted that, due to the earlier break in plant dormancy and earlier spring growth, less forage would needed to feed to the animal, thereby resulting in greater forage to supplement ratio. However, our simulations indicated that the timing of the spring "green-up" will be highly variable with climate change.

f) Conclusion

The results presented in this study provide estimates for the future effects of climatic change on livestock. The results also demonstrate the sensitivity of present-day livestock production from pasture to specific climatic perturbations. However, to assume that agricultural practices for the areas simulated will remain the same for the next fifty years would be unrealistic. Adaptation and management must be set in unison. Management is the key to adapting to the risks associated with climate change.

Management of livestock will ultimately guide animal performance. In years where production is affected negatively, a beef producer must either sell livestock or feed them. If vegetation production is more variable, then stocking rates must be decreased to ensure good animal vigor. More intense management will incur greater costs. Thus, even though the livestock may produce at similar levels, in the end, beef production costs may increase.

g) Recommendations

- Further research is needed to reduce the problems associated with the establishment of Russian wild ryegrass. This grass appears to be very important in maintaining, and indeed improving, beef productivity as the climate changes and establishment research should be given a high priority.
- Simulations of adaptation strategies should be undertaken for the other important tame and native species used on the Canadian Prairies.
- Simulated strategies should be expanded to include Alberta and Manitoba. This is possible with GrassGro but time precluded this expansion.
- It is very important that simulations for the cow/calf sector be undertaken. Cow/calf production is very important to Saskatchewan and the results presented here cannot be directly transferred to that sector of the industry because of the additional requirements of the cow for reproduction and lactation and of the calf for growth.
- Results of lagged adaptation simulations involving the establishment of forages and implementing management strategies should be examined. This will reveal what happens when adaptation efforts are not implemented immediately, when they lag behind the climate changes as farmers sort out the signal of climate change from the noise of natural variability.
- The results also indicate a need to find a way to increase the rate at which adaptation takes place relative to the changes/adjustments within the ecosystem. An "Anticipatory Adaptation" approach appears to be more appropriate for this purpose than an approach that incorporates "Reactive Methods". This means a change from the present adaptive management methods used in livestock production. By developing an understanding of the boundaries of adaptation, as well as the rate at which plant and animal systems respond to changes in the ecosystem, we will be able to reduce the amount of risk involved in the inherently risky business of livestock production. Economics, cost efficiency, benefits, and implementability are all factors of adaptation and should be considered in any further development of adaptation strategies.

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Appendix 1. Summary of simulation and management strategies.

Site	**Time interval**	**Turnout date**	**Species**	**Stocking rate**
1 Melfort	**1**. Baseline	**1**. April 15th	**1**. Russian Wildrye/ Alfalfa	**1.** High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**2**. May 15th		**1**.High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**1**.April 15th	**2.**Crested wheatgrass	**1**. High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**2**. May 15th		**1**.High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**1**. April 15th	**3**. Smooth bromegrass	**1**. High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**2**. May 15th		**1**.High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**1**.April 15th	**4**. Native with Fescue	**1**. High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**2**. May 15th		**1**.High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low

Site	**Time interval**	**Turnout date**	**Species**	**Stocking rate**
2. Saskatoon	**1**. Baseline	**1**. April 15th	**1**. Russian Wildrye/ Alfalfa	**1.** High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**2**. May 15th		**1**.High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**1**.April 15th	**2.**Crested wheatgrass	**1.** High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**2**. May 15th		**1**.High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**1**. April 15th	**3**. Smooth bromegrass	**1.** High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**2**. May 15th		**1**.High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**1**.April 15th	**4**. Native with Fescue	**1.** High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**2**. May 15th		**1**.High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low

Site	Time interval	Turnout date	Species	Stocking rate
3. Swift Current	**1**. Baseline	**1**. April 15th	**1**. Russian Wildrye/ Alfalfa	**1.** High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**2**. May 15th		**1**.High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**1**.April 15th	**2**. Crested wheatgrass	**1.** High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**2**. May 15th		**1**.High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**1**. April 15th	**3**. Smooth bromegrass	**1.** High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**2**. May 15th		**1**.High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**1**.April 15th	**4**. Native with Fescue	**1.** High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low
	1. Baseline	**2**. May 15th		**1**.High
				2. Medium
				3. Low
	2. 2051-2080			**1**.High
				2. Medium
				3. Low

Appendix 2. Summary of the simulation results for average live weights and condition scores over a graze period of May 15th – Oct 30th and April 15th- Oct 30th.

Option	Avg. Live Wt (kg)	Condition score	Option	Avg. Live Wt (kg)	Condition score	Option	Avg. Live Wt (kg)	Condition score
1.1.1.1.1	422	3.13	2.1.1.1.1	424	3.33	3.1.1.1.1	471	3.90
1.1.1.1.2	501	4.08	2.1.1.1.2	445	3.57	3.1.1.1.2	481	4.15
1.1.1.1.3	528	4.48	2.1.1.1.3	461	3.79	3.1.1.1.3	498	4.33
1.2.1.1.1	461	3.74	2.2.1.1.1	345	2.23	3.2.1.1.1	455	3.65
1.2.1.1.2	506	4.36	2.2.1.1.2	424	3.31	3.2.1.1.2	471	3.95
1.2.1.1.3	512	4.45	2.2.1.1.3	446	3.56	3.2.1.1.3	490	4.17
1.1.2.1.1	376	2.65	2.1.2.1.1	415	3.12	3.1.2.1.1	497	4.10
1.1.2.1.2	503	4.09	2.1.2.1.2	443		3.1.2.1.2	513	4.34
1.1.2.1.3	525	4.46	2.1.2.1.3	467	3.71	3.1.2.1.3	517	4.43
1.2.2.1.1	456	3.65	2.2.2.1.1	397	2.86	3.2.2.1.1	496	4.07
1.2.2.1.2	494	4.16	2.2.2.1.2	426	3.27	3.2.2.1.2	510	4.35
1.2.2.1.3	508	4.38	2.2.2.1.3	456	3.55	3.2.2.1.3	518	4.41
1.1.1.2.1	416	3.02	2.1.1.2.1	369	2.52	3.1.1.2.1	435	3.40
1.1.1.2.2	457	3.47	2.1.1.2.2	376	2.71	3.1.1.2.2	449	3.57
1.1.1.2.3	484	3.84	2.1.1.2.3	381	2.74	3.1.1.2.3	448	3.60
1.2.1.2.1	429	3.26	2.2.1.2.1	346	2.32	3.2.1.2.1	411	3.04
1.2.1.2.2	452	3.54	2.2.1.2.2	354	2.43	3.2.1.2.2	425	3.20
1.2.1.2.3	469	3.82	2.2.1.2.3	358	2.48	3.2.1.2.3	428	3.25
1.1.2.2.1	385	2.66	2.1.2.2.1	362	2.71	3.1.2.2.1	451	3.42
1.1.2.2.2	441	3.24	2.1.2.2.2	372	2.79	3.1.2.2.2	464	3.60
1.1.2.2.3	472	3.62	2.1.2.2.3	383	2.99	3.1.2.2.3	469	3.68
1.2.2.2.1	403	2.90	2.2.2.2.1	356	2.53	3.2.2.2.1	437	3.16
1.2.2.2.2	433	3.26	2.2.2.2.2	368	2.76	3.2.2.2.2	449	3.35
1.2.2.2.3	451	3.52	2.2.2.2.3	375	2.83	3.2.2.2.3	454	3.42
1.1.1.3.1	287	1.78	2.1.1.3.1	361	2.74	3.1.1.3.1	423	3.16
1.1.1.3.2	451	3.39	2.1.1.3.2	368	2.92	3.1.1.3.2	442	3.45
1.1.1.3.3	474	3.69	2.1.1.3.3	375	2.98	3.1.1.3.3	448	3.55
1.2.1.3.1	336	2.20	2.2.1.3.1	347	2.60	3.2.1.3.1	398	2.82
1.2.1.3.2	452	3.54	2.2.1.3.2	354	2.61	3.2.1.3.2	417	3.07
1.2.1.3.3	566	3.74	2.2.1.3.3	361	2.82	3.2.1.3.3	423	3.17
1.1.2.3.1	286	1.69	2.1.2.3.1	355	2.70	3.1.2.3.1	441	3.27
1.1.2.3.2	430	3.12	2.1.2.3.2	361	2.81	3.1.2.3.2	452	3.43
1.1.2.3.3	457	3.42	2.1.2.3.3	371	2.92	3.1.2.3.3	447	3.56
1.2.2.3.1	315	1.80	2.2.2.3.1	352	2.62	3.2.2.3.1	428	3.02
1.2.2.3.2	428	3.20	2.2.2.3.2	361	2.74	3.2.2.3.2	438	3.18
1.2.2.3.3	446	3.42	2.2.2.3.3	373	2.92	3.2.2.3.3	461	3.31