The Impact of Climate Change on Montana's Agriculture Economy

Prepared for

MONTANA FARMERS UNION
COOPERATION • EDUCATION • LEGISLATION

Power Consulting Inc.

Thomas Michael Power, PhD

Donovan S. Power, MS

February 24, 2016

<u>About the Authors</u>:

Thomas Michael Power is a Principal in Power Consulting, Inc. and a Research Professor and Professor Emeritus in the Economics Department at the University of Montana where he has been a researcher, teacher, and administrator for over 40 years. He received his undergraduate degree in Physics from Lehigh University and his MA and PhD in Economics from Princeton University.

Donovan S. Power received his undergraduate degree in Geosciences at the University of Montana and his M.S. in Geology from the University of Washington. He has been the principal scientist at Power Consulting, Inc. for the past seven years.

The Impact of Climate Change on Montana's Agricultural Economy

Executive Summary

1. Climate Science and Projected Climate Change in Montana

The Intergovernmental Panel on Climate Change has made it abundantly clear that human-caused greenhouse gas emissions are the dominant cause of the observed warming of the earth since the mid-20th century and that warming will continue through to the next century. Using geographically more detailed versions of Global Climate Models, the earth's observed and predicted warming can be brought down to the regional level of U.S. states and parts of the larger states to analyze geographically much more specific observed and predicted changes. Using the Third National Climate Assessment, we break Montana out of the Great Plains states to view the likely changes that Montana will see in the future due to climate change. We focus on a business-as-usual scenario where the world does not work to try and reduce the release of greenhouse gasses and, as a consequence, the mean global temperature is predicted to rise by 6.5 degrees (F) by 2100.

We focus on the two dominant variables driving climate change in Montana: temperature and precipitation.

Temperature: Montana is predicted to see a temperature rise of 4-5 degrees (F) by 2055. The temperature change will be greater in the winter with a temperature change of as much as 6.5 degrees (F) in the northeastern portion of the state. Montana is predicted to have a decreased number of days where the temperature drops below 10 degrees (F) (at least 15 fewer days and as many as 30 depending on the geographic location). Montana is predicted to see a decrease in the number of days that the temperature drops below 32 degrees (F) (at least 20 fewer days and as many as 40 depending on the geographic location). For the winter it is the increased number of warm days and the increase in precipitation that have the largest effect on the plants that grow within the different Montana ecosystems.

Montana is predicted to see an increase in the number of days where the temperature exceeds 95 degrees (F) (at least 5 more days and as many as 15). Montana is predicted to see an increase in the number of frost free days (at least 15 more and as many as 35 depending on the geographic location). For the summer, it is the days of extreme heat and the lack of precipitation that has the largest effect on the plants that grow within the different Montana ecosystems.

Precipitation: Although precipitation is less certain within the more geographically detailed Global Climate Models because of the existence of multi-year weather cycles (like El Nino or the Pacific Decadal Oscillation) and the lack of data specifically looking at these cycles, precipitation is an important and controlling variable for plant growth in the different Montana ecosystems.

Montana is predicted to get more precipitation by 2055. Most of Montana is predicted to receive 3-6 percent more precipitation while the northeast portion will receive 6-9 percent more precipitation. The ecologically critical point for precipitation is when it falls. Significantly more precipitation will fall in the winter and significantly less precipitation will fall in the summer. This is especially true for western Montana where precipitation will be 5-10 percent lower in the summer and 10-15 percent more in the winter.

Because Montana is predicted to warm in the winter, less precipitation will fall during the winter as snow and more will come in the form of rain. Because Montana is predicted to get less precipitation in the summer and the summer is predicted to be hotter there will be significant plant stress due to drought and extreme heat during the summer. The combination of changes in precipitation and temperature may have large impacts on the industries, like agriculture, in Montana that are dependent on a climate that many Montanans mistakenly see as largely stable despite its wide range of variability at any given time.

Less snowpack in the high country means less runoff for our streams in late spring and early summer, and the runoff will come earlier.

Disease and beetle kill will increase as the temperature increases and the summer moisture decreases and the native trees are too stressed to resist. The very composition of our forests will change causing the loss of the white bark pine and a transition from Ponderosa Pine and Douglas-fir to spruce-fir. The grasslands of Montana will convert to sagebrush and other scrub brush dominant species.

Livestock and rangeland will have to compete with invasive species that are less palatable to the cattle. The forage that cattle currently rely on will have less nitrogen, as the plants grow too fast from the increased carbon uptake in the spring while lacking the nitrogen necessary to keep the nitrogen ratios at levels that will be nutritive for the cattle. The rangeland will be stressed during the summer and autumn because of the lack of precipitation and the increased number of very hot days.

The Montana wheat industry will have to balance a potential increase in winter wheat harvest with a dramatic loss in spring wheat. The shorter, warmer, and wetter winters may initially allow for an increased harvest in winter wheat that is more than offset by a decline in spring wheat. However, by mid-century, the higher temperatures and depletion of nitrogen in the soil will also decrease winter wheat yields.

Based on the application of the recent climate science projections for Montana, we concluded that one of the greatest economic impacts will be on the state's agricultural activities, specifically declines in grain crops, especially wheat, livestock, and cattle production.

2. The Relative Importance of the Agricultural Sector

Forecasted climate change in Montana puts aspects of agriculture at risk of significant change and potential serious loss. For that reason we obtained estimates of the relative importance of agriculture to Montanans and the Montana economy.

Montana's grain production and cattle raising are the source, directly and indirectly, of over $3.3 billion in labor earnings and about 111,000 jobs. Table Sum-1 provides the break down between these two sectors.

Table Sum-1.

The Relative Importance of Grain Production and Cattle Raising in the Montana Economy, 2014		
Product	Jobs	Labor Earnings $millions
Grain Production	49,828	$1,489,331,480
Cattle Raising	60,835	$1,818,337,891
Total Grain & Cattle	110,662	$3,307,669,371

Sources: See Tables 11 and 12 of this report.

Clearly the grain and cattle sectors of the Montana economy are of significant importance. Climate change that threatens these sectors, poses a serious threat to the overall Montana economy.

3. The Estimated Economic Losses to Agriculture Associated with Climate Change in Montana

Both climate change and its agricultural and economic impacts are difficult to calculate. Projections require professional judgement based on the best evidence available. In public policy discussions aimed at reducing human releases of greenhouse gases (GHG) there tends to be a heavy emphasis on the economic *costs* associated with adopting those policies. When these costs of controlling GHG are discussed, there is rarely a similar discussion of the economic *benefits* that are the objective of those climate change public policies, namely avoiding the future costs associated with climate change. The result is a cost-only analysis that would typically produce quantitative and very large measures of the costs associated with policies aimed at reducing future human-caused climate change.

A "cost only" analysis of climate change public policy cannot be categorized as an *economic* analysis since it is the net costs or net benefits after both the benefits and costs of a public policy have been estimated that matter. Implicit in typical cost-only analyses is the assumption that the benefits of reducing human-caused climate change are known in precise, quantitative, detail, namely, that they are zero. The overwhelming scientific evidence is that this precise quantitative value of slowing or stopping human-caused climate change is wrong. The future costs associated with climate change that could be avoided are not zero.

In the analysis below we combine the quantitative information that is available with expert judgement to produce estimates of the likely economic costs associated with climate change in Montana if no public policy steps are taken to reduce human GHG emissions. That expert judgement is tied to a half-century of experience analyzing the Montana economy, the role that natural and social amenities have contributed to economic vitality in Montana, and long run economic trends within the state and region. In our professional judgement, these estimated economic costs of projected climate change in Montana are far more reliable and accurate than the explicit alternative assumption that there are *no costs at all* associated with that ongoing climate change in Montana.

4. Losses in Grain Crops and Cattle Raising

Warmer springs and the delay in the first hard frost in the fall might be interpreted to mean that Montana will face a longer growing season. Since carbon dioxide (CO_2) in the atmosphere is a crucial input to plant photosynthesis, high concentrations of CO_2 could also be seen as productive "fertilizer" for crops and forage for cattle on rangelands.

This is unlikely to be the case. The seasonal pattern of changes in temperatures and precipitation will favor rapid growth of plants in the spring and then hot dry summers that severely stress the plants. In addition, the carbon in the atmosphere has to combine with nitrogen in the soil to produce high yields of nutritious plants. As discussed in this report nitrogen depletion may prevent this. In addition the hot, dry weather and increased CO_2 concentrations will favor invasive species and plants unpalatable to livestock. The desiccation of early, fast-growing plants will increase rangeland wildfires, which, in turn, will encourage a degradation of the vegetation on rangeland for cattle. Similar problems will occur with grain production with spring wheat harvested in the fall being initially hardest hit by the hot dry summers. Winter wheat ultimately will also be negatively impacted.

The economic impact of these consequences of climate change on Montana's two primary agricultural sectors is projected to be a 20 percent decline in rangeland cattle production and a 25 percent reduction in grain production. The economic losses associated with this aspect of climate change would be the loss of about 25,000 jobs and $736 million in labor earnings by mid-century.

Table Sum-2 summarizes these particular projected economic losses due to Montana climate change.

TABLE SUM-2
Projected Economic Losses Due to Climate Change on Montana Agriculture

Agricultural Activities	Jobs	Labor Earnings ($millions)
Cattle Raising	12,167	$364
Crops	12,457	$372
Total	24,624	$736

Table of Contents

I. Global Climate Change and Montana Impacts

The Intergovernmental Panel on Climate Change (IPCC) released their fifth assessment in 2014.[1] In that assessment the Panel made clear that human-caused greenhouse gas (GHG) emissions were the dominant cause of the observed warming of the earth since the mid-20th century. On July 3rd of 2015, at the Lindau Nobel Laureate Meetings, a group of 39 Nobel Winners from different scientific fields signed a declaration warning that the world faces a threat that is comparable to the nuclear threat of nearly 60 years ago for which a similar group of Nobel Laureates signed a warning declaration.[2] In the recent declaration the Nobel Laureates expressed their confidence in the fifth IPCC report calling it the "the best source of information regarding the present state of knowledge on climate change."[3]

What has become increasingly clear is that there is no longer a credible debate among scientists who study global warming. Global warming is happening, the primary driver of global warming is human GHG emissions, and unless humans collectively do something about it, every inhabitant of earth will be affected by it. In this report we seek to understand what the likely impacts of global warming will be on the Agricultural sector of the Montana economy.

Although global climate models (GCM), like the ones that are used in the IPCC reports have been around for quite some time, the geographic detail of those models has been relatively poor until recently when scientists began "downscaling" their GCM. The resolution of the downscaled models allows the large grid size of the global models, which are generally 60-120 miles[4] and could potentially miss large-scale regional features such as mountain ranges, to be downscaled to local data sets with a resolution of 7.5 x 7.5 mile (1/8 degree).[5] This finer geographic detail allows very specific future climate predictions to be analyzed at a sub-state level in Montana.

The Third National Climate Assessment (NCA3) was published in 2014 by the U.S. Global Change Research Program. In that assessment the state of Montana was grouped with the Great Plains states.[6] That regional and state climate assessment was supported by an analysis

---

[1] IPCC. Fifth Assessment Report (AR5). https://www.ipcc.ch/report/ar5/index.shtml
[2] Mainau Declaration 2015 on Climate Change. http://www.lindau-nobel.org/wp-content/uploads/2015/07/Mainau-Declaration-2015-EN.pdf
[3] Ibid.
[4] Ibid. page 7.
[5] Downscaled CMIP3 and CMIP5 Climate Predictions. Bureau of Reclamation. May 7, 2013. Page 4. http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/techmemo/downscaled_climate.pdf
[6] Shafer, M., D. Ojima, J. M. Antle, D. Kluck, R. A. McPherson, S. Petersen, B. Scanlon, and K. Sherman, 2014: Ch. 19: Great Plains. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 441-461. doi:10.7930/J0D798BC. http://nca2014.globalchange.gov/report/regions/great-plains
The eastern two-thirds of Montana is part of the Great Plains geographic region. The western and southwestern third, from the eastern foothills of the Rocky Mountains to the Montana-Idaho border is often classified as part of the Pacific Northwest or Northern Rocky Mountain geographic region.

carried out by the National Oceanic and Atmospheric Administration (NOAA) and published in 2013.[7] We use these predictions of future climate change in Montana as a basis for our analysis. These predictions were made using the same GCM and the same scenarios that the IPCC reports use, but applies them to much smaller geographic regions.

The scenario on which we are focusing our study is "A2" in the NOAA Great Plains study mentioned above. Scenario A2 is the closest to what is traditionally called the "business as usual" scenario. It is a scenario where the "underlying theme is self-reliance and preservation of local identities"[8] which means that the world does not come together to try and abate the collective emissions of the many different countries. The end result for the earth is a mean global temperature rise by the year 2100 of about 6.5 degrees (F). We must then look to the downscaled or regional climate models to see what this increase in GHG and the accompanying change in temperature and precipitation are predicted to be in Montana. It should be noted that the dates that we are looking at do not always match up. In a perfect world all of the scientists would choose to look at the same dates for their different climate change predictions. However, in practice they do not all choose the same dates. Wherever possible we choose to present the projections that are as close to 2055 as possible. Although the dates of the different projections do not always match up, the trend of the change is always in the same direction.

1. Climate Change in Montana

We will begin by focusing on the two dominant drivers of climate change in Montana: temperature and precipitation. The general trend in Montana, like the world trend mentioned above, is that Montana gets warmer. Precipitation patterns are a little less well understood with GCM but generally precipitation in Montana increases. Warmer air can hold more moisture than cold air and allow more moisture to be carried into the state during the winter months, which is not offset by the reduced moisture during the summer months.

A. Temperature changes in Montana

Montana is predicted to see a temperature rise of 4-5 degrees (F) by 2055.[9] This temperature increase will be greater in the winter with a temperature change of as much as 6.5 degrees (F) in the northeastern part of the state and smaller in the spring with an average temperature rise of 3 degrees (F) for most of the state.

Montana is predicted to see an increase in the number of days when the temperature exceeds 95 degrees (F). By 2055 Montana is predicted to have between 5 and 15 more days where the

[7] Regional Climate Trends and Scenarios for the U.S. National Climate Assessment, Part 4. Climate of the U.S. Great Plains. National Oceanic and Atmospheric Administration. 2013.
[8] Ibid. Page 6.
[9] Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 4. Climate of the U.S. Great Plains. Figure 14, page 38. U.S. Department of Commerce. National Oceanic and Atmospheric Administration. January, 2013.

temperature reaches above 95 degrees (F).[10] The western portion of the state will see the lower end of the extreme heat (mainly due to the mountains) while the central and eastern portions of the state see the larger end of the extreme heat days.

Montana is predicted to have a decreased number of days where the temperature drops below 10 degrees (F). The change is not as homogenous as the increased temperature, but all of Montana is predicted to have at least 15 fewer days below 10 degrees and as many as 30 fewer such days in the southwest portion of the state.[11] These future temperature predictions fit the research of Pederson who looked at what climate change in Western Montana has already taken place and found that:

> The last extremely cold day of the winter season, however, has changed significantly, arriving an average of 19 days earlier. During the early-20th century (1900–1910) extremely cold temperatures (*t*min ≤ −17.8◦C) typically ended on winter [year day] YD 248 (~March 5). Over the past decade (1996–2006) the end of winter season's extremely cold events has occurred on average by winter YD 228 (~February 15). The earlier termination of extreme cold events (*t*min ≤ −17.8◦C) documented here reflects the autumn/spring asymmetry in warming noted below.[12]

Montana will have a decreased number of days where the temperature drops below 32 degrees (F). Again the change is not as homogenous as the temperature increases across Montana. There is a range of decreased days when the temperature drops below 32 degrees ranging from 40 less days in the northwest portion of the state to 20 fewer days in the eastern and northeastern third of the state.[13]

Montana will have an increased number of freeze-free days by 2055. The western part of the state, which is also the mountainous region, will see the largest increase in frost free days with an increase of 36 days, and the northeastern corner of Montana will see the smallest increase with 15 days.[14] Again Pederson confirms that these predictions about the direction and magnitude of temperature trends in Montana have already begun:

> With a demonstrated increase in number of "hot" days (≥32.2◦C) experienced per year across western Montana, it follows logically that a reduction in number of "cold" days per year should be evident. With few exceptions, western Montana meteorological stations have experienced a decrease in annual number of freeze/thaw days (*T*min ≤0◦C), and extremely cold days (*T*min ≤ −17.8◦C). The average loss of number of days at or below the freeze/thaw threshold (*T*min ≤0◦C) in western Montana is approximately 16 days, declining from an average of

---

[10] Ibid. Figure 17, page 44.
[11] Ibid. Figure 18, page 45.
[12] YD refers to "year day." Pederson et al. A Century of climate and ecosystem change in Western Montana: what do temperature trends portend? *Climate Change*. 98:133-154. 2010.
[13] Ibid. Figure 19, page 46.
[14] Ibid. Figure 21, page 49.

~186 to ~170 days−yr. The sharpest decline in number of freeze/thaw days has occurred within the last 20 years.[15]

By 2055 Montana will have an increase in the number of cooling degree days.[16] Western Montana will see an increase of 200 cooling degree days and eastern Montana will see an increase of 400 cooling degree days.[17] By 2055 Montana will also have a large decline in the number of heating degree days.[18] Southwestern Montana will see -1,650 heating degree days while most of the eastern half of Montana will see -1,250 heating degree days.[19] Heating degree days are a measure of the temperature relative to a benchmark (65 degrees F). A decrease in heating degree days thus describes a Montana future where there are far less days below 65 degrees and the magnitude of the heating degree days describes how far above 65 degrees it will be over the year. For each day and each degree above 65 degrees, one heating degree day is added. So, for example, if there is one heating degree day where the temperature is 75 degrees (F), that represents 10 heating degree days.

The overall trend for Montana is that the winters will be warmer and a little wetter while the summers will be hotter and a little drier. This is a trend that has already begun and is increasing, as Pederson points out. The distribution of temperature changes is not homogenous with the northeastern portion of the state receiving the most severe changes and the mountainous west receiving slightly less dramatic changes.

B. Precipitation

As noted above, the predicted change in precipitation is a little less certain within the more geographically detailed GCM. This uncertainty is largely related to the models' ability to capture multi-year cyclical events that can have large influences on the moisture that Montana receives. The Pacific Decadal Oscillation, El Nino, and La Nina are examples of multi-year cycles that impact Montana but are poorly represented in the climate change models.[20] Because of this lack of clarity associated with these cyclical events and in part because detailed climate records only go back 60 years (which doesn't capture enough of the multi-year cycles to make the projections as precise as we would wish) precipitation is modeled with less confidence than temperature going forward.

---

[15] Pederson et al. A Century of climate and ecosystem change in Western Montana: what do temperature trends portend? *Climate Change*. 98:133-154. 2010.

[16] Cooling degree days are a summation of the temperature above 65 degrees (F) for each day of the year. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/degree_days/ddayexp.shtml

[17] Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 4. Climate of the U.S. Great Plains. Figure 22, page 51. U.S. Department of Commerce. National Oceanic and Atmospheric Administration. January 2013.

[18] Heating degree days are a summation of the temperature below 65 degrees (F) for each day of the year. NOAA. Climate Prediction Center. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/degree_days/ddayexp.shtml

[19] Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 4. Climate of the U.S. Great Plains. Figure 23, page 52. U.S. Department of Commerce. National Oceanic and Atmospheric Administration. January 2013.

[20] Ibid. Page 9.

Montana is predicted to get more precipitation by 2055. Most of Montana will receive 3-6 percent more precipitation while the northeastern portion of Montana will receive 6-9 percent more precipitation.[21] The increased precipitation is not uniform over the different seasons. Significantly more precipitation will fall in the winter and significantly less precipitation will fall in the summer. This is especially true for western Montana where summer precipitation will be 5-10 percent lower and winter precipitation will be10-15 percent higher.[22] As was discussed earlier, the increase in winter precipitation is closely linked to the temperature changes that are predicted for Montana's winters. As the winters become warmer more moisture is able to be carried into Montana in part because warm air can carry more moisture.

As Montana's winters become warmer, more precipitation will fall as rain as opposed to snow. Headwater Economics, in their report on the climate impacts on the Montana skiing and sport fishing industry sum up the predicted changes in precipitation succinctly:

> Changes in precipitation patterns are predicted to include a greater proportion of winter precipitation falling as rain than snow, decreased snow season length at most elevations, decreased spring snowpack, earlier snowmelt runoff and peak streamflow, increased frequency of droughts and low summer flows, and amplified dry conditions due to increased evapotranspiration, even in places where precipitation increases, as mentioned above. These changes have important implications. Historically, moisture delivered through snowmelt provided inputs to aquifers, rivers, and streams gradually throughout the summer.[23]

How the different sectors of the Montana economy will deal with the temperature and precipitation changes in the future is an open question. The ability of many industries in Montana to adapt is unknown. In this report we take the same approach as the climate modeling that we relied on for the temperature and precipitation changes. That is, we will assume a business as usual approach to the Montana economy and assume that some portion of the impacted sectors will decline due to a changing climate to which they cannot adapt.

In some sectors of the economy this "business as usual" approach makes a lot of sense because of the unknown reliability of adaptations and their costs. In other sectors of the economy there appear to be recognized adaptations that may help mitigate the coming climate change at an affordable cost. Because the predicted impact of climate change can be mitigated to some degree, any forward projections that look at the impact of climate change always have some speculation in them. This does not mean that analysis of those "business as usual" impacts does not provide useful information.[24] This report is meant to highlight what will likely

---

[21] Ibid. Figure 24, page 55.
[22] Ibid. Figure 25, page 57.
[23] The Effects of Climate Change on the Downhill Skiing and Recreational Fishing Economy in the Crown of the Continent. Headwater Economics. Page 19. January, 2011.
[24] Projections that are often made about the negative economic impacts of reducing the use of coal or other fossil fuels suffer from the same weakness: They assume, for instance, that if a coal mine or an electric generator is shut down that all associated jobs and earnings are lost forever. The adaptation of the economy to provide those energy services from other sources, e.g. renewable resources, improved energy efficiency, less carbon intensive fuels, etc., and the reemployment of the now under-utilized labor

happen if nothing is done to mitigate climate change and adaptation is either not possible or perceived to be too expensive.

It is within this complex backdrop of future climate conditions and the economic implications of those climate changes that we investigate the potential economic cost of climate change in Montana.

2. Montana Agriculture

What will climate change look like for the agricultural sectors in Montana?

We will begin this section by looking at how the climate change that we described above will likely impact the agricultural sectors of the Montana economy that are potentially vulnerable to climate change. Climate change will not affect all agricultural industries equally and climate change will be different across the state of Montana. We will begin by looking at how the climate change, projected by climate science for Montana, is likely to impact the agricultural industry. Then we will look at the potential economic implications of those impacts.

A. Livestock and Rangeland

About 60 million acres (or 65 percent) of Montana is agricultural land.[25] Of that 60 million acres about 18 million are cropland and 38 million acres are pasture and rangeland. Wheat, barley, and cattle account for about 80 percent of all farm and ranch cash receipts in Montana during any given year.[26]

The likely impact of climate change on rangeland and raising cattle is not as clear as it is for some other sectors of the economy given the current scientific knowledge. Less harsh winters coupled with the same or possibly slightly more moisture during the winter and spring could lead to more plant production and less winter stress on cattle. However, the lengthening of the summer season and the lack of moisture coupled with increased heat and an increase in the number of very hot days puts stress on both the cattle and rangeland forage. Water available for the cattle and the rangeland during the summer season are predicted to decline with increased evaporation and evapotranspiration, adding to the stress on the cattle and the rangeland. A potential increase in the CO_2 concentration and a lengthening of the growing season has the potential to increase the rate at which the rangeland forage grows, but the forage may be less nutritious for the cattle.[27] The increased uptake of CO_2 may be entirely offset by the increased

---

and capital resources in other valuable economic activities are typically ignored when projecting job and payroll losses.

[25] Climate Change and Agriculture Land Use. MONTANA.GOV. Accessed on 7.13.2015. http://deq.mt.gov/ClimateChange/Commerce/Agriculture/LandUse.mcpx

[26] Ibid.

[27] Pederson et al. A Century of climate and ecosystem change in Western Montana: what do temperature trends portend? *Climate Change*. 98:133-154. 2010.

heat, which causes increased plant respiration in the summer and fall months.[28] A recent study from Brookshire and Weaver takes this one step farther showing that there has been a greater than 50 percent decline in production of native grassland in the Greater Yellowstone Ecosystem over the last four decades due to an increasing lack of moisture in the late summer.[29] Finally the future climate may invite exotic invasive species into the rangeland, which are less palatable for the cattle.[30]

With this complicated story of the relationship of cattle and the rangeland to climate change, various scientists have studied the future of the cattle industry in Montana. Pederson makes the case that the livestock industry in Montana may be threatened by the changing climate as pasture quality declines.[31] Briske makes a more nuanced case that the nitrogen ratios of the crops will provide less nutritive forage causing livestock to require dietary nitrogen supplements that could potentially be prohibitively expensive.[32] From Briske's perspective it is the possibility of the expansion of exotic invasive species of plants that will become better suited to the rangeland that will make the larger difference in livestock growth since those invasive species are often unpalatable to livestock.[33] The overall scientific evaluation indicates that there will be less forage for cattle due to climate change and that forage will be less nutritious.

B. Agricultural Crops

As mentioned above about 18 million acres in Montana are used to grow agricultural crops. About 8.75 million of these cropland acres are harvestable each year.[34] About 8 million acres are tilled and about 7 million acres are left in seasonal follow in any given year. Fifty percent of the planted acreage in any given year is for wheat production. Hay is planted on 30 percent of the land and barley on about 9 percent. About 3.5 million acres are enrolled in federal Conservation Reserve Program that allows farmers and ranchers to place specific cropland into non-productive conservation use in return for payments from the federal government.

"Dryland strip fallow" practices dominate the production of small grains in Montana (wheat and barley). This allows farmers to leave alternate strips of their fields untilled for a year to accumulate soil moisture and then swap the fallow field for the producing fields the following year. As a result much of the dryland wheat acreage produces one crop of wheat every two years.

[28] Piao et al. Net carbon dioxide losses of northern ecosystems in response to autumn warming. Natue Letters. Vol. 451. January 2008. Doi:10.1038/nature06444
[29] Brookshire, N and Weaver, T. Long-term decline in grassland productivity driven by increasing dryness. Nature Communications. May 14, 2015. DOI: 10.1038/ncomms8148.
[30] Briske, D. et al. Climate-change adaptation on rangelands: linking regional exposure with diverse adaptive capacity. Ecological Society of America. 2015.
[31] Op. Cit. Pederson et al. 2010.
[32] Briske, D. et al. Climate-change adaptation on rangelands: linking regional exposure with diverse adaptive capacity. *Frontiers in Ecology and Environment.* 13(5): 249-256. 2015.
[33] Ibid.
[34] Climate Change and Agriculture Land Use. MONTANA.GOV. Accessed on 7.13.2015. http://deq.mt.gov/ClimateChange/Commerce/Agriculture/LandUse.mcpx

On the whole, as discussed above, Montana is predicted to become warmer and slightly wetter. It is the timing of those changes that puts crop production in Montana potentially at risk. The summer months will become drier and hotter with an increased number of days with extreme heat. Relating those changes to agricultural production in Montana is something that is just beginning to be studied. A study of agriculture in the Flathead Valley of Montana highlights the difficulty in quantifying climate change's impact on agriculture in the future. That study of the overall impact of climate change on crops in the Flathead Valley of Montana by Tony Prateo and Zeyuan Qui[35] found that the net crop return per hectare would decrease 24 percent and net farm income decrease by 57 percent. The range of the predicted impacts was much broader than these averages indicate. Soil type, crop type, climate scenarios, and mitigation measures had very large effects on the outcome of the predicted climate change impact on yield and income. Depending on the soil type and crop type, some famers could see an increase in crop yield with some mitigation measures.

Antle found that a change in the crop yields for Montana farmers was likely to be seasonal. Winter wheat yields will increase across the state for at least the next couple of decades while spring wheat yields will decline in all but two of the zones that they studied. The difference, as discussed above, has much to do with precipitation patterns and changes in temperature with the winter wheat growing season receiving more moisture compared to the spring wheat.[36] As was discussed above it is the combination of increased temperature and moisture that allows wheat to flourish or be stunted.[37] Unfortunately, the precipitation increases that are modeled to come to Montana are less certain than the temperature changes. As Antle points out, "relatively small reductions in precipitation could lead to substantial changes in production systems, primarily from grain production to pasture."[38]

The final piece of this puzzle hinges on CO_2 fertilization effects. With projected climate change, but without accounting for the potential CO_2 fertilization effects, Antle found that all crops in all regions of Montana had declining grain yields. Yet with CO_2 fertilization accounted for, winter wheat saw a 17-55 percent increase in yield. When climate effects are taken into account along with elevated CO_2, the results were somewhat offsetting (as presented above). Winter wheat increased its yield and spring wheat declined by 20-30 percent.[39] The complex nature of this problem makes predictions on farming in Montana, and specifically wheat yields, hard to quantify. As it gets warmer the wheat yields suffer, ultimately even winter wheat yields decline. As it gets wetter and there is more CO_2 for fertilization, the wheat yields increase (except for spring wheat) *if* there is sufficient nitrogen to complement the CO_2 fertilization. Finally the

---

[35] Pratoe, T and Qui, Z. Potential Impacts of Adaptation to Future Climate Change for Crop Farms: A Case Study of Flathead Valley, Montana. INTECH. 2013. http://dx.doi.org/10.5772/39265
[36] Antle, J., Capalbo, S., Elliot, E., Paustian, K. Adaptation, spatial heterogeneity, and the vulnerability of agricultural systems to climate change and CO_2 fertilization: An integrated assessment approach. *Climactic Change*. 64:289-315. 2004.
[37] Ibid.
[38] Ibid. Page 296.
[39] Ibid. Page 302-303.

increased heat in the summer and fall all but negates the increases in fertilization and moisture across the year.[40]

The trend that appears through these different studies is that there may be a higher yield of winter wheat during the spring at least for the next couple of decades and a lower yield of spring wheat during the summer.[41] The winter wheat increase will not make up for the spring wheat decline unless mitigation measures are taken by Montana farmers. This not the first time that farmers have faced climate induced challenges in Montana. In the 1920s and 30s sustained drought in Montana led to massive farm foreclosures[42] and a consolidation of most of the small farms into the much larger farms that dominate wheat production in Montana today. From 1919-1925 half of the farmers in Montana lost their farms[43] and Montana's bankruptcy rate was the highest in the country.[44] The advent of modern farming techniques (like the use of tractors) allowed relatively small numbers of people to farm massive tracts of land. As a result the farming regions in eastern Montana and across the Great Plains lost population and population density and never recovered that population.[45]

II. The Relative Importance of Montana's Agricultural Sectors to the State's Economy

1. Measuring the Relative Importance of Different Parts of the Local Economy

There are a variety of ways of quantifying the relative importance of a particular set of economic activities in the overall regional economy, e.g. the state of Montana as a whole or a county or set of counties. Each economic measure describes the economy in a somewhat different way.

---

[40] Piao et al. Net carbon dioxide losses of northern ecosystems in response to autumn warming. *Natue Letters*. Vol. 451. January 2008. Doi:10.1038/nature06444

[41] Proto and Qiu show an overall loss of 24% for wheat. Antle shows a decline in spring wheat of 20-30 percent and an increase in winter wheat. Pederson states that crop yields will decline and more xeric conditions will prevail.

[42] Pederson et al. A Century of climate and ecosystem change in Western Montana: what do temperature trends portend? *Climate Change*. 98:133-154. 2010.

[43] Holems, K. Montana: Stories of the Land. Chapter 18, page 354. http://svcalt.mt.gov/education/textbook/chapter18/Chapter18.pdf

[44] Strahn, D. Historic Homesteads. *Distinctly Montana*. 4.4.2007. http://www.distinctlymontana.com/montana-history/04/04/2007/frontier-homestead

[45] Gutmann, M. et al. Population and Environment in the U.S. Great Plains. Population, Land Use, and Environment: Research Directions. National Academic Press. 2005. http://www.ncbi.nlm.nih.gov/books/NBK22969/

In the discussion below, we will use two different measures: the number of jobs and the labor earnings associated with those jobs.[46]

Other measures of relative economic importance that are often used include the sales value of output and value-added. We do not use those measures because total sales value tends to exaggerate the value actually created when production moves through multiple sales transactions in the economy. Value-added, the measure of economic value preferred by economists, is not used because it is not a concept with which most participants in the economy are familiar. Most citizens, however, are very familiar with the concepts of jobs and paychecks.

The measurement of the relative importance of, say, a particular industry, can be presented in two quite different ways. One is to simply ask how much of all the jobs or labor earnings in the state or a county is associated with that industry. This measure of importance is typically labeled the *direct* impact. Often that straightforward measure is not used because the potential "ripple" or "multiplier" impacts of a particular industry that stimulate additional jobs and payrolls in other sectors of the overall economy would be ignored. One common way of looking at the local economy does not treat all jobs and earnings as of equal importance. Some jobs, those that draw income into the local economy, are seen as the engine of local economic change. As that income is spent and re-spent within the local economy additional jobs are created and additional income is generated. These "more powerful" jobs or income flows typically are labeled "basic" jobs and all of the other jobs, which are assumed to be "caused" by those basic jobs, are labeled "secondary" jobs.[47] In this view, "basic" jobs and income have "ripple" or "multiplier" impacts elsewhere in the economy that also have to be measured and included when evaluating the relative importance of those "basic" jobs and income.

2. The Relative Importance of Agriculture in the Montana Economy

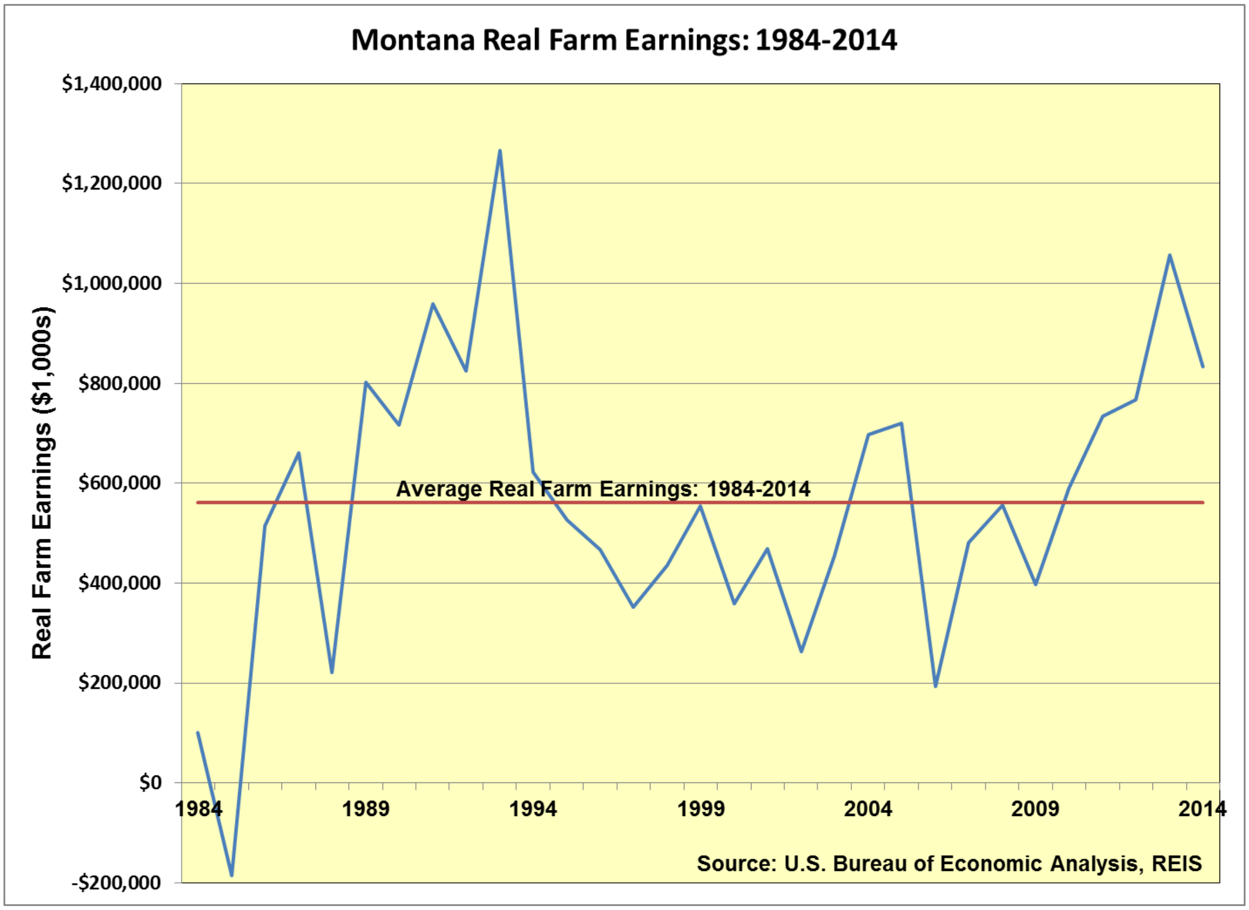
If we define the agricultural economy in Montana as consisting of farm and ranch enterprises, the service sectors that support agriculture (e.g. providing custom harvesting or pesticide applications, etc.) as well as food manufacturing, the total labor earnings from the "agriculture-related" sectors of the Montana economy totaled about $1.2 billion in 2014. The labor earnings just of farm operators and hired farm workers came to $871.7 million in 2014 about two-thirds of the total agricultural-related labor earnings. That represented about 4.2 percent of all worker and proprietor earnings in Montana.

[46] "Jobs" need to be distinguished from "employed persons." A person can hold more than one job. "Jobs" sum up full- and part-time jobs without distinguishing between them. So the "jobs" are *not* "full-time equivalent" jobs. "Jobs" also include the self-employed. "Employee Compensation" includes wages and salaries plus the value of non-wage benefits such as insurance, pensions, etc.

[47] The basic jobs and income are labeled "direct" impacts. The secondary impacts are broken into "indirect" and "induced" jobs. Indirect jobs and income are those associated with economic activity supplying the basic sectors with required inputs. Induced jobs are those stimulated by workers spending their paychecks.

The real earnings of farm and ranch operators, however, fluctuates widely from year-to-year as agricultural commodity prices and weather conditions fluctuate. The 2014 real earnings of farm operators and hired farm workers in 2014 were 48 percent *above* the average for the thirty-year period 1984-2014. In that sense farm and ranch payroll and the measure of the relative importance of agriculture in the Montana economy in 2014 may exaggerate somewhat the "typical" role of agriculture as a source of income in the Montana economy. See Figure 1.

Figure 1.



In terms of employment in 2013, there were about 37,200 full- and part-time workers in agriculture-related businesses, 23,000 of which were self-employed farm proprietors. That was 5.8 percent of all jobs in Montana.[48] The somewhat larger share of jobs in agricultural-related activities than in labor earnings is due to the fact that hired farm workers, in general, face low wages and farm proprietors often earn a quite low return for their labor and capital investments. The number of farm operators and farm workers is much more stable from year-to-year than is the real income of those workers.

[48] All data from the U.S. Bureau of Economic Affairs, BEA, Regional Economic Information System, U.S. Department of Commerce.

The Montana Bureau of Business and Economic Research at the University of Montana estimates that when the multiplier impacts associate with agriculture-related activities are accounted for, Montana agriculture is the source, directly and indirectly, of 15 percent of all labor earnings in the state.[49] The difference between the 4.2 percent direct impact of agriculture on labor earnings in Montana and the 15 percent relative importance when indirect and induced impacts are also counted indicates the size of the assumed ripple or multiplier impacts.

As mentioned above the agricultural sector in Montana is dominated by grains and beef cattle. Wheat and barley represented 68 percent of the value of crops sold in Montana in 2014. If hay is included, those three crops represent 97 percent of crop values. Those crops, in turn represented a little over half, 53 percent, of total agricultural sales in Montana in 2014.

Livestock and related products, including poultry and milk cows, were responsible for the other half (47 percent) of Montana agricultural sales value. Cattle and calves dominated the livestock sector, producing 90 percent of the sales value.

Cattle and calves plus wheat and hay production were the source of 88 percent of Montana agricultural sales. Thus the focus here on the impact of climate change on the beef and wheat sectors of Montana agriculture, comes close to encompassing the vast majority of agricultural activity in Montana.

III. The Projected Impact of Climate Change on Montana's Agricultural Economy

As discussed above, we have chosen to measure the economic impacts of the way climate change will affect Montana's agricultural industries by using two familiar economic metrics: lost jobs and reduced labor earnings. Although this is how economic impacts are usually measured, farming and ranching are not *just* one set among many economic activities whose importance is limited to employment opportunities and associated wages, salaries, and small business net income. As economists have often pointed out, the net income earned by farmers and ranchers rarely justify the investments they make in land and equipment and the long hours of work all members of farm families put into their agricultural enterprises. Farming and ranching is more than an economic enterprise. It is also a way of life.[50] For that reason there are cultural and social values associated with those undertakings, not just for the farmers and ranchers themselves but also for their communities and the state of Montana as a whole. Agriculture has helped define Montana's identity and that of many, if not most, of its non-agricultural residents. In that sense, damaging or weakening agriculture and reducing its role in the state has cultural

[49] To smooth out the fluctuating earnings in agriculture and other basic industries from year to year, the BBER used an average of earnings from 2012 to 2014 for its calculations. Montana Economic Outlook. Patrick M. Barkey, *Montana Business Quarterly,* Spring 2015, Figure 5, p. 13.
[50] Income Earning Potential versus Consumptive Amenities in Determining Ranchland Values. L. Allen Torell, *Journal of Agricultural and Resource Economics* 30(3):537-560, 2005.

and social costs which our economic metrics do not reflect. For that reason our economic estimates may represent a serious understatement of the overall loss to Montana.

1. The Impact of Climate Change on Rangeland and Cattle Production

As discussed above climate change is expected to lead to shorter winters with less snowfall, fewer extremely low temperatures, and more winter and spring precipitation coming as rain. Spring seasons will be warmer as will autumns, leading to a longer "growing season." However, this will not lead to more forage being produced on rangelands. The details of climate change will, ultimately, make Montana rangelands less productive, not more productive. There are several aspects to this: [51]

Summers will be hotter, have more extreme temperatures, and will be drier. This will seriously stress the forage available and increase the problem of providing the cattle with access to water. It will also stress the cattle and calves.

The early rapid growth of vegetation due to warm and wet conditions and increased CO_2 concentrations may be nitrogen limited and the forage produced will not be as digestible or as nutritious. Nitrogen dietary supplements may have to be used, boosting operating costs and labor requirement.

The high temperatures and high CO_2 concentrations will boost competition from leafy spurge and knapweed among other invasive species that are not valuable for forage. The productivity of rangeland will decline.

The early warm and wet weather will create "blooms" of vegetation that will then, in summer, become desiccated vegetation that increases the probability of fire. Those fires will encourage the encroachment of woody plants on rangeland.

It should be pointed out that the study that came to the above conclusions actually projected a near-term possibility that higher stocking levels would be possible in the Northern Great Plains that could offset some of the cattle production losses in Texas and the Southern Great Plains due to climate change. The authors of that tentatively optimistic conclusion about the Northern Great Plains added a caution:

> However, it is uncertain to what extent elevated atmospheric CO_2 will reduce forage quality, and thus livestock production and profitability, by increasing plant C:N [carbon: nitrogen] ratios. Nitrogen concentrations of live plant tissue less than 1.5 percent are likely to reduce animal growth and reproduction, while

---

[51] Briske, D. et al. Climate-change adaptation on rangelands: linking regional exposure with diverse adaptive capacity. *Frontiers in Ecology and Environment*, 13(5): 249-256, 2015.
The potential of CO_2 enhancing plant growth depends on the ability of soil to release more available nitrogen to meet increased demand by the plant. But that growth may deplete soil nitrogen and quickly reduce the productivity of the rangeland. Page 251

> values of 1 percent will be sufficient to meet maintenance requirements for mature animals. The adverse effects of low nutritive forage can be offset by dietary N supplements, but this will increase both operating costs and labor requirement. [52]

The authors also emphasized that the warmer temperatures and higher CO_2 concentrations would also facilitate recruitment and growth of invasive herbaceous plants as well as several species of sub-shrubs in the Northern Great Plains. "We anticipate that increased abundance and expanded ranges of exotic invasive species are more likely to adversely affect livestock production than such change in native species, because exotics are often unpalatable and occasionally toxic to livestock."[53]

Another analysis of the implications of climate change for the Great Plains Rangelands made clear that climate change would not permanently boost the cattle stocking potential of Northern Great Plains rangelands although it might do so for that region in the near term, 10 to 20 years out.[54] Ultimately the rising summer temperatures and increased frequency of drought would lead to the same negative impacts on forage in the Northern Great Plains that will be experienced sooner in the Southern Great Plains and Texas.

> Greater production in northern and high-altitude rangelands in the near future might initially allow greater stocking rates, although not if soil [nitrogen] levels become depleted and forage quality declines. Increased occurrence and severity of drought in the southern and central Great Plains might reduce stocking rates or season for grazing in the next 30 yr. or so. The same might eventually happen in the north.[55]

A study of the impact of climate change on agriculture in *western* Montana was also skeptical that the warmer spring temperatures and rainfall as well as increased CO_2 concentrations would have a positive impact on forage for cattle.

> "…western Montana's highly productive and high-quality valley grasslands have always served as valuable land for livestock production. With changes in timing of specific chilling periods, which is likely happening as shown by decreases in winter season cold temperatures, it is expected that crop yields will decline and more xeric conditions will prevail reducing pasture quality and threatening Montana's livestock industry." [56]

Given the uncertainty as to the timing of the impact of higher temperatures on rangeland productivity in the Northern Great Plains, we project a 20 percent decline in the rangeland cattle

[52] Ibid, pp. 254-5. Quote from page 251.
[53] Ibid. p. 251.
[54] Jack A. Morgan et al. Management Implications of Global Change for Great Plains Rangelands. *Rangelands*. 30(3):18-22.
[55] Ibid, p. 21.
[56] Gregory T. Pederson et al. A century of climate and ecosystem change in Western Montana: what do temperature trends portend? *Climatic Change.* 98:133-154, 2010, p. 150.

industry in Montana by 2055. The economic impacts of this change in cattle production is shown in Table 1 below.

Table 1.

Impact of Climate Change on Montana Cattle Production		
	Jobs	**Labor Earnings ($millions)**
Size of Montana Cattle Sector at Risk	60,835	$ 1,818,337,891
Loss of Jobs and Income Due to Climate Change	12,167	$ 363,667,578

Source Sources: Size of sector: U.S. National Agriculture Statistics Service, "2014 Montana Agriculture Overview;" "Montana Economic Outlook," *Montana Business Quarterly,* Spring 2015, Figure 5, p. 13; U.S. BEA REIS agriculture sector jobs and labor earning.

2. The Impact of Climate Change on the Crop Production

As discussed above, climate change is expected to bring warmer and wetter, but shorter winters with more of the precipitation coming as rain and less as snow. The summer, however, is expected to be drier and hotter with more extreme hot and dry periods. The hot and dry periods, like wildfire season, are expected to stretch back into the spring and out into the fall.

This presents a conflicting picture for agriculture. A longer growing season, with more moisture, and somewhat warmer weather in the spring and additional concentrations of CO_2 in the air could be interpreted as providing optimal conditions for more verdant vegetative growth. That might be true for crops that can be raised and harvested before the hot dry summer weather seriously stresses the vegetation. But the higher temperatures in the summer can easily "cancel out" the higher precipitation rates, especially when peak surface water flow pass earlier and soil dries out sooner and there is less water available to use for irrigation. The burst of growth that warmer spring days and more plentiful precipitation and CO_2 support can lead to stunted, desiccated, plants with lower nutritional value if soil nitrogen cannot complement the more abundant CO_2 and/or summer heat stress overwhelms the plants before they are harvested.[57]

[57] US EPA. 2013 Climate Change Impacts on Crops, http://www.epa.gov/climatechange/impacts-adaptation/agriculture.html#impactscrops . "Warmer temperatures may make many crops grow more quickly, but warmer temperatures could also reduce yields. Crops tend to grow faster in warmer conditions. However, for some crops (such as grains), faster growth reduces the amount of time that seeds have to grow and mature. This can reduce yields (i.e., the amount of crop produced from a given amount of land)." Exactly this was reported in the 2015 Winter Wheat harvest in Montana. "Drought dings quality of winter wheat in Montana, Northwest. July 20, 2015, Alison Noon.

As discussed above, a 2013 study of the impact of climate change on Montana crop production focused on farms in the Flathead Valley.[58] The farms produced spring and winter wheat, spring barley, irrigated and unirrigated alfalfa hay, lentils and peas, and canola. The impact of the projected climate change over the next several decades was a 24 percent decline in the net crop return per acre and a 57 percent decline in net farm income relative to the historical period. A variety of adaptations to the changing climate were also modeled, but they would not have been successful at eliminating the losses even if those adaptations were widely adopted.

Another study of the impact of climate change on Montana agriculture focused on the principal agricultural zones in eastern Montana.[59] That 2004 analysis first calculated what the impact of projected changes in seasonal temperatures and precipitation would be on winter wheat, spring wheat, and annual grass production. It found that the projected new climatic pattern would lead to very large declines in wheat yields: 45 to 80 percent losses. Grass yields, however, were projected to increase 10 to 20 percent.[60]

That particular study separated the impacts of changes in temperature and precipitation from the impacts of the increased CO_2 concentrations on crop yields. Increased atmospheric carbon has the potential to “fertilize” vegetation, boosting yields. The effects on crops of elevated CO_2 concentrations, by themselves, on wheat production were projected to be positive for both winter and spring wheat: Yields would be boosted 17 to 55 percent. When the combined effects of the changes in temperature and precipitation patterns and the increased CO_2 concentrations were calculated, this study found that spring wheat yields would decline 20 to 30 percent but that there would be an increase in winter wheat yields (0 to 20%) and yields of grass grown for pasture (10 to 30 percent).

This study did not discuss the conditions under which the higher concentrations of CO_2 can effectively boost crop yields. As discussed above in early warm moist periods plants can grow more quickly, but, for crops like grains, faster growth can reduce the amount of time that seeds have to grow and mature. This has led to reduced rather than increased yields.

A recent study of the impact of rising temperatures on wheat production confirms this. It concluded that wheat production was estimate to fall by 6 percent for each degree centigrade of further temperature increase. Thus, a 5 degree C summer temperature increase could lead to a 30 percent decline in wheat production.[61]

Based on these projections, we estimate that Montana grain crop yields could be reduced by 25 percent in 2055 due to climate change. As discussed above, the grain sector of Montana agriculture is the source of 53 percent of agricultural sales. Table 2 summarizes the impact of this loss on Montana jobs and labor earning, including multiplier impacts.

[58]Op.Cit Pratoe and Qui, 2013.
[59] Op. Cit. J. Antle et al. 2004
[60] Ibid. Table 1 and page 301.
[61] S. Asseng et al. Rising temperatures reduce global wheat production. *Nature Climate Change.* Vol 5. February 2015. Pp 143-147.

Table 2.

Impact of Climate Change on Montana Grain Production		
	Jobs	**Labor Earnings ($millions)**
Size of Montana Grain Sector at Risk	49,828	$1,489,331,480
Loss of Jobs and Income Due to Climate Change	12,457	$372,332,870

Sources: Size of sector: U.S. National Agriculture Statistics Service, "2014 Montana Agriculture Overview;" "Montana Economic Outlook," *Montana Business Quarterly,* Spring 2015, Figure 5, p. 13; size of agricultural sectors, U.S. BEA REIS for Montana jobs and labor earnings.

Many of the studies that we have cited not only analyzed the changes that climate change would bring to Montana agriculture, but also discussed the types of adaptive strategies that could be adopted to avoid these impacts. Because we are focused on a "business as usual" scenario, we have not taken those possible adaptations into account in reporting the likely impact of climate change in Montana on its major agricultural industries. Adaptive strategies require farm and ranch enterprises to confront the risks associated with climate change and take on other risks by modifying how they operate their enterprise. Farmers and ranchers have successfully dealt with variable weather and a variety of threats to their operations in the past, and they may feel confident that they can cope with the changing and variable weather just as they always have. Successful adaptation will require the industry to come together and advocate for the resources they will need. Adaptation, such as changing crops and cropping patterns, often involves additional costs including additional investment in equipment and expenditures on supplies and labor. It also involves taking on more risk. Similarly, shifting patterns of feeding cattle and providing supplemental nutrients may be costly in terms of labor effort and farm and ranch infrastructure. Analyzing how farms and ranches may (or may not) adjust their operation and what the net impact on productivity and profitability would be is beyond the scope of this report.

This is not a "dodge" of an important issue. Most economic impact analysis takes exactly this approach. For example, if a coal-fired electric generator and its associated coal mines are shut down for economic and regulatory reasons, the impacts are usually measured by the jobs, payroll, and tax revenues "lost." That is, it is assumed that those resources will remain permanently unemployed and electric consumers will simply, in some sense, go without that electricity. In fact the economy will adapt to the new situation pursuing alternative supplies to those energy needs. The development of those alternative energy sources will employ new resources, and, as the economy adapts, the demands of customers will be met and under-utilized economic resources will be redeployed. In short, the full picture of economic change and adaptation is more complex to spell out and quantify than the description of the short run impacts of the initial disruption.

IV. Conclusions

Given that climate change in Montana will impact one of the most important economic sectors of the state economy, it should not be surprising that the impact is likely to be significant. The total impact on employment is the loss of about 25,000 jobs and $736 million dollars in labor earnings by 2055 See Table 3 below.

Table 3.

Projected Economic Losses Due to Climate Change on Montana Agriculture		
Agricultural Activities	**Jobs**	**Labor Earnings ($millions)**
Cattle Raising	12,167	$364
Crops	12,457	$372
Total	**24,624**	**$736**

These impacts will hit Montana's rural areas and small towns most heavily, especially in eastern Montana. Population density will fall further, undermining the viability of local businesses as well as the services provided by local governments. Schools districts already hard-hit by shrinking enrollments will face broader consolidation and longer bussing routes for their students. The loss of commercial and government infrastructure will make these rural areas and small towns less and less attractive to those who do not continue to be employed in agriculture. Even for those farms and ranches that successfully adapt, the more limited off-farm income-earning opportunities, the increased isolation, and deteriorating community will partially undermine the way of life that has held them in agriculture. In addition, the same climate changes that threaten farming and ranching, longer, hotter, and drier summers, are also likely to discourage new in-migrants seeking to live in ex-urban or rural areas. That too would contribute to undermining local economic vitality in Montana's small towns and rural areas.

Clearly the economic cost of taking a business-as-usual approach to climate change in Montana will be far removed from the precise zero cost that is usually casually assumed during most discussions of the appropriate public policy response to mitigate future climate change in Montana.

Bibliography

Antle, J., Capalbo, S., Elliot, E., Paustian, K. Adaptation, spatial heterogeneity, and the vulnerability of agricultural systems to climate change and CO_2 fertilization: An integrated assessment approach. *Climactic Change*. 64:289-315. 2004

Asseng, S. et al. Rising temperatures reduce global wheat production. *Nature Climate Change Letters*. 5, 143-147. 2015. doi:10.1038/nclimate2470.

Barkey, P. Montana Economic Outlook: More Balanced, but Slower Growth Ahead. *Montana Business Quarterly.* p. 13, Figure 5. Spring 2015.

Brekke, L., Thrasher, B., Maurer, E., and Pruitt, T. Downscaled CMIP3 and CMIP5 Climate Projections. May 2013. http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/techmemo/downscaled_climate.pdf

Briske, D., Joyce, L., Polley, W., Brown, J. Wolter, K., Morgan, J., McCarl, B., and Bailey, D. Climate-change adaptations on rangelands: linking regional exposure with diverse adaptive capacity. *Frontiers in Ecology and the Environment*. 13:249-256, doi:10.1890/140266. 2015.

Brookshire, N and Weaver, T. Long-term decline in grassland productivity driven by increasing dryness. Nature Communications. May 14, 2015. DOI: 10.1038/ncomms8148.

Holems, K. Montana:Stories of the Land. Chapter 18, page 354. http://svcalt.mt.gov/education/textbook/chapter18/Chapter18.pdf

IPCC. 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. 2014.

Montana Department of Environmental Quality. Climate Change and Agricultural Land Use. Montana.GOV Official State Website. Accessed on 1.12.2016. http://deq.mt.gov/ClimateChange/Commerce/Agriculture/LandUse.mcpx

Montana Department of Environmental Quality. Climate Change and Water Drought. Montana.GOV Official State Website. Accessed 7.8.2015. http://deq.mt.gov/ClimateChange/NaturalResources/Water/Drought.mcpx

Morgan, J., Derner, J., Milchunas, D., and Pendall, E. Management Implications of Global Change for Great Plains Rangelands. *Rangelands*. 30(3):18-22. 2008.

Nobel Laureates. Mainau Declaration 2015 on Climate Change. Lindau Nobel Laureate Meetings. 2015. http://www.lindau-nobel.org/

National Oceanic and Atmospheric Administration. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 4. Climate of the U.S. Great Plains. NOAA Technical Report NESDIS 142-4. January 2013.

National Oceanic and Atmospheric Administration. Climate Monitoring: Summary Information. http://www.ncdc.noaa.gov/sotc/summary-info/national/201502

Noon, A. Drought dings quality of winter wheat in Northwest. Associated Press. July 20, 2015. http://bigstory.ap.org/article/b760c73ba3214a95ac917abc74405363/drought-dings-quality-winter-wheat-northwest

Pederson, G., Graumlich, L., Fagre, D., Kipfer, T., and Muhlfeld, C. A century of climate and ecosystem change in Western Montana: what do temperature trends portend? *Climactic Change*. 98:133-154. 2010.

Piao et al. Net carbon dioxide losses of northern ecosystems in response to autumn warming. Natue Letters. Vol. 451. January 2008. Doi:10.1038/nature06444

Pratoe, T and Qui, Z. Potential Impacts of Adaptation to Future Climate Change for Crop Farms: A Case Study of Flathead Valley, Montana. INTECH. 2013. http://dx.doi.org/10.5772/39265

Running, S. Impacts of Projected Climate Change on Pacific Northwest Ecosystems: Analyzing Carbon/Water Balance Vulnerability to 2100. Final Report to Stratus Consulting and National Commission on Energy Policy. March, 31 2009.

Shafer, M., D. Ojima, J. M. Antle, D. Kluck, R. A. McPherson, S. Petersen, B. Scanlon, and K. Sherman, 2014: Ch. 19: Great Plains. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 441-461. doi:10.7930/J0D798BC. http://nca2014.globalchange.gov/report/regions/great-plains

Stephens, C. Raising Grain in Next Year Country: Dryland Farming, Drought, and Adaptation in the Golden Triangle, Montana. *Thesis Dissertation, Professional Papers.* Paper 4513. Department of Environmental Studies. 2015.

Strahn, D. Historic Homesteads. *Distinctly Montana*. 4.4.2007. http://www.distinctlymontana.com/montana-history/04/04/2007/frontier-homestead

Tollefson,P. Ag forecast promising for cattle ranchers, dim for farmers. *Missoulian*. July 2, 2015. Accessed on 7.13.2015. http://missoulian.com/business/local/ag-forecast-promising-for-cattle-ranchers-dim-for-farmers/article_b3c108ba-741e-5f96-818f-2f05d9092d01.html

Torell, L. Allen et al. 2005. Income Earning Potential versus Consumptive Amenities in Determining Ranchland Values. *Journal of Agricultural and Resource Economics* 30(3):537-560.

U.S. Bureau of Economic Analysis. Regional Economic Information System. http://www.bea.gov/regional/

U.S. Census Bureau. American Community Survey. https://www.census.gov/programs-surveys/acs/

U.S. Census Bureau. State and County Quick Facts: Montana. http://quickfacts.census.gov/qfd/states/30000.html

U.S. Environmental Protection Agency. Agriculture and Food Supply: Impacts on Crops. Accessed on 8.14.2015. http://www.epa.gov/climatechange/impacts-adaptation/agriculture.html#impactscrops