The Economic Impact of Climate Change on Montana Agriculture

Prepared for

Farm Connect Montana

by

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Executive Summary

The Impact of Montana Climate Change on Montana Agriculture

Climate change continues to impact Montana's agricultural sector. Using the Intergovernmental Panel on Climate Change 6th Assessment, the 4th National Climate Assessment, and the Montana Climate Assessment, among many other sources, we present the changes in climate that Montana will see by mid-century under the "business-as-usual" scenario. This is a scenario where we do nothing globally to mitigate climate change, and impacted sectors of the Montana economy do not adapt to try and minimize the impacts of climate change. We then look at the agricultural sector of the Montana economy that will be impacted by climate change and use the best available science to determine how it will be economically impacted.

Climate Change in Montana

We begin by focusing on the two dominant drivers of climate change in Montana: temperature and precipitation. The general trend in Montana, like the national trend, is that Montana will get warmer. Precipitation patterns are a little less well understood, but generally, precipitation in Montana will increase. Warm air can hold more moisture than cold air, so more moisture is carried into the state during the winter and spring months, which is not offset by the reduced moisture during the summer months. Montana is projected to see a temperature rise of at least 6° F by mid-century. This temperature increase will be greater in the winter and summer, with August seeing the largest projected change. Autumn through spring will be warmer and a little wetter, and spring and autumn will come earlier, while the summers will be hotter and drier.

Montana is predicted to get more precipitation by the middle of the century. Montana is projected to receive an increase of about two inches per year of precipitation, as well as an increase in extreme precipitation events. The increased precipitation is not uniform over the different seasons: autumn, winter, and spring will see increases in monthly precipitation, whereas summer will see a decrease in monthly precipitation. There will be an increase of about 50% in two-day heavy rainfall events by mid-century. Although fewer hail days are expected, a 40% increase in damage potential from hail results from an increased occurrence of large hail in the spring months. As winter warms, there will be more rain-on-snow events, which leaves less snow in the mountains and changes the timing and intensity of the spring melt runoff.

What will climate change look like for the agricultural sectors in Montana? Climate change will not affect all agricultural industries equally, and climate change impacts will vary across the state of Montana. We will begin by looking at how climate change impacts projected by climate scientists is likely to impact Montana's agricultural sector. Then, we will look at the potential economic implications of those impacts.

Livestock and Rangeland

About 58 million acres (or 62%) of Montana is agricultural land. Of that, about 16 million acres are cropland and 42 million acres are pasture and rangeland. Wheat, barley, hay, and cattle accounted for about 80% of all farm and ranch annual cash receipts in Montana in 2020.

By mid-century, climate change in Montana will bring 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 cattle and the rangeland during the summer season is predicted to decline with increased evaporation and evapotranspiration, adding to the stress on the cattle and the rangeland. The overall scientific evaluation indicates that there will be less forage for cattle on the range due to climate change and that the available forage will be less nutritious.

Agricultural Crops

Sixteen million acres in Montana are used to grow agricultural crops. In 2020, about 10.5 million acres of that cropland was harvested. In any given year, about eight million acres are tilled and about seven million acres are left in seasonal fallow. Also, in any given year, 50% of the planted acreage is for wheat production. In 2020, hay was planted on about 30% of the land and barley on about 7%. In 2021, 2.8 million acres were enrolled in federal Conservation Reserve Programs that allow farmers and ranchers to place specific cropland into non-productive conservation use in return for payments from the federal government.

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. 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.”[1] The final piece of this puzzle hinges on CO_2 fertilization effects. CO_2 helped to fertilize wheat crops and adaptation helped to make up for increased temperature from climate change, but in the long term, global wheat production falls significantly as the temperature increases. 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, and 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 increased heat in the summer and autumn all but negates the increases in fertilization and moisture across the year.

The trend that appears through these different studies is that there may be a higher yield of winter wheat during the spring, for the next decade or two, and a lower yield of spring wheat during the summer. The winter wheat increase will not make up for the spring wheat decline unless mitigation measures are adopted by Montana farmers.

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[1] 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. Page 296.

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

There are a variety of ways to quantify the relative importance of a particular set of economic activities in the overall regional economy, e.g., the state of Montana, an individual county, or a set of counties. Each economic measure describes the economy in a somewhat different way. In the discussion below, we will use two different measures of the relative importance of particular segments of the Montana economy or changes in particular segments of that economy: the number of jobs and the labor earnings associated with those jobs. While farm earnings have been relatively volatile for the last 50 years, employment has remained relatively stable, declining as a share of total Montana jobs to about 7%.

The Makeup of the Montana Agriculture Sector

The Montana agricultural sector is broken into crops and animals, with crops representing about 55% and animals representing 45% of cash receipts. If we look closely at the Animals and Animal Products sector, we see that the cash receipts associated with cattle and calves make up almost 85% of the cash receipts from Animals and Animal Products. Similarly, if we look at the importance of wheat, barley, and hay in the cash receipts associated with crop production in Montana, those three crops are the source of 76% of cash receipts associated with all crop marketings. The agricultural sector accounts for almost 29,000 jobs and almost $450 million in labor earnings in the state.

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: jobs and labor earnings. Farming and ranching are more than an economic enterprise; it is also a way of life. 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, even for many of its non-agricultural residents. In that sense, damaging or weakening agriculture and reducing its role in the state has cultural and social costs which our chosen economic metrics do not reflect.

The Impact of Climate Change on Rangeland and Cattle Production

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: Summers will be generally hotter and drier, with more extreme temperatures. 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. Vegetation that experiences early rapid growth due to warm and wet spring 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 requirements. 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.

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% decline in the rangeland cattle sector in Montana by midcentury. It is important to note that a decline of 20% has already happened on range land in the West in our recent historical record as the result of climate change. In New Mexico, there has already been a 20% decline in rangeland carrying capacity when comparing 1920-1976 compared with 1976-2017. We project that 4,514 cattle ranching jobs and more than $86 million in labor earnings from cow and calf operations will be lost due to climate change by mid-century (Table ES-1).

The Impact of Climate Change on Montana Crop Production

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 generally drier and hotter with more extreme hot and dry periods. The hot and dry periods, like wildfire season, are expected to stretch earlier into the spring and later into the autumn.

This presents a conflicting picture for agriculture. A longer growing season, more moisture, 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 passes earlier, 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.

As discussed above, plants can grow more quickly in early warm moist periods, but faster growth can reduce the amount of time that seeds have to grow and mature for crops such as grains. This has led to reduced yields, rather than increased yields. A study of the impact of rising temperatures on wheat production confirms this. It concluded that wheat production was estimated to fall by 6% for each degree centigrade of further temperature increase. Based on these projections, we estimate that Montana grain crop yields could be reduced by 20% by mid-century due to climate change. Wheat, barley, and hay sectors of Montana agriculture are the source of about 76% of agricultural sales. Table ES-1 shows the loss of almost 5,000 wheat, barley, and hay jobs and more than $95 million in labor earnings that would be lost due to climate change by mid-century (Table ES-1).

Given that climate change in Montana will impact one of the most important economic sectors of the state economy – agriculture – it should not be surprising that the impact of a 20% reduction in the two largest metrics is likely to be significant. The total impact on employment is the loss of more than 9,500 jobs and more than $181 million dollars per year in labor earnings by mid-century (Table ES-1).

Table ES-1.

Projected Direct Impact of Climate Change on Agriculture Jobs and Labor Earnings: Montana 2021		
	Jobs	**Labor Earnings**
Livestock	4,514	$86,070,296
Crops	4,989	$95,130,327
Total	**9,503**	**$181,200,623**

Table of Contents

Global Climate Change and Montana Impacts

The Intergovernmental Panel on Climate Change (IPCC) released its Sixth Assessment Report in March 2023.[2] In the 6th assessment, the IPCC 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 3, 2015, at the Lindau Nobel Laureate Meetings, a group of 39 Nobel Laureates 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 prior for which a similar group of Nobel Laureates signed a warning declaration.[3] In the 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."[4]

What has become increasingly clear is that there is no longer a credible debate among scientists who study climate change. Climate change is happening, the primary driver of climate change 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 climate change will be on agriculture in Montana.

The Fourth National Climate Assessment (NCA4) was published in 2018 by the U.S. Global Change Research Program.[5] In that assessment, the state of Montana was grouped with the Northern Great Plains states (MT, WY, ND, SD, NE).[6] While this is an improvement over the Third National Climate Assessment – the northern plains were broken out – it still leaves Montana grouped with a fairly large geographic portion of the U.S. However, the Montana Climate Assessment (MCA) released in 2017 is Montana-specific,[7] and we use these projections of future climate change in Montana as a basis for our analysis. These predictions

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[2] IPCC. AR6 Synthesis Report (SYR).https://www.ipcc.ch/report/sixth-assessment-report-cycle/
[3] Mainau Declaration 2015 on Climate Change. http://www.lindau-nobel.org/wp-content/uploads/2015/07/Mainau-Declaration-2015-EN.pdf
[4] Ibid.
[5] USGCRP. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II: U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.
[6] Conant, R.T., D. Kluck, M. Anderson, A. Badger, B.M. Boustead, J. Derner, L. Farris, M. Hayes, B. Livneh, S. McNeeley, D. Peck, M. Shulski, and V. Small, 2018: Northern Great Plains. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 941–986. doi: 10.7930/NCA4.2018.CH22
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.
[7] Whitlock C, Cross W, Maxwell B, Silverman N, Wade AA. 2017 Montana Climate Assessment. Bozeman and Missoula MT: Montana State University and University of Montana, Montana Institute on Ecosystems. 318 p. doi:10.15788/m2ww8w. 2017.

were made using the same climate models and the same scenarios that the IPCC reports use but apply them to much smaller geographic regions.

The scenario on which we focus our study is "RCP 8.5" in the MCA and NCA4 mentioned above. Scenario RCP 8.5 is the closest to what traditionally has been called the "business-as-usual" scenario. It is a scenario that "is generally associated with higher population growth, less technological innovation, and higher carbon intensity of the global energy mix,"[8] which means that the world does not come together to try and abate the collective emissions of many different countries. The result is a mean U.S. temperature rise of 9° F or more by the year 2100.[9] This projection is especially true for Montana, as well as most of the northern latitudes of the U.S. To see what is in store for Montana, we must then look at the downscaled, or regional, climate models. It should be noted that the dates that we are looking at do not always match up. In a perfect world, all 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.

In some sectors of the economy, this "business-as-usual" approach makes a lot of sense because of the unknown reliability of decentralized 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.[10] This report is meant to highlight what will likely 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.

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[8] USGCRP. 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II: [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4. 2018. Page 6.

[9] USGCRP. 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II: [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018. Page 42

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

Climate Change in Montana

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

1. Temperature Changes in Montana

Montana is projected to see a temperature rise of at least 6° F by mid-century.[11] This temperature increase will be greater in the winter and summer, with August seeing the largest projected change.[12]

Montana is predicted to see an increase in the number of days when the temperature exceeds 90° F. 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 higher end of the extreme heat days. By mid-century, northwestern and north-central Montana will see 11 more days of at least 90° F, and south-central and eastern Montana will see 33 more days.[13]

Montana is predicted to have fewer extreme cold days where the temperature drops below 10° F. In the southwestern parts of the state, there will be 20-30 fewer days, while the rest of Montana will see 15-25 fewer days.[14]

Montana is predicted to have fewer days where the temperature drops below 32° F, which are labeled "frost free days." The western portion of Montana will see an increase of 41 days, and the eastern portion seeing an increase of 32 days.[15] 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 (Tmin

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[11] Here, mid-century is taken to mean 2040-2069. Whitlock C, Cross W, Maxwell B, Silverman N, Wade AA. 2017. 2017 Montana Climate Assessment. Bozeman and Missoula MT: Montana State University and University of Montana, Montana Institute on Ecosystems. 318 p. doi:10.15788/m2ww8w. Page 46.
[12] Ibid. Figure 2-11, Page 49.
[13] Ibid. Page 50.
[14] The time period for these projections is slightly altered and "mid-century" here is 2041-2070. Kunkel, Kenneth & Stevens, Laura & Stevens, Scott & Sun, Liqiang & Janssen, Emily & Wuebbles, Donald & Kruk, Michael & Thomas, Devin & Shulski, Martha & Umphlett, Natalie & Hubbard, Kenneth & Robbins, Kevin & Romolo, Luigi & Akyuz, Adnan & Pathak, Tapan & Bergantino, Antony & Dobson, J. Regional climate trends and scenarios for the US National Climate Assessment: Part 4. Climate of the US Great Plains. NOAA Technical Report NESDIS 142–4. 2013. Figure 18, Page 45.
[15] Whitlock C, Cross W, Maxwell B, Silverman N, Wade AA. 2017 Montana Climate Assessment. Bozeman and Missoula MT: Montana State University and University of Montana, Montana Institute on Ecosystems. 318 p. doi:10.15788/m2ww8w. 2017. Page 52.

> ≤0◦C), and extremely cold days (Tmin ≤ −17.8◦C). The average loss of number of days at or below the freeze/thaw threshold (Tmin ≤0◦C) in western Montana is approximately 16 days, declining from an average of ∼186 to ∼170 days−yr. The sharpest decline in number of freeze/thaw days has occurred within the last 20 years."[16]

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

2. Precipitation Changes in Montana

As noted above, the predicted change in precipitation is a little less certain within the more geographically detailed Global Climate Models (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 as well as the precipitation increases associated with elevation. With respect to the elevation changes, this primarily impacts western Montana.[17] The Pacific Decadal Oscillation, El Niño, and La Niña are examples of multi-year cycles that impact Montana but are poorly represented in the climate change models.[18] Because of the 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.

Montana is predicted to get more precipitation by the middle of the century. For the "business-as-usual" scenario (RCP8.5), Montana is projected to receive an increase of around two inches per year of precipitation.[19,20] The western half of the state is projected to receive slightly more (an additional 0.2 inches) of the precipitation increase compared to the eastern half of the state. The increased precipitation is not uniform over the different seasons. Autumn, winter, and spring will see increases in monthly precipitation, while summer will see a decrease in monthly precipitation.[21] There will be an increase, of about 50%, of two-day heavy rainfall events by mid-

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[16] Pederson et al. A Century of climate and ecosystem change in Western Montana: what do temperature trends portend? *Climate Change*. 98:133-154. 2010.
[17] Whitlock C, Cross W, Maxwell B, Silverman N, Wade AA. 2017. 2017 Montana Climate Assessment. Bozeman and Missoula MT: Montana State University and University of Montana, Montana Institute on Ecosystems. 318 p. doi:10.15788/m2ww8w. Page 54.
[18] Ibid. Page 9.
[19] Whitlock C, Cross W, Maxwell B, Silverman N, Wade AA. 2017. 2017 Montana Climate Assessment. Bozeman and Missoula MT: Montana State University and University of Montana, Montana Institute on Ecosystems. 318 p. doi:10.15788/m2ww8w. Page 55.
[20] USGCRP. 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II: [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018. Page 954.
[21] Whitlock C, Cross W, Maxwell B, Silverman N, Wade AA. 2017. 2017 Montana Climate Assessment. Bozeman and Missoula MT: Montana State University and University of Montana, Montana Institute on Ecosystems. 318 p. doi:10.15788/m2ww8w. Page 58.

century. Although fewer hail days are expected, a 40% increase in damage potential from hail "due to more frequent occurrence of larger hail is predicted for the spring months."[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 can 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 its report on the climate impacts on the Montana skiing and sport fishing sector, sums 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]

This recap of winter changes is echoed by Lackler who projects a change in the median number of skiable days at Montana ski areas to drop by as much as 51 days (at Great Divide) and by an average of 33 days for all ski areas in Montana.[24] 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.

Climate change will not affect all industries equally and will manifest differently across the state of Montana. This report will focus on how the specifics of climate change that we described above will likely impact different sectors of Montana agriculture. We will begin by looking at how the climate changes projected by climate science for Montana are likely to impact sectors of agriculture including livestock, rangeland, and agricultural crops.

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[22] USGCRP. 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II: [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018. Page 954.

[23] Headwater Economics. The Effects of Climate Change on the Downhill Skiing and Recreational Fishing Economy in the Crown of the Continent. January, 2011. Page 19.

[24] Lackler, C Geerts, B, and Wang, Y. Impact of Global Warming on Snow in Ski Areas: A Case Study Suing a Regional Climate Simulation over Interior Western United States. American Meteorological Society. February 2021. Table 2.

I. The Impact of Climate Change in Montana on Agriculture

1. 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 or operation sizes 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 sector. Then we will look at the potential economic implications of those impacts.

A. Livestock and Rangeland

About 58 million acres (or 62%) of Montana is agricultural land.[25] Of that 58 million acres, about 16 million are cropland and 42 million acres are pasture and rangeland. Wheat, barley, hay, and cattle account for about 80% of all farm and ranch annual cash receipts in Montana in 2020.[26]

Farm sizes vary quite widely in Montana. 31% of farms are from 1 to 49 acres. 46% of farms are between 50 and 1,999 acres, and 23% of farms are larger than 2,000 acres.[27]

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 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 is 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.[28] The increased uptake of CO_2 may be entirely offset by increased heat, which causes increased plant respiration in the summer and autumn months.[29] A study from Brookshire and Weaver takes this one step farther showing that there has been a greater than 50% decline in production of native grassland in the Greater Yellowstone Ecosystem over the

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[25] Montana Department of Agriculture. Montana Agricultural Statistics 2022, Volume LIX. November 2022. P. 8. Varying definitions of agricultural production can lead to quantities projected varying among analysts.

[26] Ibid. Cash Receipts from Marketing by Commodities- Montana: 2016-2020. Page 19.

[27] USDA. National Agricultural Statistics Service.Montana Annual Bulletin 2022. 2022. Page 10. https://www.nass.usda.gov/Statistics_by_State/Montana/Publications/Annual_Statistical_Bulletin/2022/Montana-Annual-Bulletin-2022.pdf

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

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

last four decades due to an increasing lack of moisture in the late summer.[30] Finally, the future climate may invite exotic invasive species into the rangeland, which are less palatable to the cattle.[31]

With this complicated relationship between cattle, rangeland, and climate change, various scientists have studied the future of the cattle sector in Montana. Pederson makes the case that the livestock sector in Montana may be threatened by the changing climate as pasture quality declines.[32] 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.[33,34] From Briske's perspective, the possible expansion of exotic invasive species of plants that could become better suited to the rangeland will make the larger difference in livestock growth, since invasive species are often unpalatable to livestock.[35] The overall scientific evaluation indicates that there will be less forage for cattle on the range due to climate change and that forage will be less nutritious.

B. Agricultural Crops

As mentioned above, about 16 million acres in Montana are used to grow agricultural crops. About 10.5 million of that cropland was harvested in 2020.[36] About 8 million acres are tilled, and about 7 million acres are left in seasonal fallow in any given year. 50% of the planted acreage in any given year is for wheat production. Hay was planted on about 30% of the land and barley on about 7% in 2020. 2.8 million acres were enrolled in the federal Conservation Reserve Program in 2021, which allows farmers and ranchers to place specific cropland into non-productive conservation use in return for payments from the federal government.[37]

"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. 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.

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[30] Brookshire, N and Weaver, T. Long-term decline in grassland productivity driven by increasing dryness. Nature Communications. May 14, 2015. DOI: 10.1038/ncomms8148.
[31] Briske, D. et al. Climate-change adaptation on rangelands: linking regional exposure with diverse adaptive capacity. Ecological Society of America. 2015.
[32] Op. Cit. Pederson et al. 2010.
[33] 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.
[34] Holechek, J. et al. Climate Change, Rangelands, and Sustainability of Ranching in the Western United States. Sustainability. 2020. Page 12.
[35] 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.
[36] Montana Department of Agriculture. Montana Agricultural Statistics 2022, Volume LIX. Crop Summary 2020. November 2022. Page 25.
[37] USDA. USDA Accepts More 2.8 Million Acres for the Conservation Reserve Program. Accessed 4.6.2023 https://www.fsa.usda.gov/state-offices/Montana/news-releases/2021/stnr_mt_20210823_rel_600

The summer months will become drier and hotter with an increased number of days with extreme heat.[38] Relating those changes to agricultural production in Montana is just beginning to be studied. A study of the overall impact of climate change on crops in the Flathead Valley of Montana by Tony Prateo and Zeyuan Qui[39] highlights the difficulty in quantifying climate change's impact on agriculture in the future. That study found that the net crop return per hectare would decrease by an average 24% and net farm income would decrease by an average 57%. The range of the predicted impacts in the study 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 farmers could see an increase in crop yield if some mitigation measures are implemented.

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 decade or two while spring wheat yields will decline in all but two of the zones that they studied. This move towards winter wheat production is one that is echoed in the 2017 Montana Climate Assessment:

> "A shift from spring wheat towards winter wheat production is expected, due largely to warmer winter temperatures that facilitate greater winter wheat survival, and warmer summer temperatures that impair spring wheat production by inhibiting seed formation, germination, and early growth (Lanning et al. 2010). The increasing proportion of Montana winter wheat since 2000 (Figure 5-3) *may* be attributable to climate change in particular because of a) more consistent autumn precipitation, b) warmer winters, and c) heat damage to later maturing spring wheat."[40]

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.[41] As was discussed above, it is the combination of increased temperature and moisture that allows wheat to flourish or be stunted.[42] 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."[43]

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[38] Whitlock C, Cross W, Maxwell B, Silverman N, Wade AA. 2017. 2017 Montana Climate Assessment. Bozeman and Missoula MT: Montana State University and University of Montana, Montana Institute on Ecosystems. 318 p. doi:10.15788/m2ww8w. Pag 208.
[39] 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
[40] Whitlock C, Cross W, Maxwell B, Silverman N, Wade AA. 2017. 2017 Montana Climate Assessment. Bozeman and Missoula MT: Montana State University and University of Montana, Montana Institute on Ecosystems. 318 p. doi:10.15788/m2ww8w. Pag 208.
[41] 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.
[42] Ibid.
[43] Ibid. Page 296.

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% increase in yield. When climate effects are taken into account along with elevated CO_2, the results were somewhat offset (as presented above). Winter wheat increased its yield, and spring wheat declined by 20-30%.[44] These results are quite similar to a more recent study from Demirhan, who studied wheat grown globally and found that CO_2 helped to fertilize wheat crops and adaptation helped to make up for increased temperature from global warming, but in the long term, global wheat production falls significantly as the temperature increases.[45] 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, and 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 increased heat in the summer and autumn all but negates the increases in fertilization and moisture across the year.[46]

The trend that appears through these different studies is that there may be a higher yield of winter wheat during the spring for the next couple of decades and a lower yield of spring wheat during the summer.[47] The winter wheat increase will not make up for the spring wheat decline unless mitigation measures are adopted by Montana farmers.

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 to quantify 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. In the discussion below, we will use two different measures of the relative importance of particular segments of the Montana economy or changes in particular segments of that economy: the number of jobs and the labor earnings associated with those jobs.[48] As we

[44] Ibid. Page 302-303.

[45] Demirhan, H. Impact of increasing temperature anomalies and carbon dioxide emissions on wheat production. *Science of the Total Environment.* 2020.

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

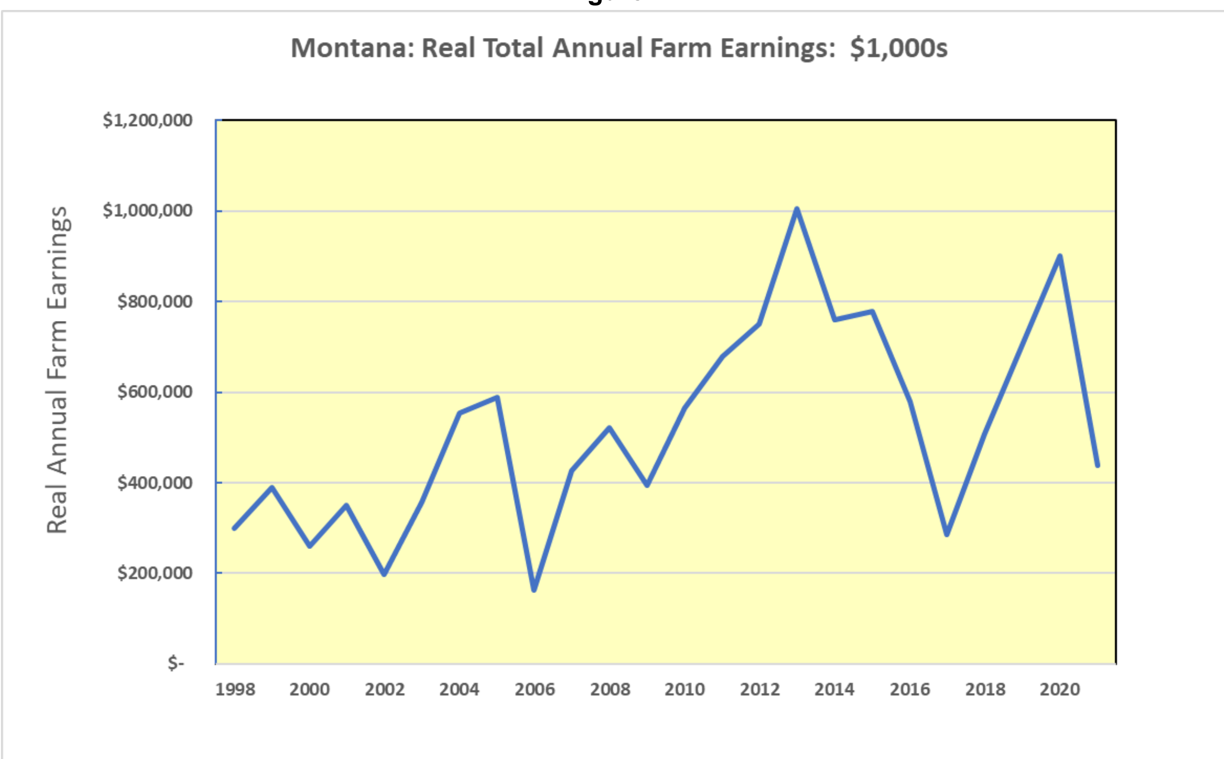
[47] Pratoe and Qiu show an overall loss of 24% for wheat. Antle shows a decline in spring wheat of 20-30% and an increase in winter wheat. Pederson states that crop yields will decline and more xeric conditions will prevail.

[48] "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. 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.

will discuss, for agriculture in Montana, this can be a somewhat volatile measure, but it is one that most people can readily understand.

Agriculture's contribution to the overall Montana economy may be large and positive, but if it is also unstable, the economic well-being of Montana's farms and ranches – and non-farm businesses that serve those farms and ranches – may be stressed. In fact, the real (i.e. inflation adjusted) earnings of farm workers and ranch operators fluctuated widely from year-to-year as agricultural commodity prices and weather conditions vary. From 1999 to 2021, the declines in real farm labor earnings averaged almost minus 50% while the upward fluctuations averaged almost plus 40%. See Figure 1 below. Because of this, farm and ranch earnings and the measure of the relative importance of agriculture in the Montana economy in any given year may swing significantly above and below the average across several years. This suggests that average value will not necessarily provide a good measure of either the "typical" role of agriculture as a source of income to Montana's farms and ranches or the overall prosperity that agriculture supports in the Montana economy in any given year.

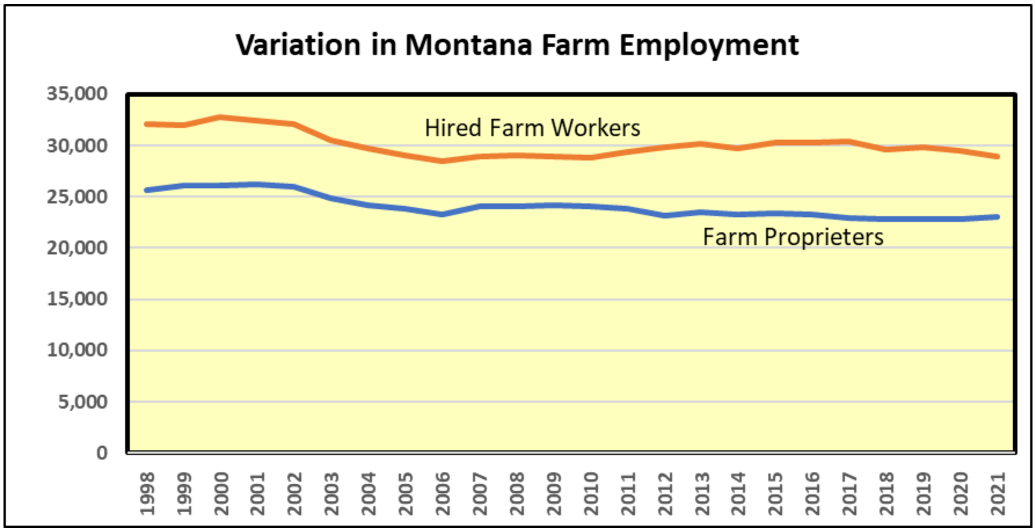
Figure 1.



Source: U.S. Bureau of Economic Analysis, CAINC45 Farm income and expenses, farm earnings (thousands of 2021 dollars). CPI used for adjustment to inflation.

What Figure 1 shows, in terms of dramatic changes in annual farm earnings, can be contrasted with what Figure 2 shows, which is rather steady farm employment. Although annual real farm labor earnings fluctuate considerably, farm and ranch *employment* does not. See Figure 2 below.

Figure 2.

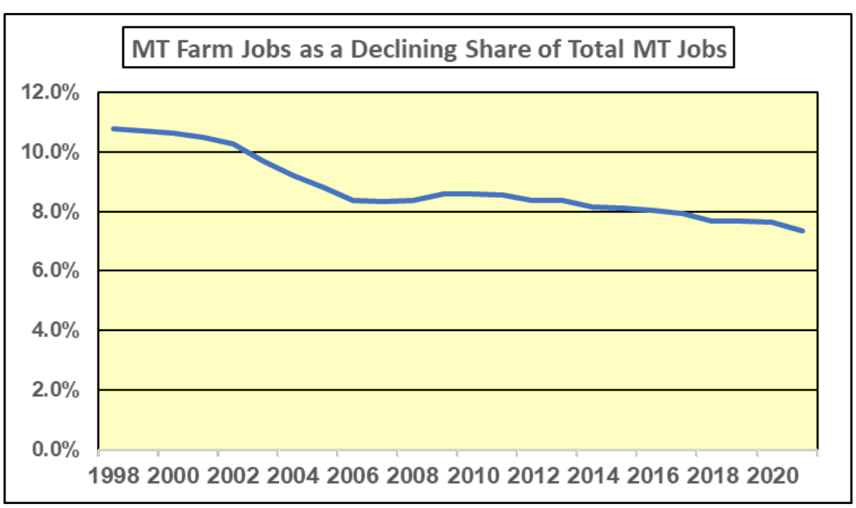


Source: BEA SAEMP25N Total full-time and part-time employment by NAICS industry.

Measuring the relative size of the agricultural sector of the Montana economy using jobs suggests a somewhat larger share of jobs in agricultural-related activities than if labor earnings are used to measure relative size. This is because hired farm workers, in general, face low wages, and farm proprietors often earn a low return for their labor and capital investments. However, as mentioned above, the number of farm operators and farm workers is much more stable from year-to-year than is the real income of those workers.

The relative importance of Montana's farms and ranches as a *direct* source of *jobs* has been declining over the last two decades, from about 11% to about 7% See Figure 3 below. It is worth noting that employment on farms and ranches shown in Figure 2 is much more stable than farm earnings. Although there is a modest downward trend in relative farm and ranch employment, nothing like the volatility in farm earnings shown in Figure 1 above is found in the farm employment data.

Figure 3.



Source: U.S. Bureau of Economic Analysis, SAEMP25N Total full-time and part-time employment by NAICS industry

2. The Makeup of the Montana Agriculture Sector

As briefly discussed above, Montana's agricultural sector is dominated by a few agricultural products: Cattle and calves and the feed grains and grasses that support them and the food grains such as wheat that are sold into international food markets. About 55% of the cash receipts from Montana's agricultural marketings are associated with the production and sale of crops. Another 45% of Montana's agricultural marketings are associated with animals and animal products. If we look more closely at the Animals and Animal Products sector, we see that the cash receipts associated with cattle and calves make up almost 85% of the cash receipts from Animals and Animal Products. Similarly, if we look at the importance of wheat, barley, and hay in the cash receipts associated with crop production in Montana, those three crops are the source of 76% of cash receipts associated with all crop marketings. See Table 1 below. This result confirms our earlier discussion of the dominance of certain agricultural sectors in the Montana agricultural economy when looked at in terms of the commitment of agricultural land to particular agricultural uses. Here, data on agricultural cash marketings confirms that specialization. We will use these receipts later to scale the impact of climate change on these agricultural sectors.

Table 1.

Montana Agricultural Cash Receipts: 2021	
Cash Receipts from all Ag Marketings	$4,101,867,000
Animals and Animal Products	$1,844,927,000
Cattle and Calves Receipts	$1,566,396,000
Cattle as a % of Animal Products	**85%**
Cash Receipts from all Crop Marketings	$2,331,927,000
Wheat, Barley, and Hay Receipts	$1,761,747,000
Wheat, Barley, and Hay as % of Crops	**76%**

Sources: USDA. Cash Receipts from Marketing by Commodities. 2021. And National Agricultural Statistics Service. Montana Annual Bulletin. 2022. P.19.

Table 2 below shows the size of the agricultural sector in Montana in 2021 in terms of direct employment and labor earnings. Agriculture is the source of almost 29,000 direct jobs and almost $440 million in direct labor earnings. as well as more than 59,000 total jobs and more than $1 billion in total labor earnings when "ripple" or "multiplier" impacts are included.[49]

[49] We used the agricultural sector multipliers that are presented in the Montana section of Feeding the Economy that is produced by the Corn Refiners Association, among 29 other food related groups. The

Table 2.

Size of the Agricultural Sector of the Montana Economy in 2021	
2021 MT Ag Direct Jobs	28,955
2021 MT Ag Direct Labor Earnings	$437,583,000
2021 MT Ag Total Jobs	59,395
2021 MT Total Labor Earnings	$1,132,503,893

Sources: U.S. Bureau of Economic Analysis. State Personal Income: Revised estimates for 2021. https://apps.bea.gov/regional/histdata/releases/0922spi/index.cfm And multiplier impacts to assess total jobs and labor earnings from the Montana section of CRA et. al. Feeding the Economy. 2023. https://feedingtheeconomy.com/

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: jobs and 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 justifies land investments, equipment purchases, and the long hours of work that farm families put into their agricultural enterprises. Farming and ranching at large or small scale are more than an economic enterprise. They are 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 of its non-agricultural residents. In that sense, damaging or weakening agriculture and reducing its role in the state has cultural and social costs which our chosen economic metrics do not reflect. For that reason, our economic estimates may represent a serious understatement of the overall socioeconomic loss that climate change may bring 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,

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multipliers that we utilized are quite similar to those used by MSU Extension report, Economic Impact of Agriculture: Statewide Report. December 2020.

[50] Torell, A. Income Earning Potential versus Consumptive Amenities in Determining Ranchland Values. *Journal of Agricultural and Resource Economics.* 30(3):537-560. 2005.

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:[51,52]

Summers will be hotter, have more extreme temperatures, and will be drier. This will seriously stress the available forage and exacerbate water access issues for cattle. More extreme summers will also stress the cattle and calves. The early rapid growth of vegetation due to warm and wet conditions in the spring 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 requirements.[53]

The high temperatures and high CO_2 concentrations will boost competition from leafy spurge, knapweed, and 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.[54]

It should be pointed out that the Briske study 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% are likely to reduce animal growth and reproduction, while values of 1% 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 requirements."[55]

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[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

[52] Holechek, J. et al. Climate Change, Rangelands, and Sustainability of Ranching in the Western United States. Sustainability. 2020.

[53] Holechek, J. et al. Climate Change, Rangelands, and Sustainability of Ranching in the Western United States. Sustainability. 2020. Page 16.

[54] Whitlock C, Cross W, Maxwell B, Silverman N, Wade AA. 2017 Montana Climate Assessment. Bozeman and Missoula MT: Montana State University and University of Montana, Montana Institute on Ecosystems. 318 p. doi:10.15788/m2ww8w. 2017. Page 199.

[55] 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.
Page 251.

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 subshrubs in the Northern Great Plains, writing, "We anticipate that increased abundance and expanded ranges of exotic invasive species are more likely to adversely affect livestock production than such changes in native species because exotics are often unpalatable and occasionally toxic to livestock."[56] Another analysis of the implications of climate change for the Great Plains Rangelands made clear that adaptation was the best strategy for cattle production on rangeland. They encourage much lower stocking rates (25% of carrying capacity) and genetically adapted breeds: "In lower and mid latitudes, the types of cattle grazed will shift towards those that can best handle harsh hot conditions, low quality forage, and limited water availability."[57] The analysis sums up the changes that will likely need to be made in the "Northern Great Plains" to mitigate for climate change in this way:

> "On the Northern Great Plains rangeland, there might be an increase in forage production, but a decline in forage quality. Therefore, for financial viability and sustainable livelihood, ranchers in this area will likely rely on sustainable intensification strategies using a set of rangeland management practices such as improved animal genetics, increasing supplemental feed inputs, and increased use of controlled fire for habitat and forage quality improvements."[58]

Improved animal genetics, increased supplementation, and habitat control for better forage are adaptation strategies that could be effective in Montana. According to Derner et al, some adaptation strategies may be easier for small-scale operations due to labor requirements and pasture sizes, but larger operations in the western United States currently have greater access to resources and support needed for climate adaptations.[59] This could speak to a more pressing need for support systems that can help smaller operations access the resources needed to plan for and achieve climate adaptation strategies.

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

[56] Ibid. p. 251.
[57] Holechek, J. et al. Climate Change, Rangelands, and Sustainability of Ranching in the Western United States. Sustainability. 2020. Page 12.
[58] Holechek, J. et al. Climate Change, Rangelands, and Sustainability of Ranching in the Western United States. Sustainability. 2020. Page 16.
[59] Derner, J., Wilmer, H.,Stackhouse-Lawson, K., Place, S., and Boggess, M. Practical considerations for adaptive strategies by US grazing land managers with a changing climate. American Society of Agronomy. Accessed 7.24.2024. https://acsess.onlinelibrary.wiley.com/doi/full/10.1002/agg2.20356

more xeric [very dry] conditions will prevail, reducing pasture quality and threatening Montana's livestock industry."[60]

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% decline in the rangeland cattle sector in Montana by mid-century. It is important to note that a decline of 20% has already happened on rangeland in the west in our recent historical record as the result of climate change; in New Mexico, there has been a 20% decline in rangeland carrying capacity when comparing 1920-1976 compared with 1976-2017.[61] The primary explanation for this decline in carrying capacity was "shrub encroachment and climate change (more frequent heat waves)", which is exactly what is predicted for Montana rangeland.[62] The economic impacts (losses) of these climate-related changes in cattle production are shown in Table 3 below. 4,514 cattle ranching jobs and more than $86 million in labor earnings from cow and calf operations would be lost due to climate change by mid-century.[63]

Table 3.

Projected Direct Impact of Climate Change on Cattle and Calf Jobs and Labor Earnings: Montana 2021

	Jobs	Labor Earnings
Livestock	4,514	$86,070,296

Sources: Bureau of Economic Analysis. State Personal Income: Revised estimates for 2021. https://apps.bea.gov/regional/histdata/releases/0922spi/index.cfm

2. The Impact of Climate Change on 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 rather than 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 autumn.

[60] 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.

[61] Holechek, J. et al. Climate Change, Rangelands, and Sustainability of Ranching in the Western United States. Sustainability. 2020. Page 8.

[62] Holechek, J. et al. Climate Change, Rangelands, and Sustainability of Ranching in the Western United States. Sustainability. 2020. Page 8.

[63] We used the Cash Receipts data from the USDA, Annual cash receipts by commodity as a scaling factor for the BEA data on employment and labor earnings to break out cattle and calves as well as wheat, barley, and hay. https://data.ers.usda.gov/reports.aspx?ID=17832#P3fa224d8a5c34fe9a6387e54f8139a18_2_17iT0R0x26 Accessed 4.27.2023.

This presents a conflicting picture for agriculture producers of all sizes. 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 higher temperatures in the summer can easily cancel out the benefits of higher precipitation rates, especially when peak surface water flow passes earlier, 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.[64]

> "Warming temperatures can also increase nitrogen export (reduction). Recent work by Brookshire et al. (2011) suggests that climate change-driven loss of soil nitrogen could outpace deposition by 3 to 1."[65]

However, many Montana farmers have been changing their farming techniques to try to add more nitrogen, among other benefits, to their soil through the use of "pulse crops" for quite some time. Pulse crops help add nitrogen to the soil because the plants fix nitrogen out of the atmosphere, as opposed to wheat which depletes the soil of the nitrogen that is in it. In fact, Montana is the number one producer of lentils, dry peas, and chickpeas, which are all nitrogen-fixing pulse crops.[66]

> "Benefits, which improve resilience, include improvements in soil fertility and water-use efficiency, plus disruption of weed, pest, and disease life cycles. This finding has encouraged incorporation of pulse crops into rotations with wheat (Long et al. 2014), replacing summer fallow years. Miller et al. (2015) also show that in a wheat-pea cropping system, producers can reduce the amount of nitrogen that they apply, but in the long run, maintain similar profits as a wheat-fallow system and reduce uncertainty around those profits."[67]

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[64] 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.

[65] Whitlock C, Cross W, Maxwell B, Silverman N, Wade AA. 2017 Montana Climate Assessment. Bozeman and Missoula MT: Montana State University and University of Montana, Montana Institute on Ecosystems. 2017. 318 p. doi:10.15788/m2ww8w. Page 181.

[66] USDA. Montana Agricultural Statistics, Volume LLIX. October 2021. Page 24.

[67] Whitlock C, Cross W, Maxwell B, Silverman N, Wade AA. 2017 Montana Climate Assessment. Bozeman and Missoula MT: Montana State University and University of Montana, Montana Institute on Ecosystems. 2017. 318 p. doi:10.15788/m2ww8w. Page 215.

As discussed above, a 2013 study of the impact of climate change on Montana crop production focused on farms in the Flathead Valley.[68] The farms produced spring and winter wheat, spring barley, irrigated and unirrigated alfalfa hay, lentils, peas, and canola. The impact of projected climate change over the next several decades was a 24% decline in the net crop return per acre and a 57% decline in net farm income relative to the historical period. Unfortunately, this is very similar to the decline that has already happened in Australia because of climate change.[69] In the 2013 study, 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.

A study in Nepal found that small-sized farmers are able and tend to adapt much more in response to their perception of a changing climate than larger operations do. The study concludes that the trend toward larger farming operations in Nepal and around the world may reduce the agricultural sector's overall responsiveness to climate change.[70] In Montana, this may underscore the need for a diversity of farming operation sizes, but more research is needed.[71]

Another study of the impact of climate change on Montana agriculture focused on the principal agricultural zones in eastern Montana.[72] 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: 45-80% losses. Grass yields, however, were projected to increase 10-20%.[73] A more recent study, looking at global wheat production found that for every 1% increase in global temperature, global wheat production would be cut 4.1-6.4%, specifically referencing the U.S.[74]

The 2004 Montana specific study from Antle[75] 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 of elevated CO_2 concentrations on wheat production were projected to be positive for both winter and spring wheat: Yields would be boosted 17-55%. When the combined effects of changes in temperature and precipitation patterns and increased CO_2 concentrations were

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[68]Op.Cit Pratoe and Qui, 2013.

[69] Hochman, Z., Gobbett, D.L., Horan, H. Climate trends account for stalled wheat yields in Australia since 1990. *Global Change Biology*. 23, 2071–2081. 2017.

[70] Koirala, P., Kotani, K., Managi, S. How do farm size and perceptions matter for farmers' adaptation responses to climate change in a developing country? Evidence from Nepal. *ScienceDirect.* Accessed 7.24.2024. https://www.sciencedirect.com/science/article/abs/pii/S0313592622000145

[71] Mase, A.S., Gramig, B.M., Prokopy, L.S. Climate change beliefs, risk perceptions, and adaptation behavior among Midwestern U.S. crop farmers. ScienceDirect. Accessed 8.29.2024. https://www.sciencedirect.com/science/article/pii/S2212096316301097

[72] Op. Cit. J. Antle et al. 2004

[73] Ibid. Table 1 and page 301.

[74] Liu, B., Asseng, S., Müller, C., Ewert, F., Elliott, J., Lobell, D.B., Martre, P., Ruane, A.C., Wallach, D., Jones, J.W., et al., Similar estimates of temperature impacts on global wheat yield by three independent methods. *Nature Climate Change.* 6, 1130–1136. 2016.

[75] Op. Cit. J. Antle et al. 2004

calculated, this study found that spring wheat yields would decline 20-30% but that there would be an increase in winter wheat yields (0-20%) and yields of grass grown for pasture (10-30%). These results are quite similar to a more recent study from Demirhan who found that CO_2 helped to fertilize wheat crops and adaptation helped to make up for increased temperature from global warming, but in the long term, global wheat production falls significantly as the temperature increases:

> "However, the serious negative long-run impact of temperature anomalies on wheat yield (90.4 million tons drop for each one-degree Celsius warming) shows that the current efforts to develop more robust crops and adaptive practices are not enough to mitigate the decrease in the wheat production in the future. The reason we get different short and long-run results is closely related to the new planting and genetic technologies, increasing cropland area, land-use management."[76]

The decrease in wheat production that Demirhan is projecting, when applied to 2022 world wheat production of 788.94 million MT of wheat,[77] is an 11% drop per degree C of global warming. Given that the IPCC is now forecasting a global increase in temperature of 3.5° C by 2081-2100,[78] above what has already been observed, this would represent a decrease in global wheat production of about 40%.

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 must grow and mature. This has led to reduced, rather than increased, yields. A study of the impact of rising temperatures on wheat production confirms this. It concluded that wheat production was estimated to fall by 6% for each degree centigrade of further temperature increase. Thus, a 5° C summer temperature increase could lead to a 30% decline in wheat production.[79] This result is echoed in more recent literature that says that "even a 1° C temperature increase over mean temperature during reproductive stage may lead to higher loss in grain yield."[80]

Based on these projections, we estimate that Montana grain crop yields could be reduced by 20% by mid-century due to climate change. Wheat, barley, and hay sectors of Montana agriculture are the source of about 76% of agricultural sales.[81] Table 4 shows the loss of nearly

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[76] Demirhan, H. Impact of increasing temperature anomalies and carbon dioxide emissions on wheat production. *Science of the Total Environment.* 2020.
[77] USDA. Wheat Explorer. Wheat 2022 World Production. Accessed 4.5.2023. https://ipad.fas.usda.gov/cropexplorer/cropview/commodityView.aspx?cropid=0410000
[78] IPCC. Summary for Policymakers In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Masson-Delmotte, V. et al. Box SPM.1 (b), Page 13. Accessed 4.5.2023. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf
[79] Asseng, S. et al. Rising temperatures reduce global wheat production. *Nature Climate Change.* Vol 5. February 2015. Pp 143-147.
[80] Poudel, P and Poudel, M. Heat Stress Effects and Tolerance in Wheat: A Review. Journal of Biology and Today's World. 2020.
[81] USDA. Annual cash receipts by commodity. https://data.ers.usda.gov/reports.aspx?ID=17832#P3fa224d8a5c34fe9a6387e54f8139a18_2_17iT0R0x26 Accessed 4.27.2023.

5,000 wheat, barley, and hay jobs (collectively referred to as Crops in Table 4) and more than $95 million in labor earnings would be lost due to climate change by mid-century.[82]

Table 4.

Projected Direct Impact of Climate Change on Crops Jobs and Labor Earnings: Montana 2021		
	Jobs	Labor Earnings
Crops	4,989	$95,130,327

Sources: Bureau of Economic Analysis. State Personal Income: Revised estimates for 2021. https://apps.bea.gov/regional/histdata/releases/0922spi/index.cfm

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. In fact, many Montana farmers are already using things like pulse crops to help with the changes that we have seen already. 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 enterprises. 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 sector to come together and advocate for the resources they will need. Adaptation, such as changing crops and cropping patterns, often involves additional costs such as labor and investment in equipment and supplies. It also involves taking on more risk. Similarly, shifting patterns of feeding cattle and providing supplemental nutrients, or cattle that are more genetically adapted to hot summers, may be costly in terms of labor effort and infrastructure. Analyzing how farms and ranches may (or may not) adjust their operation and the subsequent net impact on productivity and profitability 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

[82] We used the Cash Receipts data from the USDA, Annual cash receipts by commodity as a scaling factor for the BEA data on employment and labor earnings to break out cattle and calves as well as wheat, barley, and hay. https://data.ers.usda.gov/reports.aspx?ID=17832#P3fa224d8a5c34fe9a6387e54f8139a18_2_17iT0R0x26 Accessed 4.27.2023.

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 – agriculture – it should not be surprising that the impact of a 20% reduction in its two largest sectors is likely to be significant. The total impact on employment is the loss of more than 9,500 jobs and more than $181 million dollars per year in labor earnings by mid-century.[83] See Table 5 below for the combined impacts of climate change on Montana agriculture. A discerning reader may see that these projected impacts are smaller than what we projected the last time (2015) that we analyzed the impact of climate change on Montana's economy. This largely has to do with 2021 being a hard year for earnings for agricultural producers, a slightly more conservative impact associated with climate change, and a slightly different characterization of agriculture in Montana.[84]

Table 5.

Projected Direct Impact of Climate Change on Agriculture Jobs and Labor Earnings: Montana 2021		
	Jobs	**Labor Earnings**
Livestock	4,514	$86,070,296
Crops	4,989	$95,130,327
Total	**9,503**	**$181,200,623**

Source: Sources: Bureau of Economic Analysis. State Personal Income: Revised estimates for 2021. https://apps.bea.gov/regional/histdata/releases/0922spi/index.cfm

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. School districts already hard-hit by shrinking enrollments will face broader consolidation and longer bussing routes for their students. The

[83] We used the Cash Receipts data from the USDA, Annual cash receipts by commodity as a scaling factor for the BEA data on employment and labor earnings to break out cattle and calves as well as wheat, barley, and hay. https://data.ers.usda.gov/reports.aspx?ID=17832#P3fa224d8a5c34fe9a6387e54f8139a18_2_17iT0R0x26 Accessed 4.27.2023.

[84] Where we formerly used some BBER data to characterize the size of the secondary impacts of the direct jobs from Agriculture in Montana, we are now using multipliers from CRA and their publication Feeding the Economy. The BBER does not now produce the same reports as it did the first time that we put together projections of the potential economic impacts of climate change. , and the multipliers that we used are more closely aligned with MSU Extension characterizations of the impact of the Agricultural sector of the Montana economy. The result is a more modest impact associated with climate change in Montana.

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 – especially small operations, given adequate access to support – 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 and in place. 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, especially the Great Plains area of eastern Montana.

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