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Flexible stocking with Grass-Cast: A new grassland productivity forecast to translate climate outlooks for ranchers

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Abstract
Highly variable precipitation in western U.S. rangelands makes it challenging for ranchers to match animal demand to forage supply. Flexible stocking can enhance matching, thereby reducing losses during drought and increasing profit during wet years. Yet the benefits of flexible stocking depend on the availability of highly accurate and applicable seasonal climate outlooks. The availability and skill of seasonal climate outlooks is summarized, revealing shortcomings that make flexible stocking less practical and less beneficial. A new grassland productivity forecast, Grass-Cast, can facilitate flexible stocking by translating climate outlooks into more applicable summer-forage outlooks, and its strengths and limitations are described.

Key Words: Animal demand, forage supply, rangelands, scenario planning, seasonal climate outlooks, uncertainty, yearlings.

Flexible stocking to manage forage variability
Rangelands of the Western United States are characterized by low plant productivity and highly variable precipitation, including frequent drought, which makes it challenging for ranchers to match animal demand to forage supply (Briske et al., 2015; Petrie et al., 2018). Livestock producers have traditionally been encouraged to implement light (defined here as 25 to 30% forage use) to conservative (35 to 40% forage use) stocking rates (Boykin et al., 1962; Holechek, 1994; Parsch et al., 1997; Kachergis et al., 2014; Hamilton et al., 2016) to reduce the negative environmental impacts of drought (Thomas et al., 2015). Although these stocking rates perform as intended during dry

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years, they also reduce financial gains during wet years by underutilizing abundant forage (Garoian et al., 1990; Parsch et al., 1997; Torell et al., 2010).

Flexible stocking is an alternative strategy capable of both reducing losses during drought and increasing profit during wet years (Derner and Augustine, 2016; Bastian et al., 2018). Flexible stocking attempts to match animal demand more closely to forage availability using a two-part strategy. The first part involves incorporating a yearling enterprise (i.e., retaining weaned calves) into an existing cow-calf-only operation to increase enterprise flexibility. This requires the operation to reduce the size of the cow herd (Garoian et al., 1990; Derner and Augustine, 2016; Bastian et al., 2018), especially in areas where growing season precipitation is more variable (Hamilton et al., 2016). Secondly, once the yearling enterprise is established, yearling numbers can then be "flexed" up or down, in response to current and forecasted forage availability, as well as calf versus yearling prices (Parsch et al., 1997; Ritten et al., 2010b).

Imagine, for example, a producer with a spring-calving herd whose forage resources were abundant going into the fall. Suppose seasonal climate outlooks indicated favorable weather during the upcoming winter (i.e., conditions that reduce forage demand per animal), and the upcoming spring and summer (e.g., conditions that increase forage supply). Then the producer —after considering fall calf prices and yearling market outlooks—might flex their yearling enterprise up by retaining more weaned calves in the fall in order to sell them in the spring as "short-yearlings" or in the fall as "long-yearlings" (Parsch et al., 1997; Ritten et al., 2010b). In contrast, if forage resources going into the fall were scarce, or if seasonal climate outlooks (or yearling prices) were unfavorable, the producer might retain no additional calves, thereby flexing the yearling operation down until conditions improve. If only this producer had access to accurate seasonal to sub-seasonal climate outlooks, flexible stocking could increase their economic returns by 23 to 100% (Garoian et al., 1990; Ritten et al., 2010a; Torell et al., 2010; Bastian et al., 2018).

The economic net benefits of flexible stocking hinge on: (a) the availability of highly accurate seasonal climate outlooks for relevant timeframes, and (b) the ability of ranchers to translate these climate outlooks into terms that actually matter to them, i.e., how much grass will be available for livestock to graze (Ritten et al., 2010a; Torell et al., 2010; Bastian et al., 2018). In this paper, we review the availability and skill of existing seasonal climate outlooks, and then introduce a new grassland productivity forecast that translates climate outlooks into more directly usable summer-forage outlooks. The implications of both accuracy and usability for the practicality of flexible stocking are discussed.

Climate outlooks for flexible stocking

Returning to our earlier example of a rancher with a spring-calving cow herd, seasonal climate outlooks are first relevant in the fall (September-November) when the rancher must decide how many calves to retain through the winter to become short-yearlings (Garoian et al., 1990). To make a climate-informed decision, on October 15th for example, they would need two seasonal outlooks: 1) a 5-month temperature and precipitation outlook for November through March, with a 0.5-month lead time; and 2) a 4-month precipitation outlook for the growing season, April through July, with a 5.5-month lead time. Outlook 1) would indicate how long and severe the winter will be, which affects animal demand for forage. Outlook 2) would hint at how abundant grass will be the following summer, which influences the relative profitability of selling calves now versus next year as short or long yearlings. These two climate outlooks—in combination with fall calf prices and expected yearling prices, as well as inventories of hay or standing forage to support the herd through winter—would enable a well-informed calf-retention decision.

To make an informed short versus long-yearling decision, on March 15th for example, a rancher would need a 4-month precipitation outlook for April through July, with a 0.5-month lead time. This is particularly the case for ranchers operating in the Northern Plains, where plant biomass depends heavily on the amount of precipitation that falls during the growing season (Chen et al., in review). Note, even with an accurate 4-month precipitation outlook, a rancher would still have to translate that outlook into an estimate of how much grass will grow on their rangelands. Given the complex relationships between plant growth and precipitation (both its quantity and timing, along with other confounding weather variables), this is no simple task. Nonetheless, an accurate precipitation outlook, in combination with information about short-yearling prices relative to expected long-yearling prices, would enable a rancher to make a well-informed yearling-retention decision.

Next, with a better understanding of the climate outlooks needed to inform flexible stocking decisions, we examine the availability and skill of such seasonal climate outlooks. Additionally, we introduce a new grassland productivity forecast that helps ranchers more easily translate precipitation outlooks into rangeland forage estimates. This new grassland forecast, together with available climate outlooks, meet more of the informational needs of ranchers who want to implement flexible stocking.

Climate outlooks vary in skill

The National Oceanic and Atmospheric Administration's Climate Prediction Center (NOAA CPC) provides a variety of seasonal climate outlooks for both temperature and precipitation, which can be freely accessed at http://www.cpc.ncep.noaa.gov/products/forecasts/. NOAA CPC's seasonal outlooks typically cover 3-month periods, so a rancher interested in the 5-month period November through March would need to consider 3 different outlooks: the NDJ (0.5-month) outlook, the DJF (1.5-month lead) outlook, and the JFM (2.5-month lead) outlook. Figure 1 shows an example 3-month seasonal climate outlook from NOAA

CPC, specifically for temperature and precipitation in November-December-January of 2017-18, as produced on October 19, 2017 (i.e., a 0.5-month lead).

The "skill" of NOAA CPC's seasonal climate outlooks (i.e., the extent to which they are correct more often than a random draw from the historical climate record) varies across the Western United States, and depends on the time of year, the length of the lead-time (Barbero et al., 2017), and the forecasted ENSO phase (i.e., El Niño, Neutral, or La Niña). Figure 2 shows the skill of the Climate Prediction Center's 3-month outlook for temperature and precipitation in November through January, when released in mid-October (i.e., 0.5-month lead), based on the years 1995 through 2018 (readers can explore skill maps for other forecast periods and locations at http://vwt.ncep.noaa.gov/index.php?page=map). Skill scores show the percent improvement in number of correct forecasts compared to random forecasts (known as the Heidke Skill Score; Barnston, 1992). A perfect forecast (i.e., one that always indicates the correct weather category) receives a score of 100. A forecast that is no better than randomly selecting from the historical record receives a score of 0. A forecast that is correct less often than randomly selecting from the historical record receives a negative score (Barnston, 1992).

Comparing panels (a) and (d) of Figure 2, we see that the skill of temperature outlooks are typically higher (more orange dots, fewer blue dots) than that of precipitation outlooks (more blue dots and fewer orange dots), for many western U.S. locations (Peng et al., 2012). Comparing panels (b) and (c), we see for temperature that, when it calls for above-normal temperatures, it exhibits greater skill than when it calls for below-normal temperatures. For example, if you live in Wyoming and the 3-month temperature forecast for December through February calls for above-normal temperatures, you can place greater trust in that forecast (i.e., the orange dots in panel (b) indicate relatively high skill) than when it calls for below-normal temperatures (i.e., the purple dots in panel (c) indicate relatively less skill).

Similarly, for the Northern Rocky Mountain region, the 3-month precipitation outlook for December through February exhibits more skill when it calls for above-normal precipitation (i.e., there are many orange or red dots in panel (e)) than when it calls for below-normal precipitation (i.e., there are many purple dots in panel (f)). The opposite is true for the Southwest U.S. The take-home message is, depending on where you live in the Western U.S., the seasonal climate outlooks available to help inform your flexible stocking decisions may have more or less skill (Peng et al., 2012). This skill-level for your location can also change dramatically depending on the lead time and season (Peng et al., 2012). For example, precipitation outlooks generally have more skill in the winter than in the summer, because the El Niño Southern Oscillation (ENSO) has greater influence on winter precipitation (Peng et al., 2012).

During El Niño events, in particular, skill of the seasonal temperature outlook for October through March improves for much of the Western U.S. (see Barbero et al., 2017,

Figure 8, for a detailed map). Likewise, skill of the seasonal precipitation outlook improves for the southwestern region (see Barbero et al., 2017, Figure 9, for a detailed map). Figure 3 shows how El Niño has historically impacted temperatures and precipitation across the United States (similar maps for La Niña are available at https://www.esrl.noaa.gov/psd/enso/compare/).

One should be cautious, however, because the impacts of an El Niño (or a La Niña) event can be highly variable, depending on the event's strength and interactions with other components of the global atmospheric system, such as the Pacific Decadal Oscillation (Chen et al., 2017). For maps showing the diversity of impacts that past El Niño events have had on temperatures across the U.S., visit https://www.esrl.noaa.gov/psd/enso/images/temperature.gif. For its impacts on precipitation, visit https://www.esrl.noaa.gov/psd/enso/images/precipitation.gif. For La Niña's impacts on temperature and precipitation, visit https://www.esrl.noaa.gov/psd/enso/images/temperature.la.gif and https://www.esrl.noaa.gov/psd/enso/images/precipitation.la.gif, respectively.

Grass-Cast translates climate into forage

The seasonal climate outlooks discussed above can help inform a rancher's flexible stocking decisions, in both the fall and spring. In fall, for example, the outlooks might signal a relatively mild and dry winter. In this case, if livestock prices are conducive, a rancher might retain more calves, anticipating per-animal forage demand through the winter will be relatively low compared to their known forage supply. In spring, however, the outlooks might signal a relatively warm and dry growing season. In this case, the rancher might sell some retained calves as short-yearlings, rather than turning them out for summer grazing, to better match forage demand to anticipated shortages in forage supply. Again, this depends on the relative prices of short versus long yearlings.

Even when a rancher has access to accurate seasonal climate outlooks and a firm understanding of them, this information is still difficult to translate into more relevant, usable terms — i.e., future forage growth on their native rangelands for summer grazing. Translating climate outlooks into forage outlooks would make this information more directly usable by ranchers. Toward this purpose, a team of researchers from Colorado State University, U.S. Department of Agriculture-Agricultural Research Service, the National Drought Mitigation Center, and the University of Arizona recently developed a new Grassland Productivity Forecast, or "Grass-Cast," for ranchers in the Great Plains region (Peck and Durham, 2018). Released for the first time in spring of 2018 for the Northern Plains (Figure 4), Grass-Cast estimates the productivity of rangelands at the individual county level, using observed weather conditions to-date for past years, and precipitation outlooks for April through July. Then, the resulting productivity estimates (i.e., pounds of above-ground vegetative biomass per acre at the growing season's peak) are categorized as either above-normal, near-normal, or below-normal as compared to the individual county's 34-year production history (Peck and Durham, 2018). Grass-Cast is being expanded next to the Southern Plains and Southwest regions.

Grass-Cast is made by first incorporating observed daily weather data (historical and recent) for individual counties into an ecological model (DayCent) to simulate soil moisture dynamics and actual evapotranspiration (AET) of rangelands (Chen et al., 2017). When AET is measured cumulatively over the growing season, it correlates strongly with above-ground net primary productivity (ANPP) of rangelands, i.e., pounds per acre of above-ground biomass (Chen et al., 2017). Cumulative AET must be estimated using observed weather supplemented with simulated future daily weather, particularly precipitation. This is necessary because Grass-Cast maps are first released in May, before AET for the entire growing season can be directly observed (Chen et al., in review). The simulated weather data are constructed by ordering a county's historical season-long precipitation data from lowest to highest. Afterward, the data are sorted into terciles for below-normal, near-normal and above-normal categories. These terciles are then sampled to provide future daily precipitation data for 3 Grass-Cast scenarios, i.e., above, near, and below-normal precipitation for the remainder of the growing season.

After the DayCent model calculates cumulative AET using randomly chosen future precipitation, cumulative AET is then translated through a county-specific regression equation into a measure of greenness, specifically cumulative NDVI (Normalized Difference Vegetation Index). Then, this index is translated through a single region-wide regression equation into ANPP (pounds of above-ground biomass per acre). Finally, for ease of interpretation, a county's estimated ANPP value is compared to its 34-year historical average to calculate percent difference. This multi-step simulation and translation process is repeated 12 times for each scenario of the Grass-Cast map (i.e., 12 samples are taken from each of the 3 precipitation terciles to develop the corresponding 3 scenarios or panels of the Grass-Cast figure). The mean of these 12 iterations is the value ultimately displayed in a given panel of the Grass-Cast figure. For more details about the Grass-Cast modeling procedure, including its limitations (e.g., an inability to distinguish between desirable and undesirable plant species), see Chen et al. (in review) or watch the science webinar recordings at http://grasscast.agsci.colostate.edu.

Figure 4 shows an example set of Grass-Cast maps, which was produced on May 1, 2018, for the 2018 growing season. Each of the 3 panels in Figure 4 depicts the number of pounds per acre of rangeland vegetation forecasted to grow in individual counties, as a percent of a county's 34-year production history. A county in red, for instance, is forecasted to have at least 30% fewer pounds per acre than that county's 34-year average production, if not worse. A county in orange is forecasted to have 15 to

30% fewer pounds per acre than average. Yellow indicates 5 to 15% fewer pounds than average, and green indicates near-average (i.e., 5% less to 5% more pounds per acre than average). Finally, the various shades of blue represent more pounds per acre than average, with dark blue indicating that a county is forecasted to have at least 30% more pounds per acre than average, if not better.

Looking next at the 3 individual panels in Figure 4, each panel depicts the grassland forecast given a different precipitation scenario. The far-left panel shows the forecasted grassland production if precipitation during the rest of the growing season (through July 31st) is above-normal, i.e., drawn from the top tercile of each county's historical precipitation record. The middle panel shows forecasted production if future precipitation is near-normal, i.e., drawn from the middle third of the historical record. The far-right panel shows forecasted production if future precipitation is below-normal, i.e., drawn from the bottom third of the historical record. One final component of Figure 4 is the textbox located below the maps, which uses NOAA's seasonal precipitation outlooks to indicate whether one scenario (i.e., above, near, or below-average) is more likely to occur than the others. In Figure 4, NOAA's precipitation outlook from April 19th, 2018, indicates that precipitation has equal chances throughout the Northern Plains region of being above, near, or below normal. Thus, each panel of the Grass-Cast map is equally likely.

How can Grass-Cast inform flexible stocking?

The Grass-Cast maps are updated every 2 weeks, beginning in May and continuing through the end of July, as new observed weather data and updated climate outlooks become available. A rancher who implements flexible stocking can use the earliest-available Grass-Cast maps (like those in Figure 4) to help inform their initial short-yearling retention decision. As the growing season progresses and Grass-Cast's 3 maps are updated, producers can continue using it to adaptively manage their flexible grazing strategy (Derner and Augustine, 2016; Voth, 2018).

Grass-Cast's strength is its ability to translate existing climate outlooks, which can be difficult to interpret or apply, into a product that is more accessible and directly usable to ranchers. Grass-Cast's shortcoming is it does not eliminate uncertainty, as reflected in its use of 3 maps instead of just 1 to forecast the range of potential forage supply. With uncertainty remaining, how can Grass-Cast be useful to ranchers who use flexible stocking?

First, the 3 scenarios of Grass-Cast–depicting relative forage availability under below, near, and above-normal precipitation–provide "sideboards" on potential forage supply to which a rancher is trying to match animal demand. For example, if Grass-Cast indicates that a county's forage production might range from -15% (under below-normal precipitation) to +5% (under above-normal precipitation) in the upcoming grazing season, then a rancher can narrow the range of yearling numbers to consider retaining for the summer.

A more straightforward situation is when Grass-Cast indicates that forage availability will be similar across all 3 precipitation scenarios. For example, South Central Montana was forecasted on May 1, 2018, to have above-normal production no matter if precipitation over the rest of the growing season (between May 1 and July 31) was ultimately above, near, or below normal (Figure 4). Similarly, for Southeastern Colorado, two of the 3 Grass-Cast maps in May 1 forecasted this area to have below-normal production (Figure 4). In both locations, this may have been a strong enough signal for a producer to take proactive measures, such as retaining yearlings in South Central Montana, or selling yearlings in Southeastern Colorado.

A second way that Grass-Cast could be helpful to ranchers is by providing a regional perspective of where forage will most likely be plentiful. For ranchers with the ability to move animals, having this knowledge at the start of the growing season can enable proactive contingency planning to mitigate the risk of forage supply in their own county being less than animal demand.

A more challenging situation is when Grass-Cast indicates 3 entirely different levels of potential forage supply—a different color for the above, near, and below-normal precipitation scenarios—and NOAA-CPC's 3-month precipitation outlook indicates equal probability among them. How can such a wide-ranging Grass-Cast outlook still be useful to ranchers?

By providing 3 maps instead of just one, Grass-Cast enables them to evaluate a stocking strategy of interest through 3 different "what if" scenarios. For instance, if a rancher is thinking about retaining all of his or her yearlings for summer grazing, he or she can use Grass-Cast to help determine how successfully this strategy will match animal demand to forage supply under below, near, and above-normal precipitation. This "scenario planning" exercise can also help them develop contingency plans for selling, retaining, or adding even more yearlings as the Grass-Cast maps are updated and the grazing season unfolds (Powers and ESIP, 2018).

Parsch et al. (1997), for example, analyze a proposed stocking strategy that would generate a net revenue of $239, $63, and -$451 per hectare, respectively, if precipitation were above, near, or below-normal (holding prices constant). With these 3 possible outcomes quantified economically, and all outcomes being equally likely, a rancher could compare the expected net revenue and downside risk of the proposed stocking strategy to those of alternative strategies. Through the scenario planning process, they might even discover management strategies that perform well across multiple scenarios, i.e., strategies that are "robust" or "resilient" to weather uncertainty.

Could Grass-Cast make flexible stocking less risky?

Grass-Cast, through its forecasting of relative forage production under 3 different precipitation scenarios, provides improved yet still imperfect information to help ranchers match animal demand to forage supply. It places helpful "sideboards" on potential forage production—from the lowest, likely occurring with below-normal precipitation to the highest, likely occurring with above-normal precipitation. Combined with probabilities from NOAA's precipitation outlooks, Grass-Cast provides a decision-making spectrum that enables producers to consider strategies beyond just consistently light or conservative stocking rates.

In years when Grass-Cast indicates near or above-normal production for all 3 precipitation scenarios, ranchers could consider retaining more yearlings or increasing the grazing season length with less worry about forage demand potentially exceeding supply. Of course, not all ranchers can easily adjust the number or class of animals grazing, or the length of the grazing season; for example, those grazing on public lands or leasing pasture from another landowner. In simpler ownership or regulatory situations, however, Grass-Cast can also help ranchers determine if the upcoming grazing season is likely to be conducive for weather and production-dependent management practices, such as patch burning or grass banking. Conversely, in years when Grass-Cast indicates below-normal production for all 3 precipitation scenarios, ranchers could reduce the number of yearlings retained, shorten the grazing season, and make contingency plans to relocate animals (if economically optimal) to counties where forage is more available.

In years when Grass-Cast indicates a wide range of possible production levels across the 3 precipitation scenarios, more complex decision-making processes will be needed, and a flexible stocking strategy might entail higher risks. Here, a more thorough exploration and integration of economic, ecological, and socio-cultural benefits, costs and tradeoffs (Lubell et al. 2013) may be necessary for the successful implementation of flexible stocking. Scenario planning, experimental or experiential learning, and adaptive decision making could be used to help facilitate such exploration and integration (Derner et al. 2012).

References

Barbero, R., J.T. Abatzoglou, and K.C. Hegewisch. 2017. “Evaluation of statistical downscaling of North American multimodel ensemble forecasts over the western United States.” *Weather and Forecasting* 32: 327-341. doi: 10.1175/WAF-D-16-0117.1.

Barnston, A.G. 1992. “Correspondence among the correlation, RMSE, and Heidke forecast verification measures; refinement of the Heidke score.” *Weather and Forecasting* 7: 699-709.

Bastian, C.T., J.P. Ritten, and J.D. Derner. 2018. “Ranch profitability given increased precipitation variability and flexible stocking.” *Journal of the American Society of Farm Managers and Rural Appraisers* 81: 122-139.

Boykin, C.C., J.R. Gray, and D.P. Canton. 1962. *Ranch production adjustments to drought in eastern New Mexico*. Las Cruces, NM: New Mexico Agricultural Station, Bulletin 470.

Briske, D.D., L.A. Joyce, H.W. Polley, J.R. Brown, K. Wolter, J.A. Morgan, B.A. McCarl, and D.W. Bailey. 2015. “Climate-change adaption on rangelands: linking regional exposure with diverse adaptive capacity.” *Frontiers in Ecology and the Environment* 13: 249-256.

Chen, M., W.J. Parton, S.J. Del Grosso, M.D. Hartman, K.A. Day, C.J. Tucker, J.D. Derner, A.K. Knapp, W.K. Smith, D.S. Ojima, and W. Gao. 2017. “The signature of sea surface temperature anomalies on the dynamics of semiarid grassland productivity.” *Ecosphere* 8(12): e02069. doi: 10.1002/ecs2.2069.

Chen, M., W. Parton, M. Hartman, S. Del Grosso, W. Smith, A. Knapp, S. Lutz, J. Derner, C. Tucker, D. Ojima, J. Volesky, M. Stephenson, W. Schacht, and W. Gao. 201X. “Assessing Precipitation, AET, and NDVI as Controls of Great Plains Plant Production.” (In Review)

Derner, J.D., D.J. Augustine, J.C. Ascough II, and L.R. Ahuja. 2012. “Opportunities for increasing utility of models for rangeland management.” *Rangeland Ecology and Management* 65: 623-631. doi: 10.2111/REM-D-11-00122.1.

Derner, J.D., and D.J. Augustine. 2016. “Adaptive management for drought on rangelands.” *Rangelands* 38(4): 211-215. doi: 10.1016/j.rala.2016.05.002.

Hamilton, T.W., J.P. Ritten, C.T. Bastian, J.D. Derner, and J.A. Tanaka. 2016. "Economic impacts of increasing seasonal precipitation variation on southeast Wyoming cow-calf enterprises." *Rangeland Ecology & Management* 69: 465–473.

Holechek, J.L. 1994. "Financial returns from different grazing management systems in New Mexico." *Rangelands* 16(6): 237-240.

Kachergis, E., J.D. Derner, B.B. Cutts, L.M. Roche, V.T. Eviner, M.N. Lubell, and K.W. Tate. 2014. "Increasing flexibility in rangeland management during drought." *Ecosphere* 5(6): 77. doi: 10.1890/ES13-00402.1.

Lubell, M.N., B.B. Cutts, L.M. Roche, M. Hamilton, J.D. Derner, E. Kachergis, and K.W. Tate. 2013. "Conservation program participation and adaptive rangeland decision-making." *Rangeland Ecology & Management* 66: 609-620.

Parsch, L.D., M.P. Popp, and O.J. Loewer. 1997. "Stocking rate risk for pasture-fed steers under weather uncertainty." *Journal of Range Management* 50(5): 541-549.

Peck, D., and S. Durham. 2018. "Grass-Cast: A New Grassland Productivity Forecast for the Northern Great Plains." U.S. Department of Agriculture Blog. Available online at https://www.usda.gov/media/blog/2018/06/13/grass-cast-new-grassland-productivity-forecast-northern-great-plains [Accessed on August 27, 2018].

Peng, P., A. Kumar, M.S. Halpert, and A.G. Barnston. 2012. "An analysis of CPC's operational 0.5-month lead seasonal outlooks." *Weather and Forecasting* 27:898-917. doi: 10.1175/WAF-D-11-00143.1.

Petrie, M.D., D.P.C. Peters, J. Yao, J.M. Blair, N.D. Burruss, S.L. Collins, J.D. Derner, L.A. Gherardi, R. Hendrickson, O.E. Sala, P.J. Starks, J.L. Steiner. 2018. "Regional grassland productivity responses to precipitation during multiyear above- and below-average rainfall periods." *Global Change Biology* 24:1935–1951. doi: 10.1111/gcb.14024.

Powers, C. and ESIP (Earth Science Information Partners). 2018. "Starting the Climate Conversation: Using Scenario Planning to Promote Resilience in Beef Production." Available online at https://toolkit.climate.gov/case-studies/starting-climate-conversation-using-scenario-planning-promote-resilience-beef [Accessed on August 26, 2018].

Ritten, J.P., C.T. Bastian, S.I. Paisley, and M.A. Smith. 2010a. "Long term comparison of alternative range livestock management strategies across extended drought and cyclical prices." *Journal of the American Society of Farm Managers and Rural Appraisers* 73: 243-252.

Ritten, J.P., W.M. Frasier, C.T. Bastian, and S.T. Gray. 2010b. "Optimal rangeland stocking decisions under stochastic and climate-impacted weather." *American Journal of Agricultural Economics* 92(4): 1242-1255. doi: 10.1093/ajae/aaq052.

Sala, O.E., W.J. Parton, L.A. Joyce, and W.K. Lauenroth. 1988. "Primary production of the central grassland region of the United States." *Ecology* 69: 40-45.

Thomas, M.G., A.H. Mohamed, M.N. Sawalhah, J.L. Holechek, D.W. Bailey, J.M. Hawkes, P. Luna-Nevarez, F. Molinar, and G. Khumalo. 2015. "Long-term forage and cow-calf performance and economic considerations of two stocking levels on Chihuahuan Desert rangeland." *Rangeland Ecology and Management* 68: 158-165.

Torell, L.A., N.R. Rimbey, and O.A. Ramirez. 2010. "Economics of flexible versus conservative stocking strategies to manage climate variability risk." *Rangeland Ecology and Management* 63: 415-425.

Voth, K. 2018. "Want to Know How Much Forage You'll Have This Summer? Check Out Grass-Cast." *On Pasture*. Available online at https://onpasture.com/2018/06/11/want-to-know-how-much-forage-youll-have-this-summer-check-out-grass-cast/ [Accessed August 26, 2018].

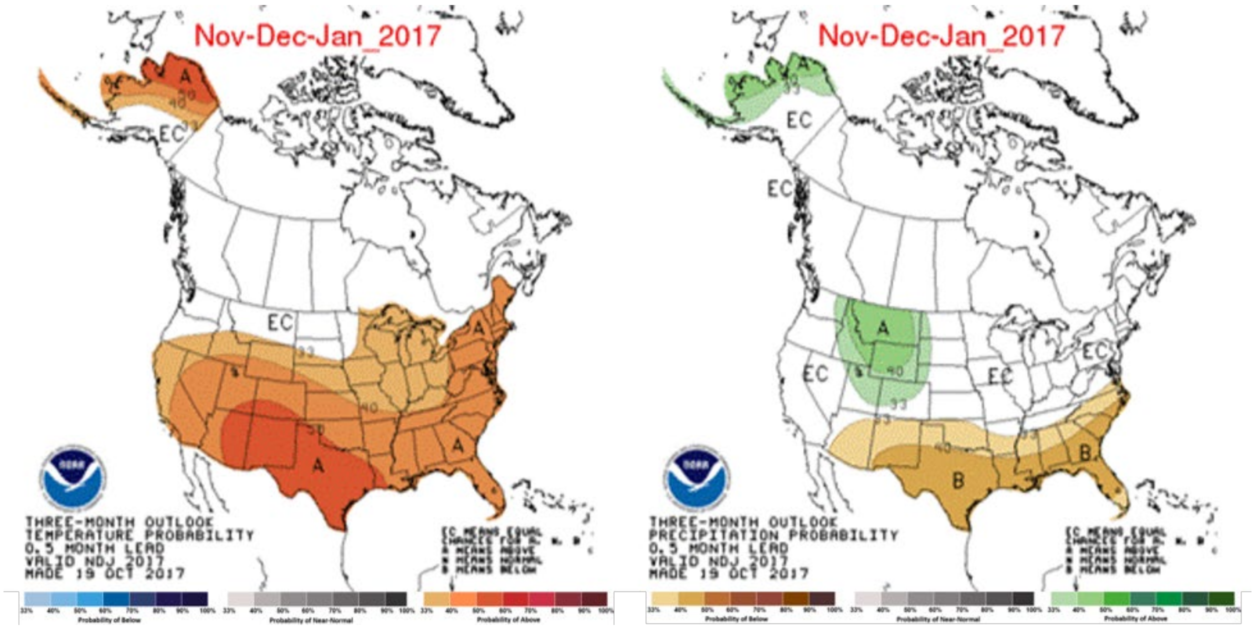


Figure 1. Example seasonal climate outlooks for temperature (left) and precipitation (right) from the National Oceanic and Atmospheric Administration's Climate Prediction Center. These outlooks were produced on October 19, 2017 for the 3-month period of November-December-January, 2017-18. In the left map, regions in orange (blue) indicate where the probability for above-normal (below-normal) temperatures is largest. In the right map, regions in green (brown) indicate where the probability for above-normal (below-normal) precipitation is largest. The numbers within the maps indicate forecast probability. Regions marked EC are indicated when probabilities for all 3 categories (above, normal, below) are equal. Adapted from publicly available maps archived at:
http://www.cpc.ncep.noaa.gov/products/archives/long_lead/llarc.ind.php.

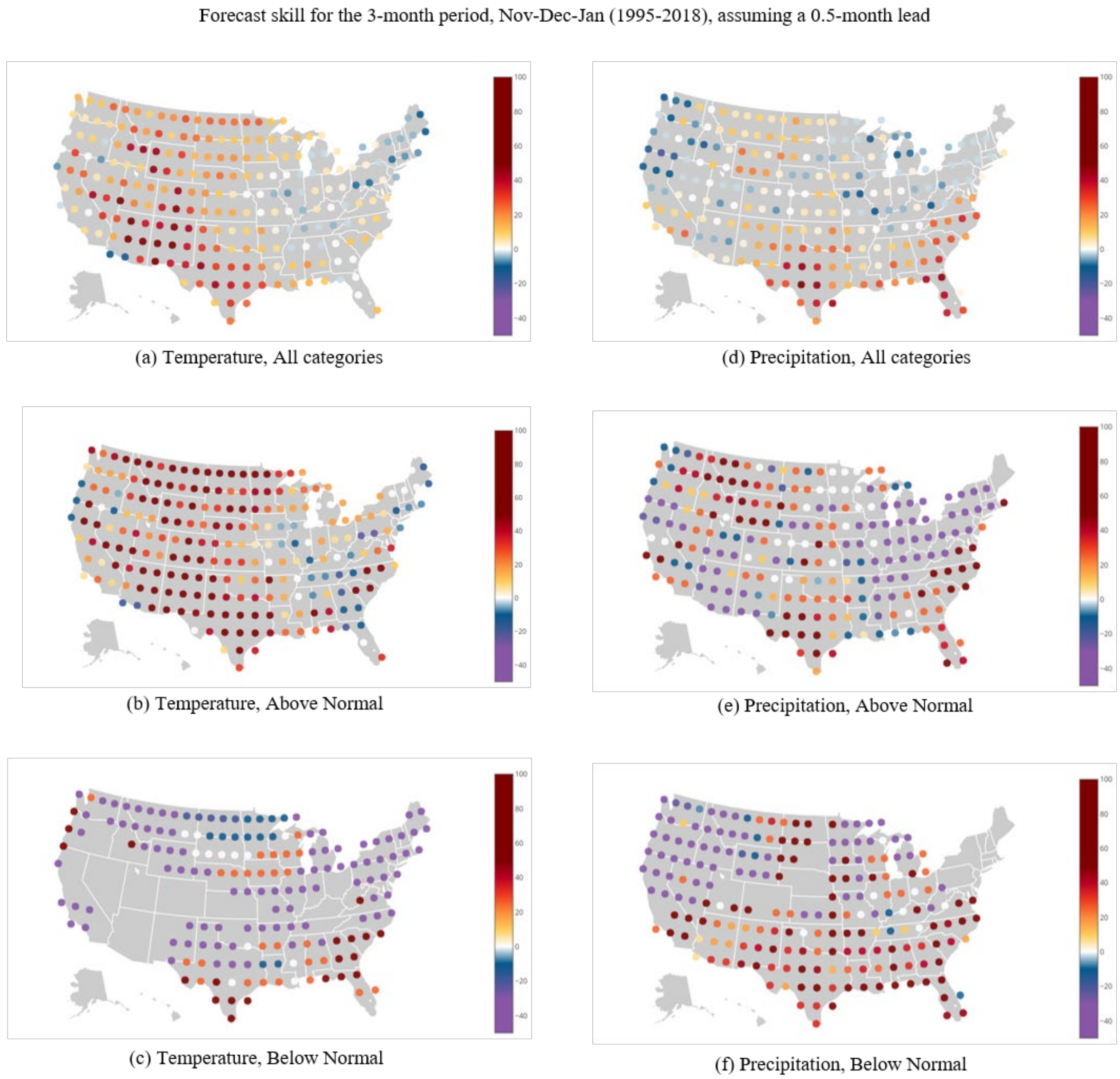
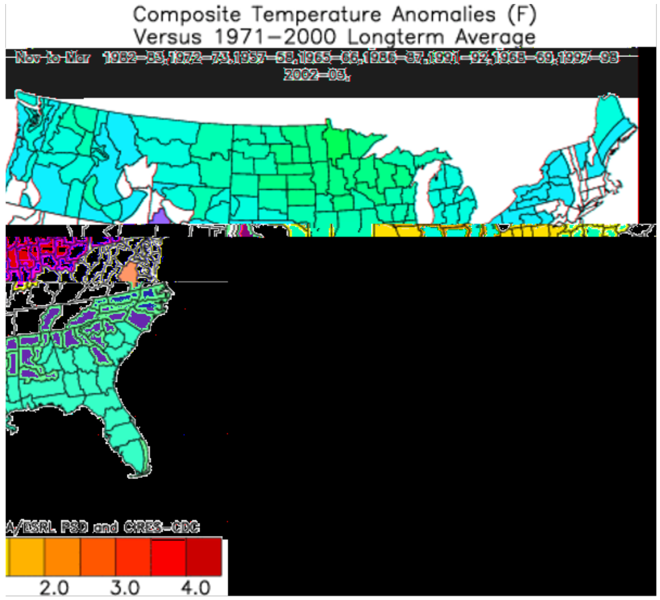
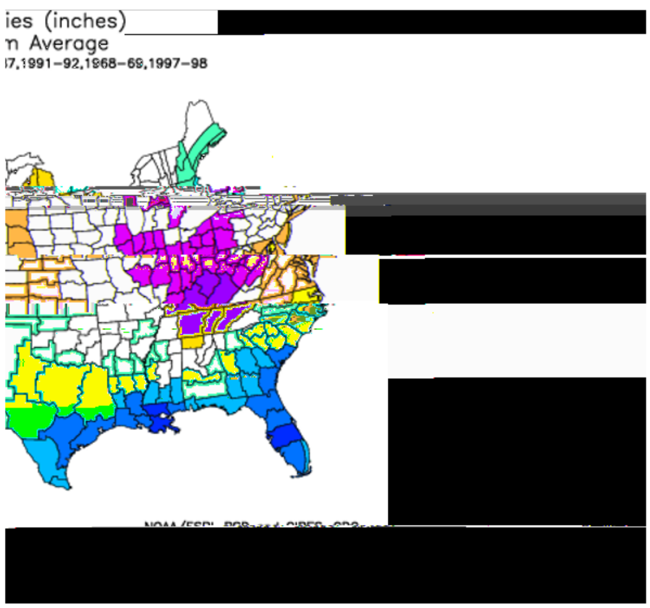


Figure 2. Forecasting skill (using the Heidke Skill Score) of the NOAA Climate Prediction Center's 3-month outlook (0.5-month lead) for temperature (panels (a) through (c)) and precipitation (panels (d) through (f)) in November through January (1995-2018). Panels (a) and (d) show skill scores unconditional on which category was forecasted (above-normal, normal, below-normal). Panels (b) and (e) show skill scores conditional on a forecast of "above-normal." Panels (c) and (f) show skill scores conditional on a forecast of "below-normal." Skill scores range from dark red (representing a perfect forecast) to white (no better than a random selection from the historical record) to blue and purple (a forecast that performs worse than a random selection). Adapted using publicly available maps at: http://vwt.ncep.noaa.gov/index.php?page=map.



(a) Temperature anomalies by climate division, November to March, under El Nino conditions



(b) Precipitation anomalies by climate division, November to March, under El Nino conditions

Figure 3. (a) Temperature anomalies and (b) precipitation anomalies, for the months of November to March, which have occurred during past El Niño events (1971-2003) versus long-term averages (1971-2000). Adapted using publicly available maps at: https://www.esrl.noaa.gov/psd/enso/compare/.

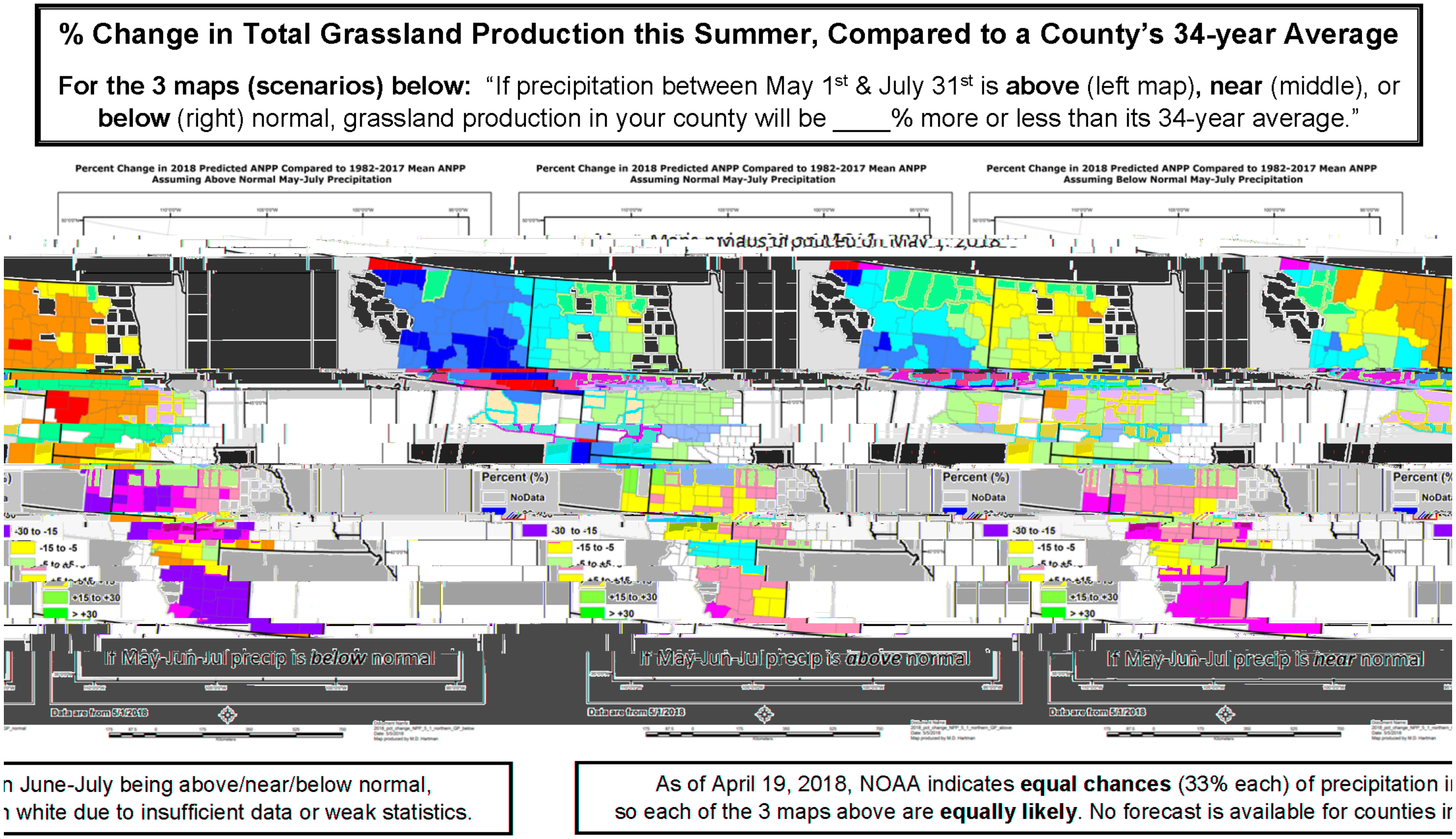


Figure 4. An example set of Grass-Cast maps, similar to those a rancher or rangeland manager would see on the Grass-Cast website, http://grasscast.agsci.colostate.edu/. This example was produced on May 1, 2018, as an early forecast for the 2018 growing season. It was updated every two weeks thereafter, through July 31, 2018. See the text box above the maps to learn how to correctly interpret the 3 panels (left, middle, right). Next, see the color-scale inside each panel, which explains for each county whether it is forecasted to have more or less pounds per acre of rangeland vegetation than the average of its 34-year production history. Finally, see the text box below the maps to learn whether one panel is more likely to occur than others, or if they are equally likely. For a demonstration of one way a rancher could use Grass-Cast to inform their stocking decisions, see Voth (2018).