COLLEGE OF AGRICULTURE, LIFE SCIENCES AND NATURAL RESOURCES 2022 RESEARCH REPORT

REFLECTIONS

In this issue,

our scientists explore. . .

Water bears

A moose mystery

Food security issues

. . .and more

UNIVERSITY OF WYOMING

University of Wyoming | College of Agriculture, Life Sciences and Natural Resources

REFLECTIONS

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Search Wyoming Agricultural Experiment Station

From the Director


Eric Webster

I am excited about the future of the University of Wyoming College of Agriculture, Life Sciences and Natural Resources and the Wyoming Agricultural Experiment Station. There will be major changes within the college in the next few months. The Zoology and Physiology Department and the Botany Department will be moving the college, and the Life Science Program will also be moving. A new name was selected for the college, and I can assure you, our mission to serve Wyoming agriculture will not change. In fact, I believe this reorganization will allow the college to expand and enhance our ability to serve our stakeholders.

The 2022 edition of Reflections contains research that has been conducted across all the departments within the College of Agriculture, Life Sciences and Natural Resources. The research presented by the scientists in this edition will directly impact the citizens of the state and beyond, and I hope that everyone will find something useful to their interests.

On a more somber note, March 17, 2022, the college lost a valuable faculty member, Dr. Jay Norton, in an avalanche in the Teton backcountry. I did not get the opportunity to get to know Jay as well as I would have liked; however, he and I had several meetings in my short time at UW. Jay had become a friend in that brief time, and I could tell how much he loved the outdoors, and how well-liked and respected he was by everyone who knew him. We've included a short tribute to Jay on page 33.

As always, we welcome your input, so please feel free to reach out to me with your comments, suggestions, and questions at aes@uwyo.edu.

Eric Webster
Associate Dean and Director
Wyoming Agricultural Experiment Station

LESSONS FROM NATURE

How a microscopic animal is helping to stabilize pharmaceuticals and send humans into space

By Thomas Boothby
Assistant Professor
Department of Molecular Biology

On a windy Wyoming morning, a documentary film crew is clustered around a makeshift lab bench and microscope at the base of the Boar's Tusk in Wyoming's Red Desert. Like many folks, the team has come to Wyoming to go hunting. But we aren't looking for elk or pronghorn. We are on a bear hunt—a water bear hunt, to be precise.

Wait… What's a water bear?

Water bears, as they are commonly known, or tardigrades to scientists, are a group of microscopic, eight-legged animals. Despite being some of the smallest known animals, water bears are extremely tough—tough enough to survive for years after being dried to a crisp, frozen, and heated up past the boiling point of water. Water bears tolerate thousands of times the radiation that humans can, and they will survive for weeks with little or no oxygen. In fact, water bears are tough enough to survive prolonged exposure to the vacuum of outer space—a feat no other animal has accomplished!

Wyomingites are no strangers to organisms that can survive in extreme environments. Yellowstone is famous for its hot springs and geysers that harbor microbes that thrive in harsh conditions. But instead of thriving under harsh conditions, water bears have evolved to tolerate extremes by entering a state of suspended animation, in which they shut down all their life processes by going into stasis, until favorable conditions return. Whether a day or

Scientists led an international documentary film crew on a 'water bear hunt' in Wyoming's Red Desert. The film crew then followed the scientists as they sent tiny water bears from Wyoming to Florida's Kennedy Space Center, then on to the International Space Station.

2022 SELECTED TOP FACULTY STORY

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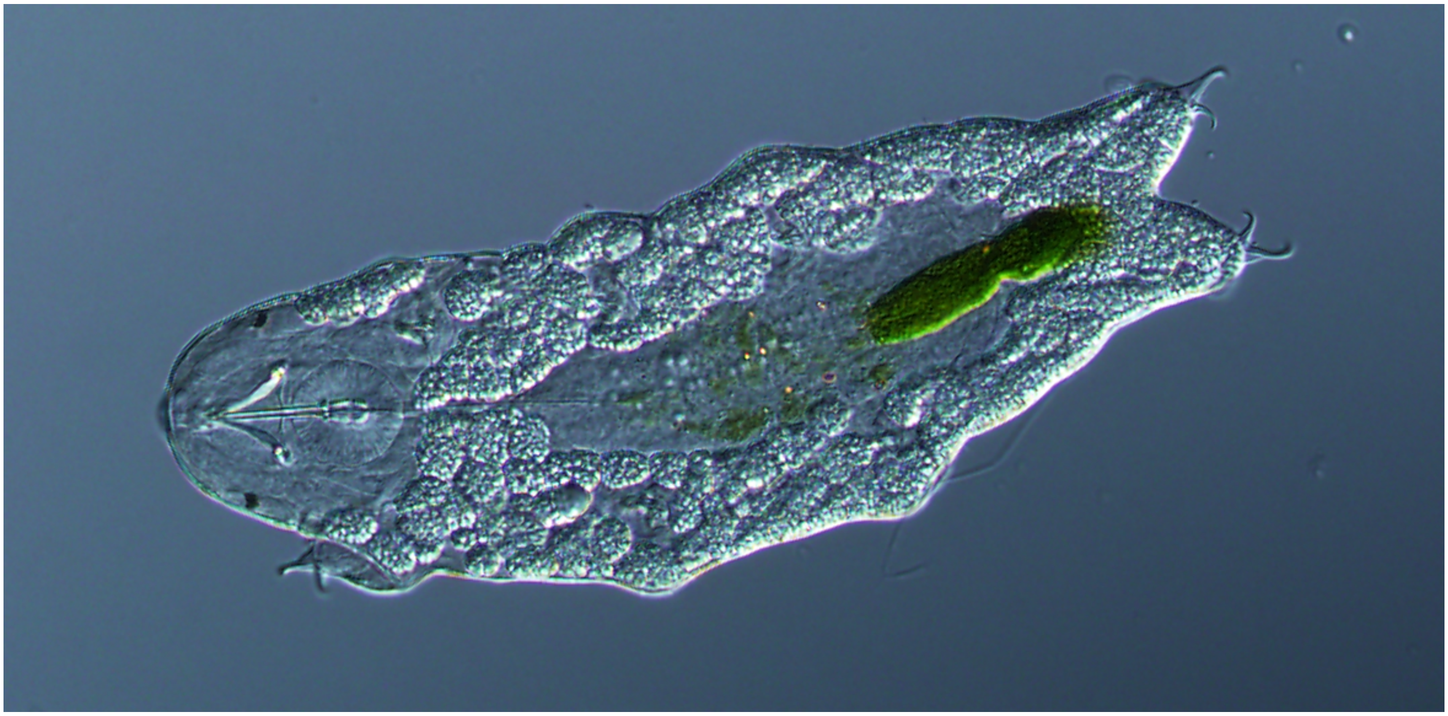
a decade later, these tiny animals can spring back to life as if nothing happened once their environment becomes hospitable again.

While the microbes in Yellowstone's hot springs have been studied for decades, almost nothing is known about water bears in Wyoming. In fact, despite finding water bears almost everywhere we have looked, from the mountains to the desert to the UW campus, only one species of tardigrade has been formally described in Wyoming.

My lab's research focuses on understanding what makes these tiny animals so tough, how they enter and exit stasis, and how we can use this practical knowledge to tackle real-world problems.

What can we learn from studying water bears?

Understanding what makes the diminutive water bear so tough will help us to understand fundamental biological questions, such as how organisms evolve



A typical water bear, tardigrade. Water bears are some of the smallest animals known to science, yet they also are one of the toughest. The author's lab studies these small but mighty animals to try to figure out what makes them so robust.

and adapt to new or changing environments. In addition, understanding how organisms survive extreme conditions here in Wyoming, and how extreme those conditions can be, is helping to guide our search for new forms of life, both on Earth and elsewhere in our universe.

Beyond helping us answer fundamental questions, we study water bears for the many potential medical and agricultural biotechnologies that could emerge from understanding what makes these organisms so hardy. For example, if we understand the tricks tardigrades use to stabilize their sensitive cellular components, like proteins and RNA, we might one day develop better ways to stabilize protein- and RNA-based vaccines or crops that can tolerate harsher, more extreme weather such as freezing and drought. But first we need to understand exactly what makes tardigrades so tough.

What makes water bears so tough?

To start to decipher how water bears survive in extreme environments, we studied which portions of their DNA, or genes, they use when exposed to stresses such as drying or freezing. DNA is a molecule that serves as the blueprint for an organism, encoding directions for making other functional molecules, such as proteins, that carry out specific tasks within cells. When we looked at which of these molecular blueprints tardigrades use when stressed, we found something exciting—tardigrades make lots and lots of a very special type of protein.

The SpaceX CRS-23 lifts off from the Kennedy Space Center carrying Wyoming water bear astronauts to the International Space Station.

These special proteins are found only in water bears, meaning organisms such as humans, plants, or bacteria do not have them. When we used genetic techniques to disrupt these proteins, the tough little tardigrades became not-so-tough and could not survive extremes, such as being dried out.

Our experiments have shown that water bears require special proteins to survive extremes, but can those proteins make other organisms as tough as water bears? To answer this question, we attempted to modify bacteria and yeast to make them produce water bear proteins. When we introduced water bear proteins into other organisms, those organisms suddenly became up to 100 times more tolerant to being dried out than they were without the proteins.

Finally, to see if these tardigrade proteins might be protective all by themselves, we figured out a way to isolate and purify them. We found that mixing our water bear proteins with sensitive biological material prevented it from breaking down when frozen or dried.

How can studying water bears help solve real-world problems?

To identify real-world applications for our understanding of tardigrade stress tolerance, we have been working with the Defense

Advanced Research Projects Agency to develop ways to store human blood in a dry, unrefrigerated state. Whole blood is extremely sensitive, requiring special cold-storage conditions and chemicals to stabilize it. Even under ideal conditions, whole human blood can only be stored for about 31 days. If conditions are not ideal, the blood can start to degrade in seconds. If we could increase the shelf-life of blood and make it easier to maintain in a range of different environments, medical personnel would have easier access to lifesaving supplies during natural disasters, wars and other austere circumstances.

We also are working to develop new ways to store life-saving pharmaceuticals, such as vaccines, in a dry state without the need for refrigeration or even electricity. This would be particularly useful in remote or developing parts of the world where it can be difficult or impossible to find and maintain the equipment and infrastructure needed to keep vaccines cold and stabilized.

The final frontier

Back in Wyoming's Red Desert, the documentary crew is wrapping up a long day of filming and hunting for water bears. They have come to Wyoming to cover our preparations to launch our water bears into space, and in August 2021, that is exactly what we did. Our tiny, robust water bears traveled from Wyoming to the Kennedy Space Center, then up to the International Space Station. Onboard the Space Station, an international team fed and monitored our animals for two months, long enough for these fast-reproducing animals to produce four generations of offspring.

The purpose of our mission was to monitor how water bears deal with the stress of space travel over multiple generations, important because space is an extremely inhospitable place for organisms—like humans—that evolved on Earth. The lack of gravity and increased radiation in space are extremely detrimental to our health and biology—but tardigrades don't seem to mind. By studying how water bears cope with the stresses of spaceflight, we hope to develop therapies and countermeasures to safeguard astronauts on extended missions to deep space.

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The water bear experiment's official NASA Mission Patch.

Mission specialist Akihiko Hoshide prepares to perform an experiment with water bears in microgravity onboard the International Space Station.

THE RURAL CHALLENGE

How data suppression affects opportunity in small-town America

By Anders Van Sandt
Assistant Professor & Extension Specialist
Department of Agricultural & Applied Economics

THE LACK OF RELIABLE DATA BECOMES CRITICAL WHEN A SMALL TOWN IS ASSESSING OPPORTUNITIES AND CHALLENGES FOR LOCAL INDUSTRIES

Driving across rural America brings warm feelings of simplicity, beauty and serenity. Many of these communities, however, are just a shadow of their former selves from just a generation ago. Consolidation and concentration in agriculture have increased to the point where farms require less labor. At the same time, local markets are more globally entwined, and our once-local supply chains now stretch across states and continents. All this has changed the economic composition of our rural communities, and many are faced with declining per capita income, shrinking populations and most importantly, a feeling of hopelessness that seems to clash with an otherwise rich sense of community.

Revitalizing rural communities requires a better understanding of how to create economic opportunities, but economic development professionals agree that this is no small challenge.

Growing up in rural America, I was never bothered by these thoughts. I remember exploring lost logging roads, bucking hay and floating the river without concern. I may not be able to prevent these memories from fading with time, but I have devoted my career to preventing these places from fading from memory.

The challenges of data suppression

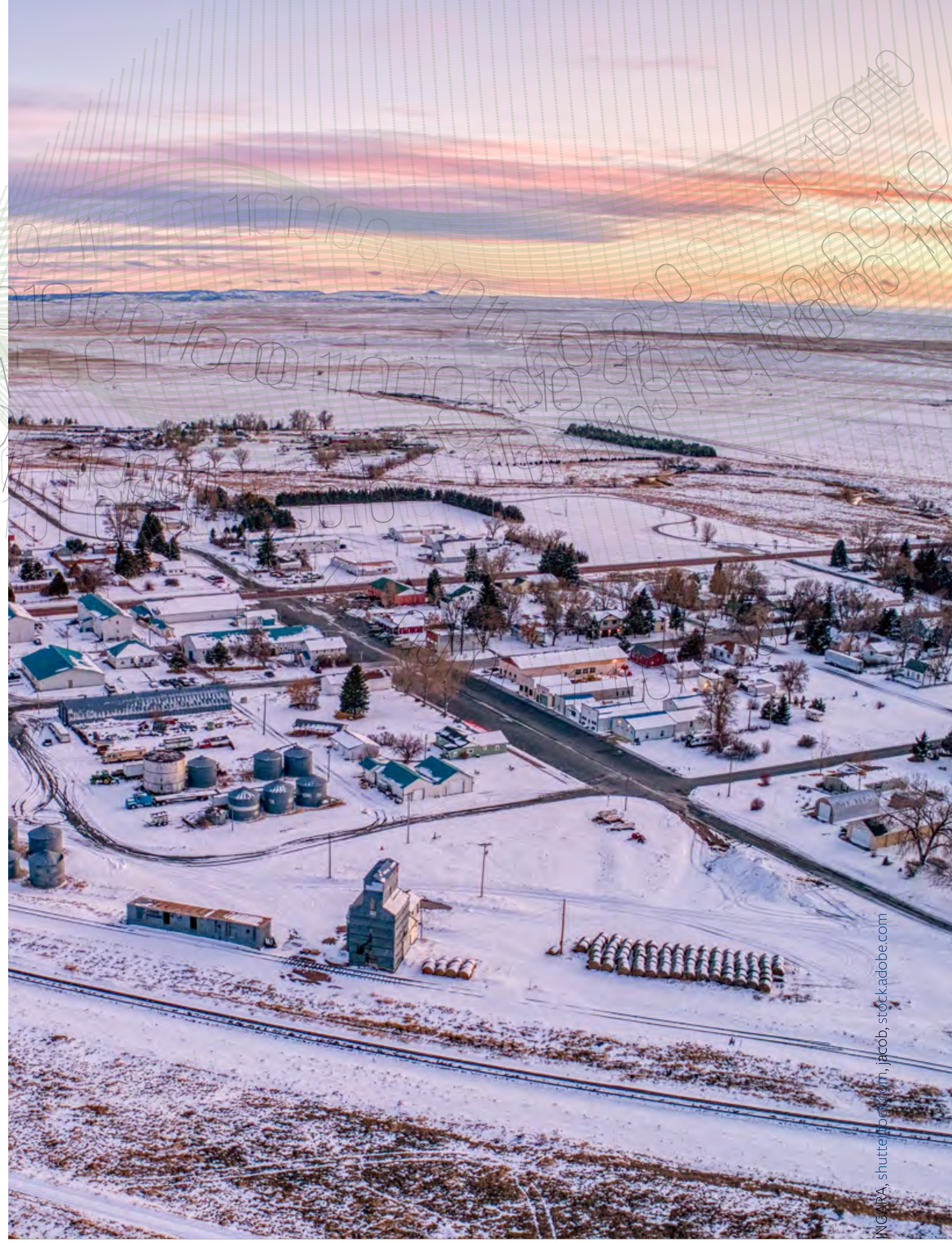
Because of reduced budgets and in an effort to maintain business and individual privacy, U.S. government statistical agencies are increasingly suppressing large portions of otherwise publicly available datasets. Unfortunately, the small sample sizes of rural communities and industries causes them to be disproportionately affected by suppressed economic data, which makes it difficult for economic development practitioners to understand the nuanced challenges they face. Using heavily suppressed data may even lead to inaccurate conclusions that could further harm rural communities. Indeed, our research has found that economic model estimates based on publicly available employment data may be biased by up to 82%, and we expect the higher privacy standards applied to data from recent years to cause an even larger bias.

The lack of reliable data becomes critical when a small town is assessing opportunities and challenges for local industries. For example, access to healthcare is a growing concern in the

United States; however, there is a proportional lack of research on healthcare establishment location decisions, largely because of the lack of reliable data. This need for data and the issue of local data reliability is visible in Figure 1, which shows the differences in physician practices and physician employment across rural and urban areas in the United States using public and restricted-access data. Two observations stand out: First, the opposite trends between micropolitan and metropolitan counties; and second, the gaps between the public and restricted-access data trends.

Over time, the number of medical practices in rural counties has decreased, although the number of health care professionals working in medical practices in those counties has increased. This is caused by the consolidation of small, local physician practices into larger, regional healthcare facilities that are fewer in number and therefore less accessible to rural residents. Regardless of innovations such as telehealth, the data are clear—access to physical healthcare in rural counties is decreasing.

These trends are persistent, but in recent years, data suppression has created even larger disparities between public and restricted data, which prevents rural community leaders and local economic development practitioners from solving present-day challenges and exacts a real toll on economic development and the future of rural America.



An aerial view of La Grange, Wyoming.

The challenges of rural healthcare

What are we able to say about the locations of rural healthcare facilities when we can access the true data? First, we see a decline in the number of rural healthcare practices as shown in Figure 1, page 8. Second, we see patterns in the locations of new healthcare facilities, indicating that location decisions are being driven in part by economics. And while these decisions can make good economic sense, they also can create a catch-22 for rural residents.

For example, new hospitals are more likely to be built on the

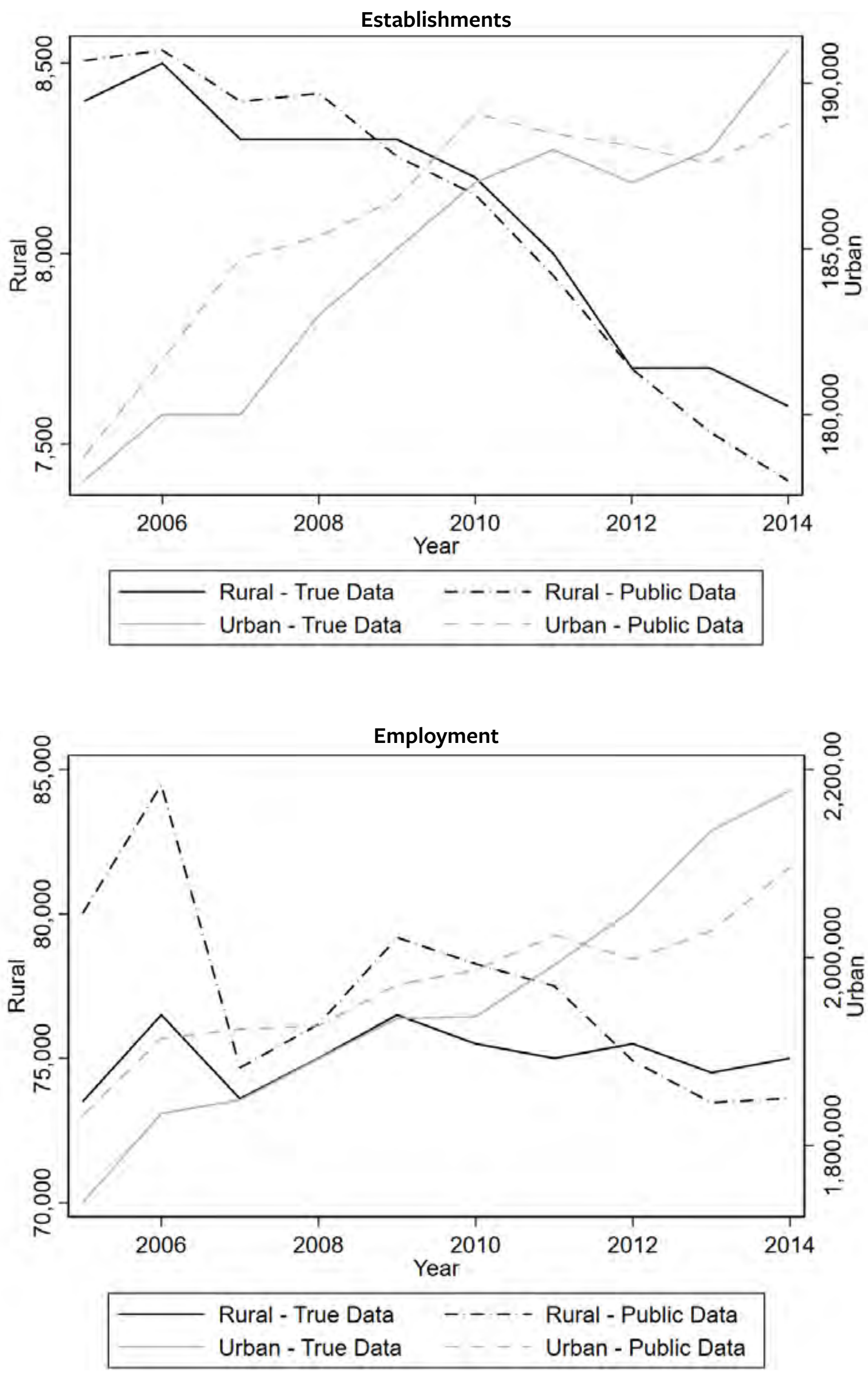


Figure 1. Physician establishments and employment across rural (black) and urban (gray) areas in the U.S. using public (dashed) and restricted-access data (solid).

outskirts of urban centers where there is cheaper land and greater highway access. The way we pay for healthcare also influences the locations of healthcare facilities. Our research indicates optometry offices are less likely to be located in counties with higher shares of senior citizens and people with disabilities, likely due to the fact that Medicare does not cover routine eye exams and glasses, making rural optometry practices less profitable.

These negative effects worsen in rural counties with high shares of Medicare or Medicaid recipients. Access to physical healthcare providers such as physicians, dentists and hospitals decreases further, while access to ambulance services, outpatient mental health/substance abuse centers and home health services actually increases. Although the increase in these types of healthcare services may seem positive, they focus primarily on transporting patients to hospitals in urban areas, providing end-of-life care and treating substance abuse such as opioid dependency, which has hit rural communities particularly hard. None of these services include significant preventative or routine care.

Opportunities through rural-urban linkages

Despite the data challenges, researchers and economic development practitioners continue to identify opportunities for greater economic growth that could enable rural communities to attract some of the services they have lost. For example, if rural communities can tie themselves to the economic activity of cities, that symbiotic relationship may lead to more balanced growth, as a rising tide lifts all boats. We have identified three ways to do this: agritourism, data processing centers and food manufacturing. Agritourism encourages urban residents to visit and spend tourism dollars in agricultural communities that offer fresh food, clean air and scenic views. When data processing centers locate in rural areas, they save money on land, energy and labor, while boosting employment rates and per capita income. Food manufacturing facilities create similar outcomes when located up to 100 miles outside an urban center. Supporting these industries through forward-looking policies may lead to potentially fruitful economic development paths for agrarian and energy-centered rural economies, allowing them to once again attract vital industries, such as healthcare.

No single solution

Rural communities face many challenges when it comes to economic development. The first is accessing reliable data to inform effective economic development strategies. As data suppression increases, unintended consequences are hampering rural economic developers more than their urban counterparts. This results in limited or misleading prescriptions for economic opportunity and lopsided growth. Even with reliable data, rural economic development is further limited by poor economic conditions such as higher numbers of uninsured and less healthy residents.

There are many hazards along the path to rural prosperity; however, if we can listen, collaborate, and provide rural communities with the necessary tools to navigate this new economy, their ingenuity and grit will enable them to blaze their own trails. Agritourism, datacenters and value-added agriculture may work for some communities, but there is no one-size-fits-all solution.

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Agritourism attracts visitors to agricultural communities.

FEEDING THE

CAN FUNCTIONAL GENOMICS BE USED

By Jeremy Block
Assistant Professor
Department of Animal Science

REPRODUCTIVE EFFICIENCY IS AN IMPORTANT ECONOMIC FACTOR IN LIVESTOCK PRODUCTION

With the global population projected to exceed 10 billion people by the year 2050, the demand for animal-derived proteins such as meat and milk also is expected to significantly increase. To meet that demand, we must figure out how to improve the efficiency of livestock production by developing critical, new management strategies and technologies.

Fertility, or reproductive efficiency, is one of the most important economic factors in livestock production; however, reproduction remains relatively inefficient in most livestock species. Nearly half of all beef cows and well over half of all dairy cows will not become pregnant within the first month after they are bred.

One of my laboratory's primary research goals is to understand what differentiates an embryo that can establish pregnancy from one that cannot. In collaboration with scientists at the University of Florida, we sought to determine whether the quantity of certain genes that are important for development differs between embryos that are able to establish pregnancy and those that fail. Not only did our experiment help distinguish genetic differences between viable and nonviable embryos, we also were able to identify the specific genes that influence embryo development.

The critical first weeks

Approximately 60–80% of pregnancy loss in cattle occurs within the first three weeks of gestation. During this time, several important developmental events must occur for pregnancy to continue (Figure 1).

In the first seven days following fertilization, the embryo, which starts out with only two cells, must undergo a series of cell divisions that result in an embryo with about 150 to 200 cells. In addition to cell growth, at this stage the embryo must undergo its first differentiation, which results in two distinct cell types, those that will develop into the placenta and those that will develop into the fetus.

At the end of the first week of development, the embryo must hatch from its protective shell and undergo a period of significant elongation. Around day 12 of gestation, the cattle embryo is a tiny, football-shaped structure approximately 1–2 mm in length, but by day 16, the embryo transforms into a string-like structure that can measure up to 60 cm in length. This elongation during the second week of gestation is important for future

FUTURE

TO IMPROVE FERTILITY IN CATTLE?

development of the placenta and is necessary for what we call "maternal recognition of pregnancy." Near day 16 of gestation, the embryo must secrete a factor that lets the mother know it is viable and present in the uterus, so she does not return to estrus, or heat.

As the embryo enters the third week of gestation, placental development is now fully underway, and the placenta starts to attach to the lining of the uterus. Attachment is critical for continued pregnancy and fetal development because it allows the mother to share vital nutrients with her developing offspring.

Factors that determine success or failure

Although we know that the vast majority of pregnancy failures occur within the first few weeks of gestation, it can be difficult to determine the cause. In cattle, pregnancy cannot accurately be diagnosed until the start of the fourth week of gestation, and earlier pregnancy failures are difficult to assess.

One important factor of many that affect the establishment and maintenance of pregnancy is genetics. The egg from the dam and the sperm from the sire both contribute genes that regulate early embryo development and are necessary for survival. Another important factor is the maternal environment, including the oviduct and uterus, two components of the female reproductive system that secrete factors to support early embryo development. These factors include various classes of molecules, such as growth factors, hormones

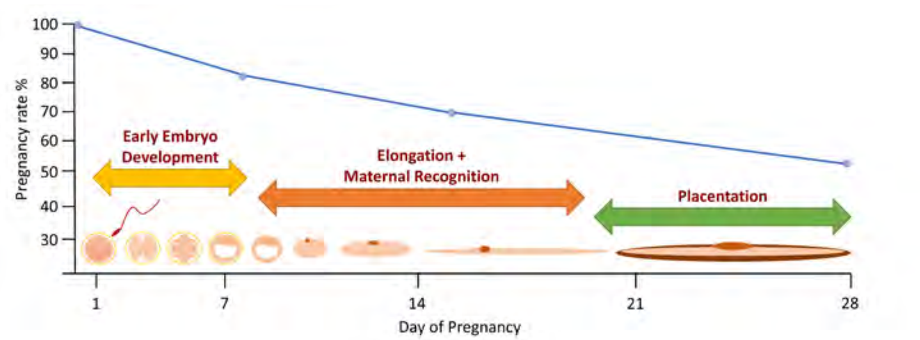

Figure 1. Developmental events that occur in the first month of pregnancy in cattle alongside the typical pregnancy rate relative to day of gestation.

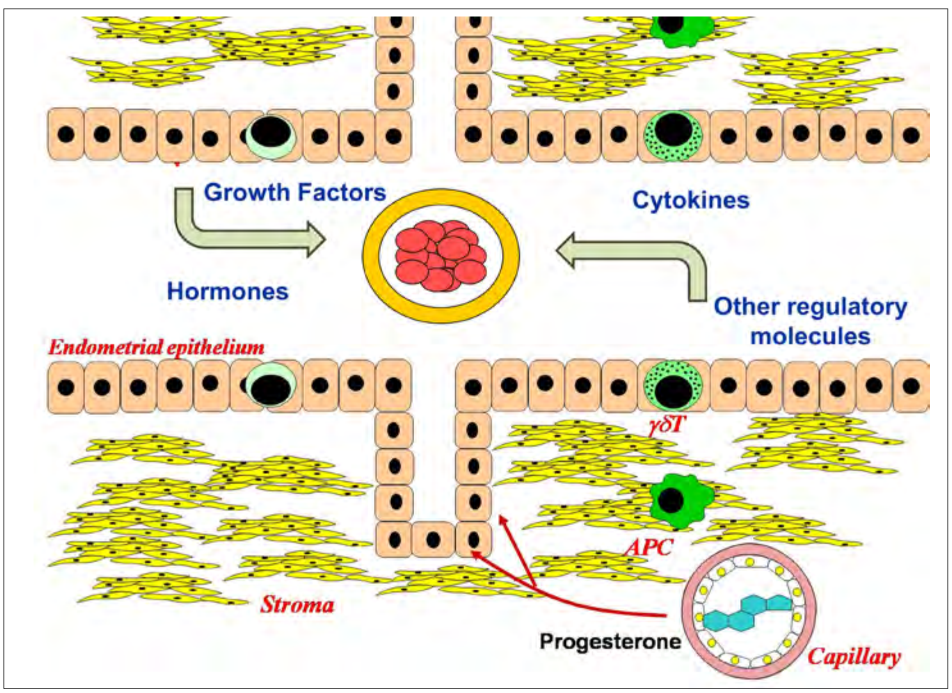

Figure 2. Maternal signals from the uterus that regulate early embryo development.

and metabolites (Figure 2). But even when the oviduct and uterus provide a favorable environment for embryo survival, the embryo itself must be able to appropriately respond to maternal signals.

Genes associated with embryo survival

In our experiment, we stimulated a group of virgin heifers with hormones to make them ovulate multiple eggs that could be fertilized using artificial insemination then develop into embryos. One week after insemination, embryos were retrieved from the uteri of the heifer donors and split in half using a microblade system (Figure 3). One half of the embryo was immediately transferred to a surrogate heifer (one half per surrogate), and the other half was frozen for gene expression analysis.

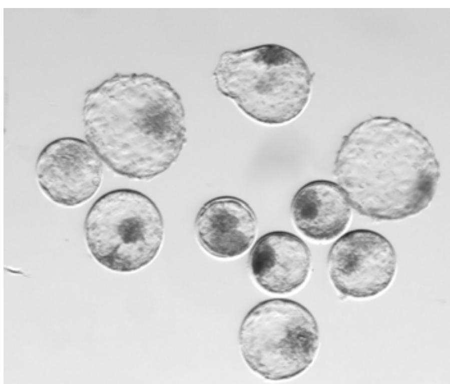

Figure 3. Cattle embryos at 7 days gestation (top). An embryo is split in half using a microblade (bottom).

We diagnosed pregnancies in the heifer surrogates at days 30 and 60 of gestation and analyzed the global gene expression patterns of the corresponding frozen embryo halves. We compared the embryos that successfully established and maintained a pregnancy with those that did not. By analyzing the data, we determined that 155 genes were differentially expressed between the two experimental groups, with 73 genes upregulated and 82 genes downregulated in embryos that successfully established and maintained pregnancy compared to embryos that failed to establish pregnancy.

Interestingly, many of the genes that were more abundant in the viable embryos were receptors for various regulatory molecules secreted by the oviduct or the uterus during early pregnancy. Our results suggest that embryos are more likely to survive if they are better able to respond to maternal signals that support their development.

We also found that many of the genes that were less abundant in viable embryos were linked to metabolic activity. The most competent embryos were less metabolically active, indicating that increased metabolic activity is associated with reduced viability.

The future of gene editing

Moving forward, my laboratory will work to utilize functional genomics tools, such as gene editing, to explain the importance of some of the genes that were differentially regulated.

Gene editing has been used for many years in research that uses rodent models, but only recently has it been used effectively in studies of large animal species, such as livestock. It can be used to insert, delete or modify specific genes related to embryo viability, to more effectively determine their roles in development and survival.

We hope that the findings from our research will enable us to develop applied approaches and technologies that cattle producers can use to improve reproductive efficiency in their herds and meet the future supply demands of our growing global population.

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BIOCONTROL OF RUSSIAN KNAPWEED IN WYOMING

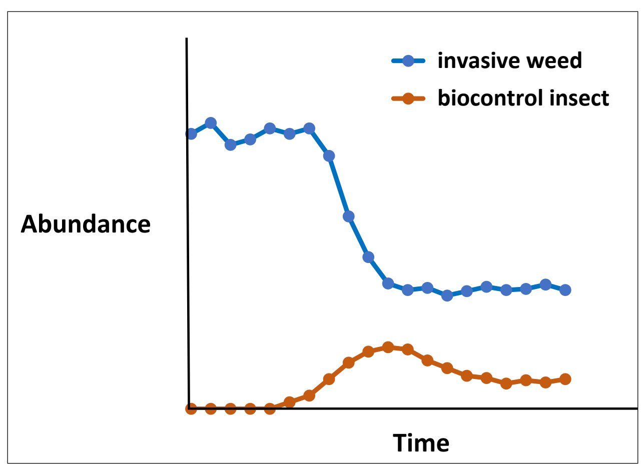
Is it working?

By Timothy Collier
Associate Professor
Department of Ecosystem Science & Management

For ranchers in Wyoming and throughout the West, non-native weeds often are a frustrating and severe threat to rangeland health and livestock production. When non-native weed species invade, ranchers can be hit with a double-whammy—weeds that are both unpalatable or toxic to horses and cattle and likely to reduce the abundance of high-quality forage.

Russian knapweed (Figure 1) is a widespread, invasive weed that has been in Wyoming since the late 1800s, when it probably was introduced as a contaminant of alfalfa seed. Its native range consists of central Asia, from Turkey east to China, and Iran north to southern Russia. Cattle tend not to eat Russian knapweed, and it is poisonous to horses, sometimes fatally. According to estimates from the Wyoming Weed and Pest Council, 21 of 23 counties have Russian knapweed, encompassing as much as 100,000 acres.

In the 1990s, the Wyoming Weed and Pest Council started to fund a "biological control" or "biocontrol" program for Russian knapweed. Biocontrol is the importation of insect herbivores from the weed's native range. Ideally, the weed biocontrol process should resemble



◄**Figure 1.** Russian knapweed, *Rhaponticum repens.*

Figure 2. In the ideal outcome of weed biocontrol, the imported biocontrol insect suppresses the abundance of the invasive weed.

the graph in Figure 2. Initially, the weed occurs at damaging levels, but after the biocontrol insect is introduced, weed abundance declines dramatically. After introduction, the insect population grows but then declines as weed abundance decreases, although the decline in the insect population occurs with what is called a "lag," i.e., it declines after the weed does. In the long term, however, the insect continues to reproduce, damage the weed and spread on its own, so suppression of the weed occurs indefinitely over large areas.

Overseas research for the Russian knapweed biocontrol program was conducted by the non-profit Center for Agriculture and Bioscience International. Insect surveys by CABI in central Asia identified a half-dozen species of insects that feed on Russian knapweed, including the knapweed midge, *Jaapiella ivannikovi* (Figure 3). About the size of a mosquito, knapweed midges lay their eggs on Russian knapweed shoot tips, causing a "gall." Each gall is a spherical bunch of distorted plant tissue, within which the midge larvae shelter, feed and grow (Figure 4). Galls negatively affect the weed by diverting nutrients and energy needed for plant growth and reproduction.

According to CABI research, the knapweed midge is specific to Russian knapweed and one other Asian plant species, garden cornflower. Garden cornflower is an ornamental species that is grown in the United States, but like Russian knapweed, it is considered an invasive weed. Based on the data collected by CABI, the U.S. Department of Agriculture approved importation of the knapweed midge. Midges were collected in Uzbekistan, reared through multiple generations in a quarantine facility at Montana State University, then released for the first time in Wyoming at a site near Riverton in May 2009 (Figure 5).

Since that initial release, and with funding from the Wyoming Weed and Pest Council and the U.S. Department of Agriculture, I have continued to release knapweed midges at new sites across Wyoming. I also have been researching the population dynamics of Russian knapweed and the midge at the first site near Riverton. From 2014 to 2018, and again in 2021, I surveyed populations in 60 research plots by counting knapweed shoots in the spring, then counting galls and galled

CABI.org

Figure 3. Adult gall midge, *Jaapiella ivannikovi.*

Timothy Collier, University of Wyoming

Figure 4. *Jaapiella* midge gall.

shoots every three weeks from June through August.

My research shows that the number of Russian knapweed shoots has declined since 2017 (Figure 6). Although the graph resembles the idealized process of weed biocontrol depicted in Figure 2, a notable difference is that the decline in midge abundance seems to have occurred at the same time as the decline in knapweed abundance, rather than with the expected lag.

Data for 2019 and 2020 may have shed more light on the relative timing of the declines, but the pattern I observed still is broadly consistent with effective biological control. Surveys are on-going in 2022 and beyond. It will be interesting to see if the pattern of lower Russian knapweed abundance persists.

There is good reason, however, to be cautious about interpreting the decline in Russian knapweed abundance in this way. The data are from a single site and did not include a control group of survey plots where the knapweed midge was absent. It therefore is possible that some factor other than the midge may explain the decline in knapweed abundance.

Using data from the Western Regional Climate Center, I explored the potential effects of precipitation, which can have significant effects on weed abundance. I discovered that when knapweed abundance was at its peak in summer 2017, the preceding eight months (October–May) were particularly wet. Relative to October–May precipitation from 1930–2021, precipitation prior to summer 2017 was 2.5 times greater than average. Precipitation during the October–May period prior to summer 2016, another high point in knapweed abundance, was twice as high as average.

Timothy Collier, University of Wyoming

Figure 5. Research site of Wyoming's first Russian knapweed midge release, a few miles north of Riverton, Wyoming. Most of the light green and gold vegetation from the foreground to the cottonwood trees is Russian knapweed.

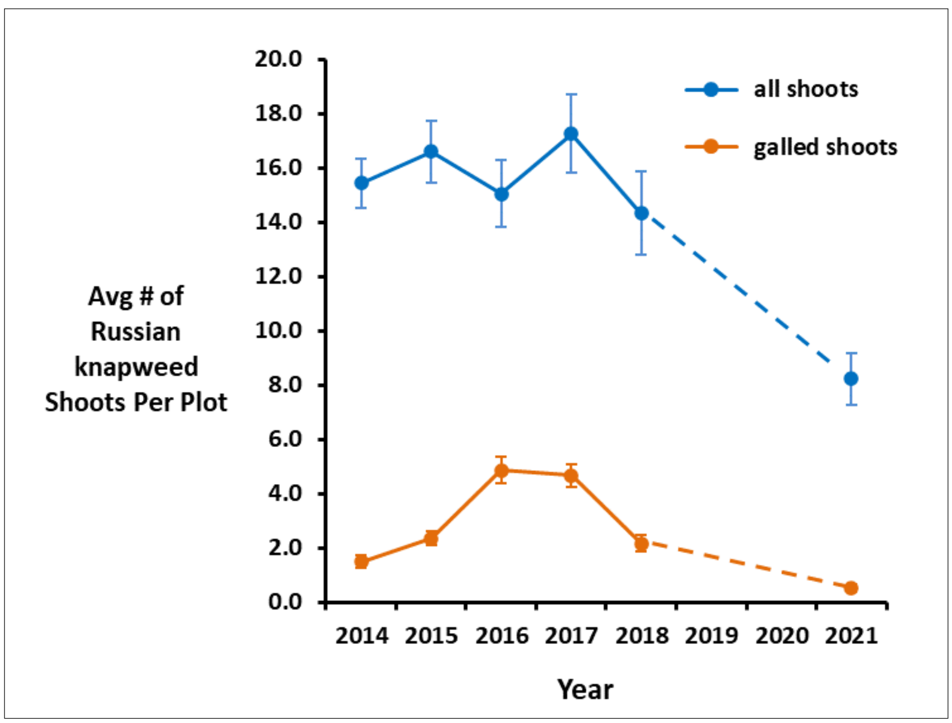


Figure 6. Results of population surveys at the research site near Riverton. Points represent average numbers of shoots across 60 plots with statistical error bars, aka "standard errors of the mean." Surveys were not conducted in 2019 and 2020.

By contrast, during the winter and spring prior to the 2021 surveys, precipitation was a bit less than average (90% of the average since 1930) and Russian knapweed shoot abundance had fallen to the lowest level that I have observed so far. In fact, across all the survey years, there was a broad correlation between knapweed abundance and October–May precipitation, with more knapweed shoots present in wetter periods. This points to the possibility that Russian knapweed may have declined, not because of the suppressive effects of the midge, but due to lower precipitation in 2021.

Eric Coombs, Oregon Department of Agriculture, Bugwood.org

Figure 7. Adult gall wasp, *Aulacidea acroptilonica.*

CABI.org

Figure 8. Adult jumping weevil, *Pseudorchestes sericeus.*

So, is Russian knapweed biocontrol working? Possibly, but the jury is still out. More time and more population surveys are needed. If biocontrol is working, then the abundance of both knapweed shoots and galled shoots eventually should level off, as in Figure 2. However, a rebound in knapweed density and/or a continued decline in the population of already-scarce midges would suggest otherwise.

Finally, it is worth mentioning that another insect biocontrol agent has been released in Wyoming and has established self-sustaining populations. The agent is a gall-forming wasp called *Aulacidea acroptilonica* (Figure 7), also from Uzbekistan. The gall wasp is beginning to appear in my research plots near Riverton, although it is still relatively rare. At other sites in Wyoming, the gall wasp has increased substantially in abundance, and early-stage surveys of this species are ongoing. The Wyoming Weed and Pest Council also is funding CABI to conduct overseas research on a new potential biological control agent for Russian knapweed—an Uzbek species of "jumping" weevil (Figure 8) that damages knapweed leaves. Clearly, there is cause for optimism. Biocontrol of Russian knapweed is proceeding well, and hopefully the impacts of one or all of these agents will one day mean that Wyoming livestock producers will have fewer problems with this troublesome, invasive weed.

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SERVING THOSE WHO HAVE SERVED

Improving food security among military-connected students

By Jill Fabricius Keith
Assistant Professor

Kerry Ray Schinkel, II
Graduate Student
Department of Family & Consumer Sciences

Collaborators: *Rachael Budowle, Assistant Professor, Haub School; Boyi Dai, Associate Professor, Kinesiology & Health; Cody Gifford, Assistant Professor, Animal Science; Christine Porter, Professor, Kinesiology & Health*

Erin Cadigan, stock.adobe.com

People with limited or uncertain access to adequate food experience food insecurity. Over the past decade, food insecurity affected 11% to 15% of U.S. households. U.S. military veterans face risks of food insecurity similar to those of the overall U.S. population, but veterans with children are much more likely to have very low food security, as are younger veterans who served in the wars in Iraq and/or Afghanistan. In 2020, we conducted a survey and conversations with military-connected students at the University of Wyoming in order to increase understanding of military-connected student food insecurity experiences and develop potential strategies to address food access.

Why should we care?

When military members return from service and transition back into civilian life, many use benefits awarded for military service by the U.S. Armed Forces to pursue advanced education. Two-thirds of today's U.S. veterans have enrolled in at least some post-secondary education, and college students in general experience high food insecurity rates, with many enduring very low food security. A 2017 survey of undergraduate students at UW showed that 37% of students experienced food insecurity. Student food insecurity is associated with anxiety, depression, homelessness, lower grades and higher drop-out rates.

In 2019–2020, 277 students at UW received military-related education benefits or assistance, and more than 600 military-connected students were enrolled. Veterans with college degrees earn a higher average salary compared to their peers without a college degree, positioning them for higher food security. However, returning from service poses barriers to success in higher education, including mental health stigma, food insecurity and integration into college settings.[1]

In the United States, 41% of student veterans attending four-year colleges have reported food insecurity, but knowledge about food security among

military-connected students is limited. The 2017 student survey at UW did not include graduate students or evaluate food insecurity among veterans and other military-connected students.

What did we do?

We asked students to share information about their demographics, their food consumption and access, and food insecurity among military-connected students, including ideas for improving food security and insights into food resources on campus.

Our project originated in the UW Food Security Taskforce, www.uwyo.edu/food-security, which identified the need for a detailed assessment of food security among UW students, including the demographic distribution of the problem and students' desired strategies to address it. We sent out a survey in spring 2020 to all UW students, and in fall 2020, we talked to military-connected students through focus groups. Among military-connected students, 127 responded to the survey and eight participated in focus groups, providing insight and feedback about food security, access and resources.

Who participated?

Most military-connected respondents were full-time, undergraduate students who did not live in campus or university housing. Select military-connected student

Table 1. Demographics of Military-Connected Student Survey Respondents at the University of Wyoming in spring 2020 (n=127).

Demographics	Responses	Demographics	Responses
Armed Forces Identity		**Commissioned Officer**	
Current Active Duty	2 (1.6%)	Yes	29 (22.8%)
Reserve Officers' Training Corp	8 (6.3%)	No	89 (70.1%)
Veteran	31 (24.4%)	No response	6 (4.7%)
Reservist (all branches)	5 (3.9%)	Other	3 (2.3%)
Guardsmen (Army or Air)	9 (7.1%)	**Service Branch or Sponsor Branch**	
Dependent (child or spouse)	71 (55.9%)	Army	32 (25.1%)
Other (e.g., widow)	1 (0%)	Navy	15 (11.8%)
Years of Service		Marine Corps	8 (6.2%)
1–4	46 (36.2%)	Coast Guard	7 (5.5%)
5–10	31 (24.4%)	Air Force	29 (22.8%)
11–15	5 (3.9%)	Army National Guard	13 (10.2%)
16–20	13 (10.2%)	Air National Guard	7 (5.5%)
21+	21 (16.5%)	Navy Reserves	6 (4.7%)
Other	3 (2.4%)	Marine Reserves	3 (2.3%)
No response	8 (6.3%)	Other	1 (0.8%)
		No response	6 (4.7%)

demographics are presented in Table 1. Compared to other military-connected students, veteran student respondents were older (average age of 38.4 years vs. 25.9 years) and more likely to be living with a spouse/partner (64.5% vs 34.4%).

Eight military-connected students (three female, five male) representing the Army, Navy, Air Force and Marine Corps volunteered for the focus groups. Participants included those who were currently on active duty, in the Reserves or National Guard, and/or retired/veterans, as well as both commissioned officers and enlisted military.

What did we find out?

Of military-connected student survey respondents, 42.5% reported food insecurity. Almost one out of four military-connected students reported personally experiencing shame/stigma "sometimes" or "often" about having access to food. A third of military-connected students said they felt our society attributes shame or stigma "quite a lot" or "a great deal" to people who do not have enough food access. A full report of survey results for UW students is available from the Taskforce survey working group.[2]

Feedback from military-connected students in the focus groups included current and planned food resources, barriers to food security and strategies to promote military-connected student food security. Feelings of both shame and pride emerged as barriers for military-connected students in using services to alleviate food insecurity. At the same time, students' feelings of connection to the military and pride in those connections offered foundations for building food security strategies tailored to reach military-connected students.

Ideas for increasing military-connected students' access to food security services fell into two areas: mitigating shame and risks to pride and tapping into culture and connections associated with the military.

Participants talked about the importance of mitigating shame and preserving pride so that students would be more comfortable using food security support services, including the importance of anonymity in food access resources and the importance of reducing shame associated with using such services. Participants talked about the need to undo this culture of shame with food insecurity and seeking help. Suggestions included efforts to normalize using food access resources and assistance programs including education, communication about food security and resources within the military-connected community, as well as encouragement and support from superiors.

Focus group participants also offered ideas for food security strategies to tap into culture and connect with services specially targeted to military-connected students for both practical access and to match military culture. A summary of information shared by military connected students is provided in Table 2.

Student feedback about UW food security strategies

UW students, faculty and staff are leading efforts to address student food insecurity. At the time of our survey, the UW Food Share Pantry was not yet in operation, and the primary strategy for student food access was through the novel food share cabinets in various buildings around campus. We asked military-connected students about institutional strategies at UW to address food security. Those strategies and the students' rankings of current and proposed UW strategies to address food security are presented in Figure 1. Military-connected students' top-ranked strategy was a centralized on-campus grocery that provides at-cost or subsidized healthy food for students.

Implications for UW students, staff, faculty, administration and alumni

Rates of food insecurity at UW, including among military-connected students, mirror trends among college students in the United States, which are significantly higher than overall national food insecurity rates. Our study suggests that more effectively reaching

1. **Campus grocery store** (weighted score: 5646)
2. **Good food recover and sharing** (weighted score: 5136)
3. **Swipe out hunger** (weighted score: 5042)
4. **Central grocery/pantry blend** (weighted score: 4814)
5. **Growing food on campus** (weighted score: 4311)
6. **More student food share cabinets** (weighted score: 3003)

Note: Weighted scores are out of 6000

Figure 1. Students were asked to rank resources they would most like to see implemented at UW. Each potential or existing food access resource included a short description. All resources received support/interest, with a campus grocery receiving the highest level of support. A campus grocery store was defined as a centralized on-campus grocery store that provides healthy foods with prices that are at-cost or subsidized for students.

military-connected college students with food security measures requires reframing food insecurity as a systemic issue, rather than a personal one associated with shame and erosion of pride. It also suggests offering food security services that are both culturally and practically tailored to the military-connected student population. Developing effective food security support with and for military-connected students is essential for ensuring that the sacrifices they make for their country are only in their service to the Armed Forces, not in feeding themselves and their families.

Ongoing food security work at UW

The UW Food Security Taskforce continues to address student food insecurity, including among military-connected students, through a variety of strategic efforts including:

- Engagement with students, staff and faculty across campus.
- Support and guidance for existing resources (e.g., UW Food Share Pantry, Meal Swipe Sharing).
- Implementation of additional resources (e.g., growing and sharing food with ACRES Student Farm, campus grocery store).
- Management of an information hub/media for food security resources.
- Connections with Wyoming community colleges to develop a statewide network food share pantry, www.uwyo.edu/dos/student-resources/food-pantry.html.

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Table 2. Examples of Significant Statements by UW Military-Connected Students on Food Security.

THEME: BARRIERS
Sub-theme: Pride
P4: "I think the only thing that I foresee sometimes is the private value or the pride factor of the military personnel not wanting to ask for help and not wanting to feel as a lesser human because they have to ask for help."
Sub-theme: Shame
P3: "I'm out of the military, I'm supposed to be an example of what an American is supposed to be, and here I am taking charity now. Are people going to look down on me for this? There is a mental disconnect there that a lot of people won't get over for centralized collection points."
THEME: STRATEGY
Sub-theme: Pride
P8: "I'd have to agree because they kind of have that suck-it-up mentality that comes with military service. Ultimately, [military-connected students] are also resourceful, the obvious solution of getting a job to go along with their education, if possible."
Sub-theme: Military connection
P6: "It would be awesome, just in general and in the country if the community had more veteran discounts or partnerships with local business. That would be cool."
P7: "One thing might be to directly involve individuals or organizations that have money with the VSC so they can directly touch the veterans. Get them aware of what's coming and provide food."

Notes

1 The University of Wyoming Veterans Service Center (VSC) is open to military-connected students and offers a variety of services to support veterans and military-connected students, with a mission of "Serving Those Who Served" (www.uwyo.edu/vetservices/index.html). VSC benefits and services were recognized and promoted by several focus group participants, and this research was supported by and shared with VSC leadership.

2 Schinkel, K., Keith, J., Budowle, R., Dai, B., and Porter, C., 2021. Combating Student Food Insecurity: Spring 2020 Student Food Insecurity Survey Results. University of Wyoming. bit.ly/2020foodinsecuritysurvey

PROTECTING WYOMING'S DRY BEAN PRODUCTION FROM SOIL-BORNE DISEASES

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Department of Plant Sciences

The next time you settle down to enjoy a steaming bowl of chili or a spicy bean burrito, thank a dry bean producer. Dry edible beans, such as pinto, navy, kidney, black and white beans, are grown in 30 states, where 1.34 million acres were harvested in 2021. Wyoming was ranked eighth for dry bean production, according to 2014 data, and is a leading producer of bright, packaging-quality pinto beans. In Wyoming, dry bean production in 2007–2016 ranged from 25,000 acres to 49,000 acres, and the top producing areas were the Big Horn Basin and the Southeast corner of the state. Wyoming also produces certified dry bean seed.

One challenge of dry bean production in Wyoming and neighboring states is soil-borne disease, particularly root rot diseases. Several pathogens cause root rot diseases, and Rhizoctonia and Fusarium root rot are common in our region. The severity of disease depends on environmental conditions, soil compaction, variety

Plant Sciences graduate student Kyle Webber, now with Wyoming Seed Certification, harvests his dry bean plots at the SAREC site.

Close-up of root-rot disease on a dry bean taproot.

and cropping history, and growers have limited options to address these issues. For the past eight seasons, our lab has conducted 11 field studies, including a master's project by graduate student Kyle Webber that investigated ways to manage dry bean root rot. Because more than half of Wyoming's dry bean production is pinto beans, we studied several pinto bean varieties using an integrated approach to root rot disease management.

Dry bean root rot diseases limit root growth, which reduces crop yields. Stress factors such as soil compaction and dry or saturated soil can increase disease severity. Fusarium root rot (*Fusarium solani f. sp. phaseoli*) is found throughout the world in areas where dry beans are grown. Fusarium root rot can almost destroy a bean crop when plants are stressed by drought, soil compaction, soil saturation or oxygen stress.

Fusarium root rot often is found in association with other disease organisms such as *Rhizoctonia solani*, in what we call a disease complex. In a study conducted in Nebraska, respective yield reductions of 52% and 42% for Great Northern beans and pinto beans were observed because of Fusarium root rot. In separate surveys conducted in Colorado in 1971 and 1972, pinto bean field yield losses averaged 27–62%, with some individual field losses as high as 89%. Commonly grown varieties are equally susceptible to root rots in this region, but some varieties are more tolerant to Fusarium infection than other varieties. If producers are going to have reliable yields, we need to continue screening new and existing varieties for tolerance to fungal root rot diseases and explore potential chemical controls.

A Kincaid research plot planter allows for in-furrow fungicide applications and changing of bean varieties while on the go. From left: SAREC farm manager Kevin Madsen, Kyle Webber, and research associate Wendy Cecil.

Testing an integrated approach

Our goal was to determine if a single, in-furrow fungicide application at planting, varietal selection, and deep tillage to alleviate soil compaction would protect the dry bean crop from the effects of soil-borne disease. The specific objectives of our study were to:

- Compare the efficacy of two commercially available in-furrow fungicides for Rhizoctonia and Fusarium disease suppression.
- Evaluate up to five locally adapted pinto bean varieties in the presence of disease.
- Investigate the utility of deep tillage on bean root development and how it affects root disease.

These studies took place over two years, from 2018 to 2019, at the University of Wyoming's Agricultural Experiment Station research sites, Powell Research and Extension Center (PREC) and James C. Hageman Sustainable Agriculture Research and Extension Center (SAREC). With support from Bayer and BASF, we also investigated other fungicides and methods of application in seven separate field fungicide efficacy studies conducted at the UW SAREC research site from 2015 to 2021.

Results… some expected, some surprising, some meh

With our deep-ripping tillage treatments, we were able to reduce soil compaction; however, there were no positive benefits to disease suppression or yield compared to our conventional field preparation. It is widely assumed that dry bean roots can tolerate root rot disease pressure more easily by having a healthy, extensive root system. Bean roots that are suppressed by the compaction layer found in some agricultural fields are much more prone to the effects of soil-borne diseases. Although this is not the first time science didn't back up conventional wisdom, it's possible that the lighter soils found at SAREC and PREC are less prone to soil compaction layers, and the roots were not stressed enough.

Because of genetic variances in breeding, we found significant differences among pinto bean varieties in terms of disease susceptibility and yields (Table 1). Sundance, a newer, slow-darkening variety whose seed does not darken with age on store shelves, had the lowest average disease severity; however, this did not translate to greater yields, most likely due to varietal differences. The other varieties had variable yield results depending on the experimental conditions. Othello, a common variety grown in Wyoming, is very susceptible to root rot infection; however, it was among the highest yielders in the presence of disease. While none of these varieties are resistant to root rot disease (all the varieties tested had 100% of the roots infected to some degree), dry beans in general can compensate for root diseases by producing extra roots once the main tap root becomes rotted. In fact, heavily infected bean plants frequently fail to show any visible above-ground symptoms. All the tested varieties in our studies have displayed very few above-ground symptoms, but under limited water conditions this could be a different story, because the newer roots that develop tend to be shallower than the deeper main tap root.

In-furrow fungicide treatments, in which fungicide is applied in furrows as seed is planted, were for the most part ineffective when used

Table 1. Effects of pinto bean variety on root rot disease severity and seed yield 2018–19 at the SAREC and PREC locations.

	SAREC				PREC			
Variety	Disease severity rating (0–4)		Bean seed yield (lbs./A)		Disease severity rating (0–4)		Bean seed yield (lbs./A)	
	2018	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
Long's Peak	2.4	3.3	1251	1361	2.7	3.1	2812	3763
Montrose	2.6	3.3	1403	1317	3.0	2.9	3420	3999
ND Palomino	2.5	3.4	1535	1325	2.9	3.2	3469	3855
Othello	2.6	3.1	1962	1898	3.2	3.1	3840	3583
Sundance	2.3	3.0	1472	1321	2.5	3.2	3209	3676

Dry bean main taproots affected with root-rot disease. Plots 101 and 102 received no fungicide.

in the integrated study. However, in the fungicide efficacy trials, which investigated different fungicide chemistries than those used in the integrated study, we did reduce early- to mid-season disease by almost 50% in some cases. Despite reductions in disease, in most studies this did not result in yield increases compared to the untreated treatments, and sometimes the fungicide applications hindered bean emergence. In 1 out of 11 studies, we did see significant yield increases with fungicide treatment. Fungicide effectiveness is time-sensitive, meaning once applied in the environment, compounds are subject to degradation and lose effectiveness over time. Unfortunately, these fungal pathogens can continue to attack the bean roots all season long. As a rule of thumb, from our years of experimentation in various cropping and disease situations, fungicide applied as seed treatment results in several weeks of protection, in-furrow applications can protect for up to a month, and in-furrow application plus a foliar application to the leaves can extend protection for 1.5 to 2 months.

So, what have we learned about managing root rot disease in Wyoming's dry beans? Alleviating stressors such as soil compaction only makes sense to keep roots growing and healthy. Lack of effects from our attempts to reduce soil compaction probably were due to the level of compaction we were able to create in our experiment. The degree of soil compaction can vary among soil types, and soils that have higher percentage of clay and silt have more of a problem with soil compaction compared to the lighter soils found at the research sites. Under a true compaction problem that some farming operations can have, reducing compaction should have a positive effect on the health of plants.

As for varieties, it's clear there is room for improvement in terms of increased plant resistance to these root rot organisms. Dry bean disease resistance breeding is an ongoing process, but it is difficult because of the number of genes involved for resistance. In any event, our local varieties, at least in our studies, seem to do relatively well under high disease incidence.

The viability of using fungicides is less clear. We were able to reduce severity, but some fungicides caused some reduced crop emergence and short-lived plant injury. Based on our results, it's difficult to justify the additional expense of in-furrow and foliar fungicide applications. At the bare minimum, growers should use fungicide-treated seed, because it's relatively inexpensive and reduces early infections. Despite some of our disappointing results, we still believe an integrated approach is the best bet to manage dry bean root rot. To better answer these questions, future research is required in field environments that are more conducive to plant stressors so these integrated approaches can be further tested.

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THE MYSTERY OF WYOMING'S VANISHING MOOSE

Could kidney disease be a culprit?

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Although moose populations are expected to fluctuate from year to year, scientists have been concerned about an overall downward trend in North American moose populations in the last few decades. In Wyoming, the estimated statewide moose population was 12,000–13,000 individuals in 1990, but only 3,500–4,000 individuals by the late 2010s. The Jackson-area moose population in northwest Wyoming is experiencing a particularly steep decline, from an estimated population of 3,500 in 1992 to just 400–450 in 2019.

But what is causing these declines? Is a single disease responsible, or are several factors contributing? Do these causes vary by region? The answers to these questions are vital to conservation efforts. Based on past studies of various North American moose populations, there seems to be no single answer, and additional studies are needed to determine what factors are most important among

courtesy of Dirk V. Baker, mountaintinker.net different subpopulations. Possible causes include habitat loss, shifts in local ecology, parasitism, malnutrition, and disturbance by human activity, including roadway collisions.

The Wyoming Game & Fish Department currently is conducting a field study to investigate causes of mortality in the declining Jackson-area moose population. As a veterinary pathologist at the Wyoming State Veterinary Laboratory, I specialize in the diagnosis of animal diseases, and I am collaborating with Wyoming Game & Fish on this project.

Field studies, which investigate conditions as they exist in the natural world, rather than using laboratory-based experiments, are a vital component of wildlife research. Surveys of causes of death (mortality) among wildlife populations are an important step in solving the mystery of population declines. The results of these studies help scientists identify diseases and other factors affecting the health of individual animals in a population. Reviewing this data can help us to identify the most significant factors contributing to a population's decline, thus providing a basis for informed conservation management decisions.

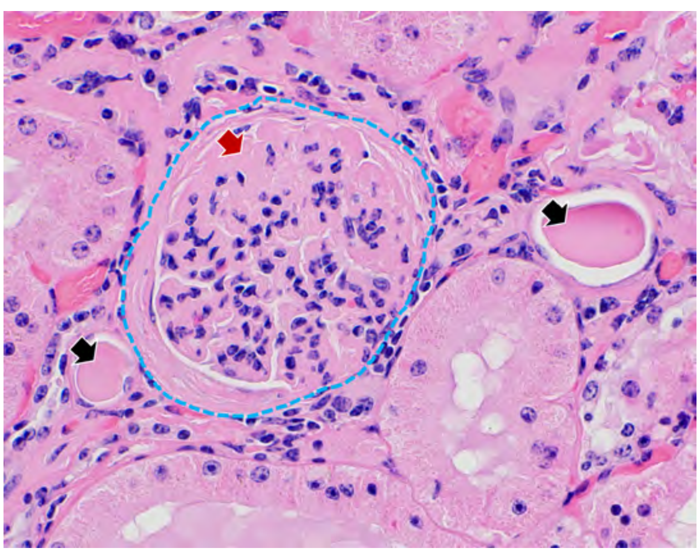
How do we determine causes of mortality?

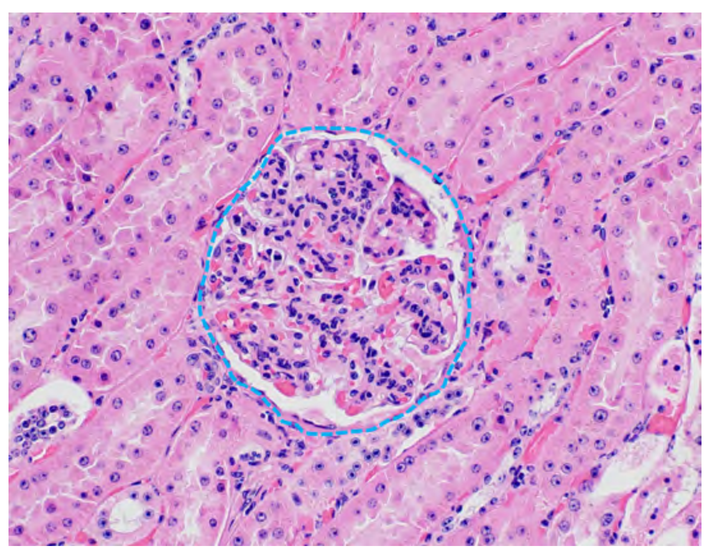
To determine why an individual animal has died requires a thorough investigation. First, a field scientist (usually a biologist or veterinarian) observes the situation in which the deceased animal was found. Relevant observations include evidence of visible hazards, such as nearby roads or toxic plants, to which the animal could potentially have been exposed, as well as eyewitness accounts from people who may have seen the animal's behavior prior to or at the time of death.

Next, we conduct an autopsy, which starts by determining the age and sex of the moose and looking for external abnormalities such as skin parasites, injuries or emaciation. Then we perform a thorough dissection to examine the internal organs for evidence of diseases that may not be visible externally. We take samples of all major internal organs, as well as feces, serum, gastrointestinal contents and parasites. The background information we gather and any abnormalities we discover during the autopsy are documented and relayed, along with the tissue samples, to the WSVL. My role is to examine the collected moose tissue samples under the microscope—because some diseases can only be detected microscopically—and decide if any other tests are needed. At the conclusion of all testing, I integrate all the findings for each moose to identify the factors that likely contributed to its death, as well as the presence of any concurrent but non-fatal diseases.

An unexpected finding

Between March 2020 and December 2021, we investigated the deaths of 33 moose and discovered that a variety of factors contributed to their deaths. Causes of death included infectious diseases, such as bacterial





Virginia Stout

Figure 1. Microscopic evidence of kidney disease in a moose. Left is a diseased kidney with a thickened and damaged glomerular membrane (red arrow), which has allowed protein (black arrows) to leak from the bloodstream into the urine filtrate. Compare this to the image on the right, of a healthy kidney. An individual glomerulus is outlined in both.

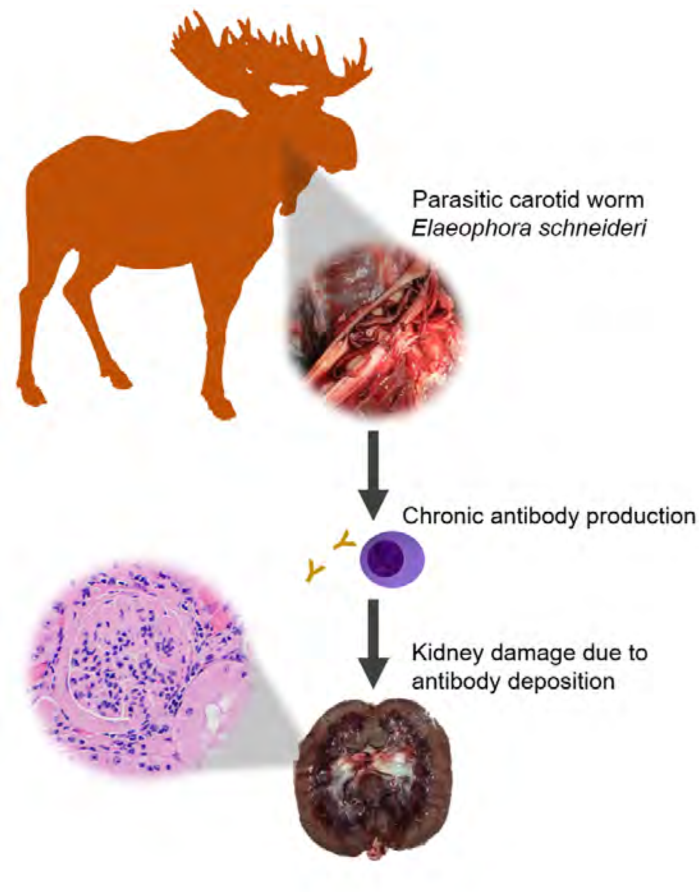


Figure 2. Hypothesized link between arterial worm parasitism and kidney disease in moose.

pneumonia; trauma, such as from vehicular collisions; exposure to environmental toxicants; and, among some calves, severe tick parasitism.

In many of the adult moose, we also found microscopic evidence of kidney disease (Figure 1). No moose died primarily of kidney disease, but this is still an important finding because kidney disease can cause weight loss and a decline in overall health. The kidney disease among these moose varied from mild to severe, in some cases to the extent that the body's ability to excrete cellular waste products was compromised. Kidney disease therefore appears to be affecting the health of some of these moose, and in this way may potentially be contributing to population decline.

Causes of kidney disease

What is causing kidney disease in these moose? To begin answering this question, we need a basic understanding of kidney anatomy.

Each kidney is made up of millions of microscopic structures called nephrons, which are responsible for filtering cellular waste products out of the bloodstream into the urine. One component of the nephron is the glomerulus, which is a spherical structure made up of a meshwork of small blood capillaries surrounded by cells forming a membrane, a selective barrier that allows waste products and fluid, but not larger blood components such as proteins and red blood cells, to be released from the bloodstream into the urine. When the glomerulus is damaged, this selective barrier becomes leaky, and excess proteins and fluids are lost with the urine.

A common cause of selective damage to the glomerulus is the deposition of antibody complexes in the glomerular membrane. Antibodies normally are formed by white blood cells in response to infectious diseases, helping to bind and inactivate pathogens, and are present in circulation. Most short-lived antibody responses do not cause glomerular damage, but antibodies produced over an extended period can deposit in the glomerular membrane, leading to glomerular membrane thickening and dysfunction. Chronic infections can result in glomerular damage.

Since these moose have selective glomerular damage, might a chronic infection be to blame? We hypothesize this to be the case. Although some of the moose with kidney disease died of infectious disease, others did not. Might there, then, be a chronic infection present in many of these moose that is not causing death, but is leading to damage of the glomerular membranes through persistent antibody deposition?

One possible culprit is the parasitic arterial worm, *Elaeophora schneideri*. The adult stage of this small worm resides in the carotid arteries of the moose's neck, in many cases causing little or no apparent disease. However, its persistent presence in the moose's body may result in continuous low-level antibody production, potentially leading to glomerular damage (Figure 2). We have found *E. schneideri* worms in a majority of the adult moose in this study, and we currently are working on testing methods to improve our ability to detect the parasite. Once these testing methods are optimized, we will begin looking for correlation between the kidney disease and this parasite's presence.

An ongoing study

With only 33 moose, it is difficult to draw any definitive conclusions about mortality trends in the

Jackson moose population, but multiple factors do appear to be involved. Kidney disease, though not a primary cause of death, may compromise the health of individual moose, and we are continuing to investigate its implications for Wyoming's moose population. As this study continues over the next few years and more deaths are investigated, we expect trends to become apparent that will help us identify the most important factors contributing to this specific population's decline.

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LYNN FELTNER AWARD
BEST STUDENT PAPER, 2021

OPTIMIZING MOUNTAIN MEADOW MANAGEMENT

Mountain meadow organic matter shows promise for improved soil fertility management

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Wyoming is famous for its harsh climate, and any local knows it's something Wyomingites embrace with pride. Throughout our state's history, the struggle with nature has created a special need for resiliency—a resiliency that might well describe many of Wyoming's agricultural systems. It's no wonder that ruminant animals, namely cattle and sheep, traditionally have been the cornerstone of Wyoming agriculture, with their ability to eke out a living on Wyoming's vast grazing resources making them the ideal food producers on our state's non-arable lands.

Early settlers quickly discovered, however, that maintaining animals through Wyoming winters requires stored forage and a lot of it—as much as 2–2.5 tons of hay per cow each year. For many ranchers today, this critical winter forage is produced on mountain hay meadows, areas of the landscape near rivers and streams where large swaths of grass hay are flood-irrigated with water from spring runoff. Meadows traditionally have been a low-input forage system that utilizes simple ditches and canals to expand the footprint of irrigable land near a water source. With the introduction of water, meadows developed naturally as water-loving sedges, rushes and grasses replaced hardy prairie vegetation, and after nearly a century, the continued influence of flood irrigation has shaped meadows as we know them today.

Although irrigating meadows increased the productive capacity of ranches, inefficient irrigation creates some unique management challenges. Meadows routinely remain saturated for weeks to months in the spring and early summer as forage grows prior to harvest. The excess water makes fertility management difficult, because fertilizers are subject to runoff, leaching and gaseous losses from the field. Early research found that, at best, the nitrogen-use efficiency of meadows caps out around 30%, and that meadows routinely respond to nitrogen fertilizer inputs. Low productivity means ranchers must balance management decisions to ensure they have enough hay available for the winter.

With recurring drought causing hay prices to skyrocket in recent months, and economic struggles of the pandemic causing fertilizer prices to double in just one year, it is time to reassess meadow management and sustainability. Here we share new ongoing research in the Departments of Ecosystem Science and

Management and Plant Sciences that seeks to better understand meadow hay production for a new generation.

Meadow soils are unique

Early research on meadows focused on agronomic and economic management strategies to maximize forage production and value for livestock producers in the Mountain West. Studies of fertilizer response, grazing, harvest, and irrigation in the 1960s and 1970s provided the foundational meadow management tactics that still are in use today. An overriding theme in the early literature is that meadows are difficult to manage because of their unique soils, as influenced by flood irrigation. Researchers commonly described the surface horizon of meadow soils as being high in organic matter and stored nutrients that were of limited availablity to plants. This "thatch" or "sod-bound" layer developed because of the reduced decomposition of organic matter in the soil during saturated conditions, which in turn did not recycle nutrients for plant growth in subsequent years. Although researchers found as much as 1–2 tons per acre of organic nitrogen in the thatch layer, they acknowledged its unavailability as a disconnect in the nutrient cycling of meadow soils.

As Wyoming steps into a future of increasing demand for food production, it is critical to utilize every resource available for plant growth. Thus, our research began as an initial curiosity about the large amounts of stored nitrogen in meadow soils. We quickly realized the thatch layer, or specifically, the O-horizon ("O" signifying a high concentration of organic matter) needs to be examined more closely. We hypothesized that continuous flood irrigation has led to the development of an O-horizon that is limiting nitrogen availability for hay production, and that proper management can naturally release nitrogen from the system for increased plant growth.

After one year of data collection, we are finding evidence to support our hypothesis. In spring of 2021, we identified four local ranches that utilize flood irrigation for meadow hay production. At each ranch, we are comparing three unique agroecosystems: long-term fertilized, irrigated hay meadows; long-term unfertilized, irrigated hay meadows; and corresponding natural rangelands. By excavating the soil in all three agroecosystems, we confirmed that continuous flood irrigation leads to the development of an O-horizon in meadow soils.

To examine the O-horizon more closely, we sampled the O-horizon of meadows, the mineral soil directly beneath the O-horizon in meadows (called an A-horizon) and soil from adjacent rangelands lacking the influence of irrigation or an O-horizon (Figure 1). Results from spring and summer of 2021 confirm how the O-horizon has accumulated organic

An irrigated meadow with a view of the Park Mountain Range near Cowdrey, Colorado.

matter and nitrogen through time. The concentration of nitrogen in the O-horizon is higher than that of the A-horizon directly beneath. This also is the case for soil organic matter, meaning there is reduced decomposition of plant residue and organic matter in meadow soils, causing them to accumulate near the soil surface. This is not the case for rangeland soils, which have slightly higher organic matter and nitrogen than the A-horizon of meadows but do not accumulate carbon and nitrogen in an O-horizon (Table 1).

To test the potential for meadow soils to provide nitrogen for plant growth, in the lab we measured potentially mineralizable nitrogen, which is nitrogen in the soil that can be decomposed from organic matter into plant-available nitrogen in conditions ideal for microbial activity. Our results for PMN also confirm the abundance of stored nitrogen in meadow soils, able to release large amounts of plant-available nitrogen (Table 1). If this is the case in the lab, then why aren't meadows naturally releasing nitrogen for ample hay production in the field? Unfortunately, for a large part of the year, soil conditions in meadows are unfavorable for microbial activity and organic matter decomposition. Meadows often are located at high elevations where long, cold winters reduce microbial activity. Then,

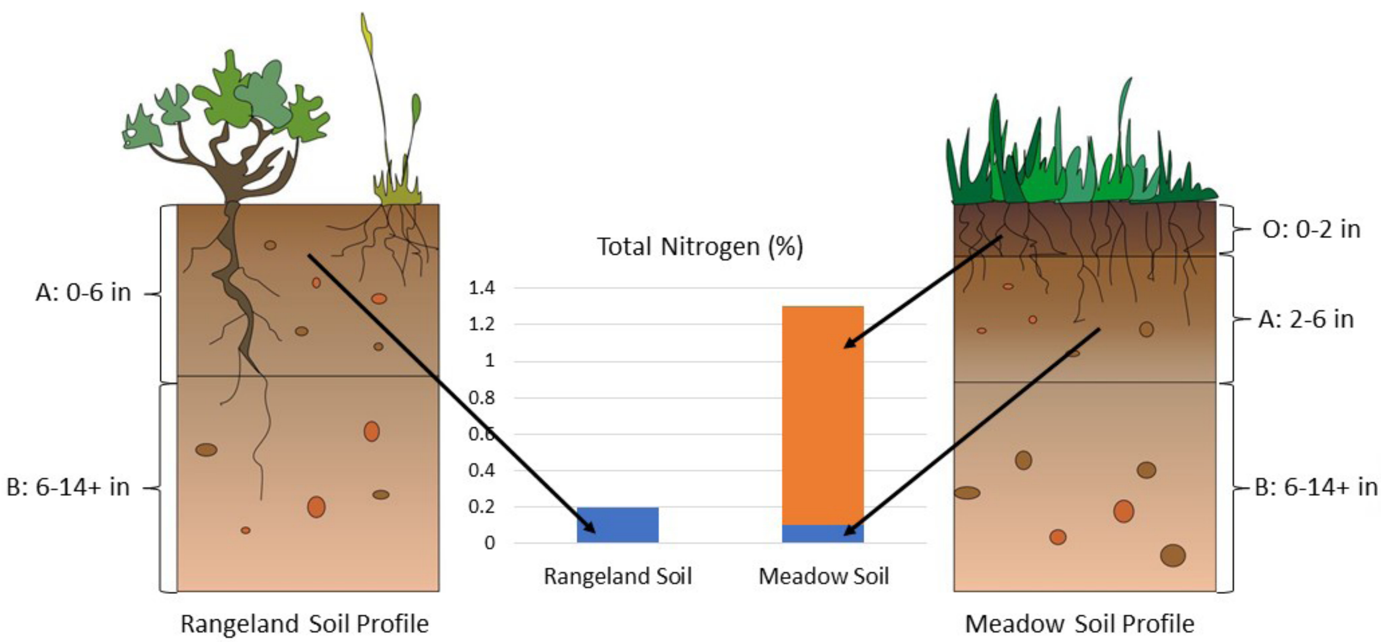

Figure 1. Exemplary rangeland and meadow soil profiles with topsoil nitrogen content (%). Values are averaged from four meadow and rangeland sites in southern Wyoming and northern Colorado observed over two sampling periods, spring and summer.

	Rangeland Soil		Meadow Soil	
Measure	**O-Horizon**	**A-Horizon**	**O-Horizon**	**A-Horizon**
Organic Matter (%)	No O-Horizon	5	32	3
Total Nitrogen (%)		0.2	1.2	0.1
PMN (ppm)		15	43	2

Table 1. Comparison of soil organic matter and nitrogen for meadow and rangeland soils for the uppermost two soil horizons. Values are averaged from four meadow and rangeland sites in southern Wyoming and northern Colorado observed over two sampling periods: spring and summer. PMN stands for Potentially Mineralizable Nitrogen, which is an indicator of nitrogen availability in optimum laboratory conditions.

spring and summer, excess irrigation water leaves the soil saturated and lacking oxygen, resulting in limited microbial metabolism, activity and nutrient release.

Future Research

Our results confirm that the O-horizon of meadow soils contains a large store of nitrogen that can be released for plant growth in ideal conditions, but the question remains, *How can we naturally release nitrogen in the field?* To answer this, our research team has initiated further work to determine management practices that promote decomposition and release of nitrogen from meadow soils. In fall of 2021, we initiated an experiment at the Laramie Research and Extension Center to examine tactics to disturb the O-horizon and stimulate nitrogen release using varying rotational grazing intensities and light tillage. We also hope to examine the effects of inter-seeding desirable legumes to increase natural nitrogen inputs to the system. Future results will help us analyze the feasibility of utilizing stored nitrogen for forage production on the field scale. Finally, we also plan to undertake a regional survey of meadow soils by sampling locations across Wyoming and Colorado. With a robust dataset, we expect to determine what is a "healthy" meadow soil, and what indicators are useful to better understand how to manage meadows for sustained forage production for years to come. Meadows have been woven into the history of Wyoming, and by researching them through a modern lens, we work to ensure they stay that way.

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Scientists conduct experimental tillage on a meadow at LREC to determine the effect of O-horizon disturbance on soil nitrogen release.

REMEMBERING JAY NORTON

As many of you already know, Dr. Jay Norton passed away this March while skiing in the Teton backcountry. Jay was a valuable faculty member in the Ecosystems Science and Management Department, with a productive lab studying soil and ecosystem health, organic agriculture, and a range of issues supporting Wyoming agriculture and ecosystem sustainability. His loss not only impacts research in the college, but many of us lost a friend and a mentor. In tribute to Jay, we thought we'd let a few of his students, friends, and colleagues remind us all why he will be so greatly missed…

"Jay was so much more than my advisor; he was central to everything about my life in Wyoming. He shaped why I do science, but he also understood the importance of having not just a good work environment, but a strong community, and he helped me build that community." — Hannah Rogers, Ph.D. student

"Jay Norton was one of the most collaborative colleagues I have ever known and with whom I had the pleasure and privilege to work. At his core, Jay embodied the desire to improve natural resource management and was committed to bringing everyone into the process."
— Dr. Ginger Paige, Interim Department Head, Ecosystem Science and Management

"Looking back, something that strikes me the most about Jay was his humility. In a world where there is constant pressure to publish, present, and contribute 'shiny science', and perhaps promote your own work, lab, and credentials, Jay remained humble." — Daniel Adamson, Ph.D. student

"The thing that stands out the most about Jay is how passionate he was about his life, about everything he did, and how he was so excited to share that with all of us. I'm forever grateful for Jay sharing that with me, everything that I've learned from him, and for all the memories." — Liana Boggs Lynch, Post-doctoral Research Associate

"Jay was a wonderful friend and terrific colleague. He had an infectious positive spirit that he carried everywhere. He is remembered for his excellence in scholarly activities as well as the warmth, friendship, and good humor he brought to his community."
— Dr. Scott Miller, Department of Ecosystem Science and Management

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