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Key Points:

- Indigenous ecological calendars contribute to food sovereignty through adaptation to an increasingly variable climate
- Calendars developed with communities in the Standing Rock Nation focus on plants, animals, and fungi used in traditional foodways
- These calendars reveal the diversity of knowledge among Indigenous communities based on context-specific ecological relations

Supporting Information:

Supporting Information may be found in the online version of this article.

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Ecological Calendars, Food Sovereignty, and Climate Adaptation in Standing Rock

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Abstract Indigenous food sovereignty relies on ecological knowledge of plants and animals, including knowledge related to their development and behavior through the seasons. In the context of anthropogenic climate change, ecological calendars based on Indigenous knowledge may enable communities to anticipate seasonal phenomena. We conducted research with communities in the Standing Rock Nation (North and South Dakota, USA) to develop ecological calendars based on their ecological knowledge. We present ecological calendars developed in seven communities through a series of workshops and interviews. These calendars are rich with knowledge about temporal relations within each community's ecosystem, including the use of plants and animals as seasonal indicators and cues for food system activities. However, the calendars also reveal the impacts of cultural genocide wrought by the United States government in its efforts to colonize the lands and minds of Indigenous communities. Given the diversity of knowledge among Standing Rock communities, we identify opportunities for knowledge exchange to revitalize ecological relations at the heart of food sovereignty. We highlight the potential for ecological calendars to facilitate climate adaptation by enabling communities to synchronize their food systems with an increasingly variable climate.

Plain Language Summary Indigenous knowledge about plants and animals is necessary for communities to produce and consume food according to their own values and traditions. In many cases, Indigenous people have learned to watch the growth and behavior of plants and animals to make decisions about when to carry out seasonal activities like planting, harvesting, gathering, or hunting. This kind of knowledge can be used to develop ecological calendars that help communities adapt to climate change. We present ecological calendars developed with seven Native American communities in the Standing Rock Nation of North and South Dakota (USA). The calendars demonstrate that local plants and animals provide useful information for adaptation to climate change. However, the calendars also show the negative impacts of colonialism on Indigenous ecosystems and knowledge. Each of the calendars is unique based on the habitat and cultural traditions of the community. We suggest that sharing knowledge among communities would help them adapt their food systems to climate change.

1. Introduction

The Sixth Assessment Report of the Intergovernmental Panel on Climate Change emphasizes the impacts of climate change on food systems, particularly the challenges associated with increasing climate variability (IPCC, 2022). Adapting food systems requires strengthening capacities to anticipate and respond to a widening array of climate conditions and increasing frequency of extreme events (Kassam et al., 2018; Tschakert & Dietrich, 2010). Among the many challenges posed by climate change is knowing *when* to plant or harvest crops, move herds, gather plants, or hunt animals given increasingly unreliable patterns of temperature and precipitation that affect the timing of seasonal processes (Inouye, 2022).

Calendars are the knowledge systems we use to plan and coordinate our activities in relation to seasons (Aveni, 1989). Most readers are familiar with calendars based on the predictable movements of celestial bodies (the Earth, sun, and moon), such as the Gregorian calendar. By contrast, Indigenous communities have developed *ecological* calendars that incorporate knowledge of the seasonal phenomena within their habitat (Kassam et al., 2011; Mondragón, 2004; Woodward & Marrfurra McTaggart, 2019). These calendars require close observation of biotic and abiotic phenomena (e.g., the appearance of flowers, the calls of migrating birds, or the fragrance of falling leaves) to measure the passage of time. Many ecological calendars relate earth-bound phenomena to

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solar and lunar cycles (e.g., Mondragón, 2004). Nonetheless, compared to celestial calendars, ecological calendars are flexible and responsive to seasonal ecological events, empowering communities to synchronize their activities with variable climate regimes (Kassam et al., 2018).

Based on knowledge systems that center on relations within their ecosystems, Indigenous communities have been first to recognize and respond to climate change (Green & Raygorodetsky, 2010; Hatfield et al., 2018). However, their ability to adapt is limited by colonial policies and programs that have decimated populations of plants and animals, restricted access to homeland territories, and disrupted the continuance of knowledge across generations (Whyte, 2017). Destruction of Indigenous food systems has had devastating consequences for communities. From a biomedical perspective, these impacts manifest as diet-related diseases. In the United States, Native Americans suffer from higher rates of diabetes and obesity as well as lower life expectancies than any other cultural group (Love et al., 2019; Rabin, 2022). Furthermore, colonialism undermines Indigenous peoples' ability to be healthy on their own terms and to advance the well-being of their communities through ecological relations (Dennis & Robin, 2020).

Food sovereignty is the right and capacity of communities and nations to determine their own food systems (Via Campesina, 1996). The global food sovereignty movement emerged in the early 1990s, when *La Via Campesina,* an international coalition of small-scale food producers including Indigenous communities, began protesting neoliberal policies that expose local food systems to global market forces (Torrez, 2011; Wittman, 2009). For Indigenous people, food sovereignty is part of broader efforts to regain autonomy within their ecosystems following centuries of colonial oppression (Coté, 2016; Grey & Patel, 2015; Huambachano, 2019). In addition to reasserting their rights to hunt, gather, grow and trade food based on their knowledge and values, Indigenous governments and non-profit organizations are working to revitalize knowledge systems that underlie their ecological relations with the plants and animals that play a role in their traditional foodways (Blanchet et al., 2021; Budowle et al., 2019; Hoover, 2017).

The process of co-generating ecological calendars with Indigenous communities facilitates climate adaptation and contributes to food sovereignty (Kassam et al., 2018). Discussion of seasonal change reveals knowledge of complex temporal relations in the community's habitat. Compiling and visualizing this knowledge enables recognition of patterns that can be used to anticipate seasonal processes, regardless of their timing according to fixed celestial calendars. For example, Dakota and Lakota Elders rely on knowledge of synchronies and sequences in the ripening of berries to plan when to gather them, despite variability with respect to the Gregorian calendar (Ruelle & Kassam, 2011). Knowledge of such patterns has developed over multiple generations; however, the unprecedented conditions wrought by anthropogenic climate change can disrupt previously reliable temporal relations. To remain relevant in new realities, ecological calendars must be consistently applied and adapted. Thus, ecological calendars provide a framework for Indigenous communities to anticipate and adapt to climate change through the ecological knowledge and relations at the heart of their food sovereignty (Kassam & Bernardo, 2022).

This article describes efforts to document and illustrate ecological calendars with Indigenous communities in the Standing Rock Nation of the Northern Great Plains (USA). We worked with communities to co-generate new calendars based on their knowledge of seasonal phenomena, including their knowledge of traditional Lakota and Dakota calendars. Given the ecological and cultural diversity within Standing Rock, the seven communities participating in this research chose to develop seven distinct calendars that reflect their unique knowledge and relations with their local ecosystems. After a description of our participatory research process, we examine the implications of these calendars for food sovereignty in the context of climate change. Although documentation of Standing Rock's ecological calendars remains a work in progress, they illustrate how diversity of knowledge within Indigenous communities forms the basis for the anticipatory capacity needed to thrive under an increasingly unreliable climate.

2. Methods

2.1. Study Area

The Standing Rock Nation is located on the western bank of the Missouri River where it crosses the border of North and South Dakota (Figure 1). The Standing Rock landscape is dominated by rolling grasslands incised by east-flowing tributaries of the Missouri, including Porcupine Creek, Oak Creek, and the Grand River. As of 2019, the estimated population of Standing Rock was 8,523, of whom 78% were Native American (UCB, 2019).

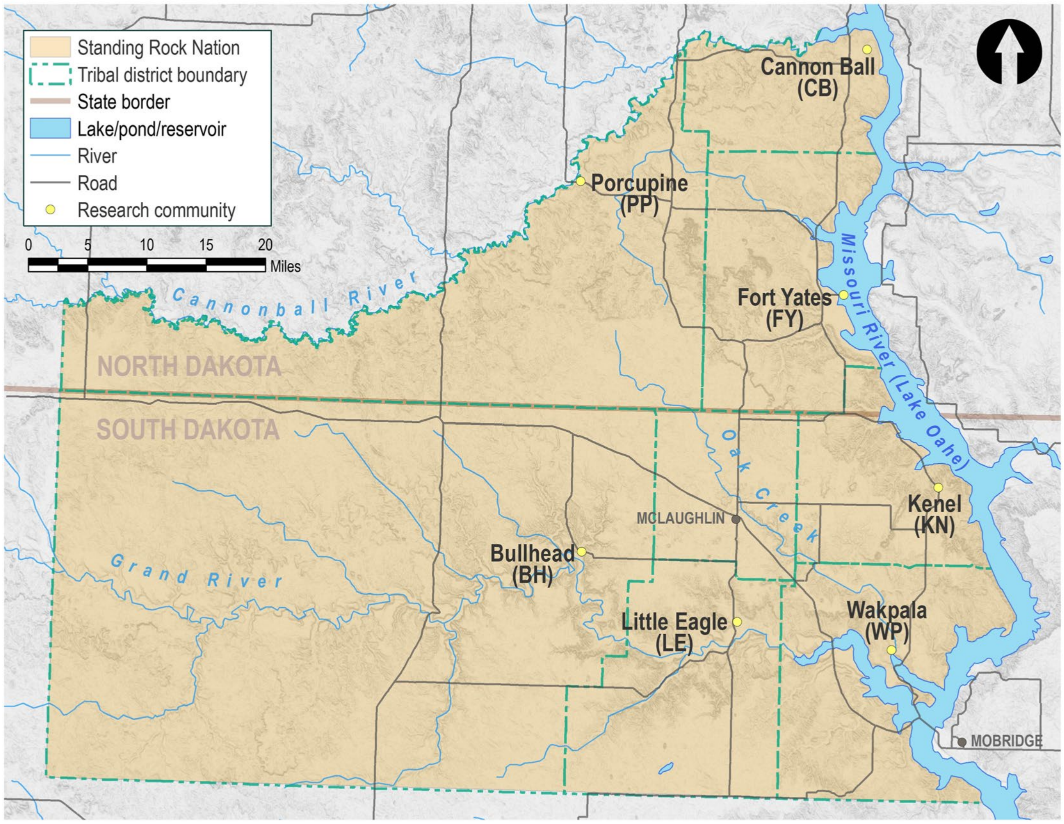

Figure 1. Map of the Standing Rock Nation, including the seven communities where workshops and interviews were conducted to co-generate and illustrate ecological calendars.

Established by the U.S. military in 1873, Standing Rock is home to the Iháŋktȟuŋwaŋna (also calling themselves Wičhíyena) and Húŋkpatina groups of the Yanktonai (Western Dakota) and the Húŋkpapȟa and Sihásapa tribes of the Lakota (Kulas et al., 1995; Ullrich, 2008), as well as members of many other Native nations.

In terms of its land area, Standing Rock is one of the largest Native American reservations in the United States (2.3 million acres or 931,000 ha). However, passage of the Dawes Severalty Act in 1887 privatized communal land, allotted small parcels to individual households, and opened up remaining areas for purchase by Euro-American settlers (49th United States Congress, 1887; Otis, 1973). Native landholdings were concentrated in the east, along the Missouri River and its tributaries, whereas western portions of the reservation were taken by Euro-American settlers (Kulas et al., 1995). In the late 1940s, the U.S. Army Corps of Engineers began work on the Oahe Dam on the Missouri River north of Pierre, South Dakota, which permanently inundated 55,000 acres (22,238 ha) of Standing Rock, including most of the reservation's forests. Despite the protests of Standing Rock's tribal government, the completion of the dam in 1959 forced hundreds of Native families to relocate from their homes in the rich bottomlands of the Missouri to new communities on windswept hilltops overlooking what is now known as Lake Oahe (Lawson, 1994, 2009).

In addition to colonizing land through seizures and destruction of habitat, the federal government sought to colonize the minds of Native communities by removing children to boarding schools where they were re-educated according to Euro-American values (Adams, 1995). Beginning in the 1870s and continuing through the late-twentieth century, Standing Rock's children were taken to schools thousands of miles from home, including Carlisle (Pennsylvania), Hampton (Virginia), Clonterf (Minnesota), St. Meinrad's (Indiana), and Chamberlain (South Dakota) (Milligan, 1976). Many were contracted out as farm or factory laborers as part of "outing programs" during the summer months (Whalen, 2016), further limiting their opportunities to hunt, gather, garden, or prepare traditional foods with their families. With designs to eliminate Indigenous language, knowledge, and values, the boarding school system is widely recognized as a program of cultural genocide (Lajimodiere, 2014; Shear, 2015; Woolford, 2015).

Agriculture census data from 2021 show that Standing Rock farmers (Euro-American and Native) plant corn (maize), oats, soybean, sunflower, and wheat, while local ranchers (also Euro-American and Native) primarily raise cattle (NASS, 2022). Locally produced crops and livestock are rarely available to local communities. Rather, residents purchase food from small grocery and convenience stores where selection of fresh produce is limited; larger grocery stores are located more than an hour away in Bismarck, North Dakota or Mobridge, South Dakota. Many residents rely on federal food assistance programs (administered by state and tribal officials) that continue to provide cheap, starchy, salty and sugary food stuffs. Lack of access to affordable, nutritious and culturally-relevant food has led to alarmingly high rates of diet-related disease in Standing Rock (CDC, 2019).

The past two decades have seen many efforts to advance Standing Rock's food sovereignty. Although the elimination of forests along the Missouri devastated populations of many plants and animals, remaining riparian forests along major tributaries (especially the Grand River in the south) provide some habitat, and ravines throughout the reservation shelter additional populations. The tribal government, North Dakota State University Cooperative Extension, and several local non-profit organizations have promoted gardening and farmers markets, including a voucher program aimed at expanding access to fresh fruits and vegetables. Wild berries, herbs, and mushrooms gathered by local residents are particularly popular at farmers' markets (Ruelle et al., 2011). Despite the U.S. Army's attempts to eliminate bison in the late 19th century, Standing Rock is now home to several bison herds. Some are privately owned by Native residents and others managed by the tribal government, and bison meat is often distributed to Elders and people with physical impairments. Residents who obtain a tribal license can fish in Lake Oahe or other local bodies of water and hunt a variety of mammals and birds.

2.2. Community Workshops and Interviews

The first author began working with the Standing Rock tribal government in 2007, initially as an AmeriCorps*VISTA volunteer and later as a Master's and PhD student at Cornell University supervised by the fourth author. He worked primarily with Nutrition for the Elderly and Caregiver Support (NFE), a tribal agency responsible for providing meals to Elders, and collaborated with the second author on multiple projects aimed at advancing food sovereignty (Ruelle, 2017; Ruelle & Kassam, 2011, 2013; Ruelle et al., 2011). In 2015, the first and fourth authors contacted Luella Harrison, then director of NFE, about a research project focused on ecological calendars and learned that members of her family had been investigating Lakota and Dakota lunar calendars. She approached the Standing Rock Tribal Council, who passed a resolution in support of this research initiative.

In December 2015, the first author worked with NFE to host a 3-day community workshop at the Prairie Knights Casino and Resort. Attendees included the Tribal Chairman and leaders of tribal government agencies, extension agents and volunteers, faculty from Cornell University and Sitting Bull College, Elders and other community members. The goal of this workshop was to introduce the general concept of ecological calendars and to discuss how such calendars might help communities anticipate and respond to climate change. Participants established the research agenda, which began with workshops in each community to compile knowledge of the seasonal round, followed by interviews with individuals identified by the community. Community input was used to develop a research proposal and protocols that were reviewed and approved by Institutional Review Boards at Cornell University and Sitting Bull College (protocol ID #1601006074 and SBC165).

In March through May of 2016, the first author organized workshops in eight communities (Figure 1). These workshops were held at community centers or congregate meal sites operated by NFE. Workshops were announced via flyers posted in the community and on the local radio station. In addition, the first author contacted Elders by telephone to invite them to join the workshop and to let others know about the event. Altogether, 26 women and 17 men participated in the workshops. Although the workshops were open to anyone from the community, most participants were Native Elders, including many who knew the first author through his prior work for NFE and previous research projects. Given the participation of many Elders, each workshop produced one version of an ecological calendar, and engaging another set of community members would likely have led to different results.

All workshops were facilitated by the first author and a research assistant from one of the seven communities who was a student at Sitting Bull College. Each workshop was accompanied by a meal prepared by a local chef and served by the research team. Each workshop began with an explanation of the research objectives and process and a request for written prior informed consent. Participants were presented with a diagram consisting of concentric circles, which served as a basis for discussing and illustrating their seasonal round (Figure 2a). The first questions

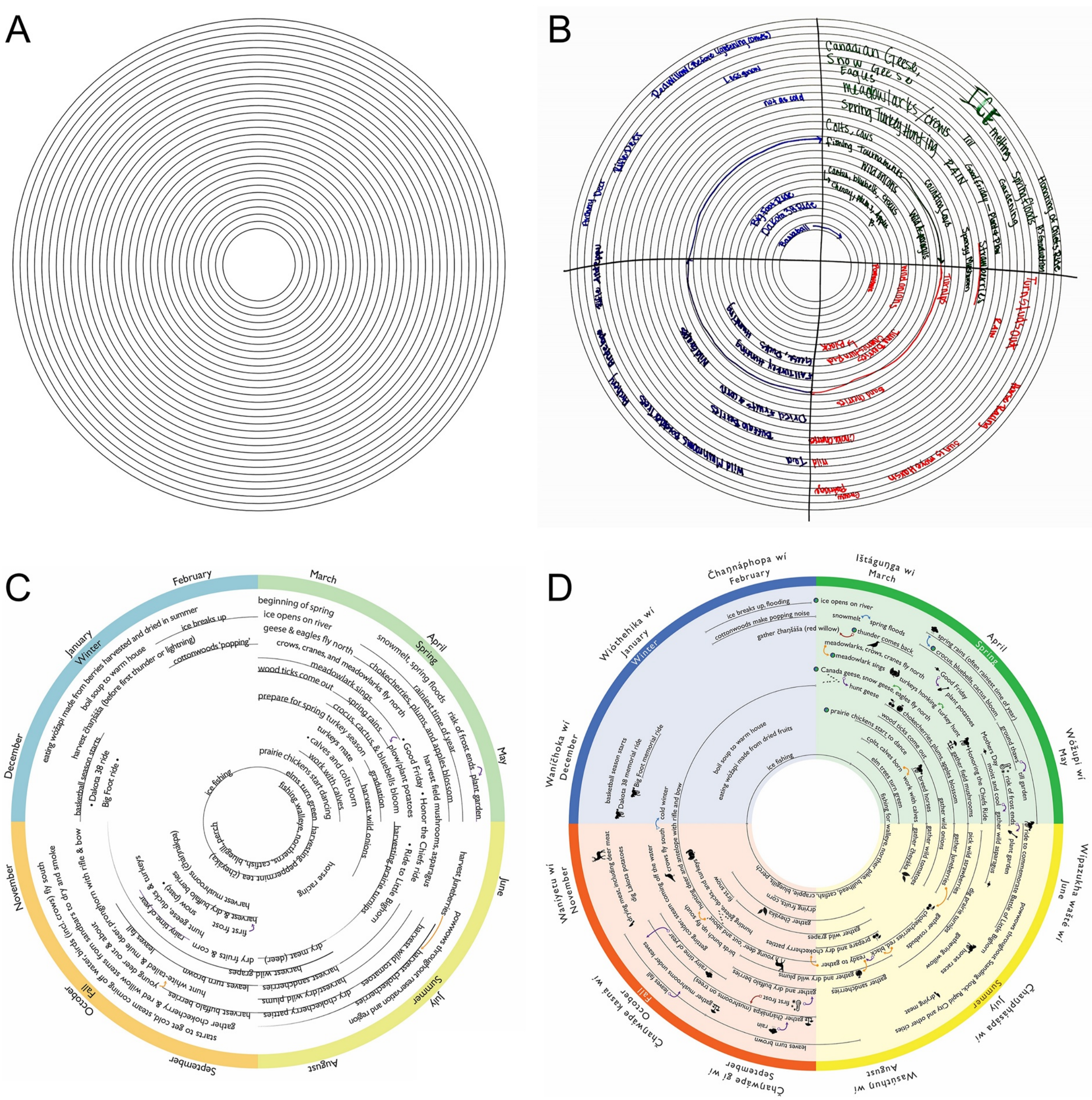

Figure 2. Stages of co-generating an ecological calendar in the community of Wakpala, including (a) blank circular diagram, (b) illustrated seasonal round generated during the first community workshop, (c) digitized seasonal round presented and reviewed at validation workshop (Kassam et al., 2021), and (d) digitized ecological calendar included in the community report (Kassam et al., 2022).

centered around the number, length, and names of seasons in English, Dakota, or Lakota. These were added to the periphery of the diagram as reference points for further discussion. In most cases, participants identified spring as the beginning of the year, so discussion proceeded with events that indicate the beginning of spring. From there, the facilitators asked participants to describe the phenomena associated with each season. These phenomena were documented on the seasonal round at the front of the room (Figure 2b); more nuanced details were recorded in the first author's field notes.

In addition to workshops, the first author conducted eight semi-structured interviews with 10 Elders (six women and four men, including two sets of partners interviewed together) who had been identified by community members as particularly knowledgeable, including artists, gatherers, language instructors, and tribal employees. As at the workshops, the first author explained the research objectives and process prior to requesting written consent. Interviews followed the same sequence as the workshops, beginning with a discussion of seasons followed by identifying important phenomena associated with each season. Information from interviews was ultimately added to the seasonal round generated during the workshop in the interviewee's community.

Ecological calendars are based on knowledge of the timing of seasonal phenomena in relation to each other, what some have described as traditional phenological knowledge (Lantz & Turner, 2003). Through collaboration with Indigenous communities in Standing Rock and the Pamir Mountains of Tajikistan and Kyrgyzstan, as well as settler communities in the Oneida Lake watershed of upstate New York, the authors developed a common lexicon to be used in the development and analysis of ecological calendars. Field notes from community workshops and follow-up interviews were analyzed following an iterative open coding protocol (Bernard et al., 2016) using ATLAS.ti software (version 8). Codes included the names of organisms and categories of temporal relations, which will be explained with examples in the Results section of this article.

In December of 2018, the first and fourth authors organized a second series of workshops to validate the knowledge generated with each community, including the categorization of temporal relations within the seasonal rounds developed by the research team. Previous workshop participants and interviewees were contacted and invited by phone, and workshops were announced via flyers and radio announcements. Altogether 30 women and 12 men participated in validation workshops, most of whom had attended the first set of workshops in 2016. The research team presented the information they had gathered in two forms: a seasonal round, which illustrated the cyclical nature of seasonal phenomena (Figure 2c), and as a table, which was easier to read. Attendees were asked about each element, beginning with phenomena associated with spring and proceeding through the year. In addition to verifying information from the first set of workshops and interviews, the workshops provided an opportunity to provide additional knowledge or withdraw sensitive information that should not be published. Again, each workshop included a meal prepared by a local chef and served by the research team.

Following the validation workshops, the first author generated new illustrations intended to serve as a first iteration of ecological calendars (Figure 2d). Based on requests from participants in several communities, a unique ecological calendar was created for each community to reflect their context-specific knowledge and activities. The resultant ecological calendars maintain the structure of illustrated seasonal rounds, which are familiar to participants, but incorporate symbols indicating categories of temporal relations (seasonal indicators, synchronies, etc.). In addition, plants, animals, and activities that appeared in multiple seasons on the same calendar were identified by icons to provide visual linkages.

Information gathered during the research was compiled and organized as a community report (Kassam et al., 2022), which includes (a) the illustrated ecological calendars; (b) instructions to engage the calendars, including explanation of categories of temporal relations; and (c) a knowledge base with entries for the weather events, plants, animals, and human activities included in the calendars. All information in the knowledge base is attributed to one or more communities, allowing the reader to observe points of consensus as well as differences in knowledge.

Community knowledge presented in the knowledge base was further supported by quantitative analysis of publicly available historical weather records and citizen science data conducted by the third author. Importantly, the goal of including such information was to complement (as opposed to compare or validate) indigenous knowledge in the development of effective ecological calendars. Two examples from the community reports are included in this article. First, given the significance of frost in many of calendars, the timing of the first (fall) and last (spring) frost was analyzed for the period between 1914 and 2020 at the closest, reliable weather stations in Mandan, North Dakota and Mobridge, South Dakota (NCEI, 2021). Linear regression of first and last frost dates was conducted to identify significant changes. Second, migrations of birds mentioned by participants were assessed using observations reported on the Cornell Lab of Ornithology's eBird platform (2021).

As mentioned earlier, all seven illustrated ecological calendars are available in the community report (Kassam et al., 2022). One example from the community of Cannon Ball is available as Supporting Information S1 (Figure S1).

3. Results and Discussion

3.1. Plants, Animals, and Fungi Included in the Ecological Calendars

The ecological calendars documented and illustrated with the seven communities in Standing Rock include 42 plants, 4 fungi, and 48 animals (Table 1, Table S1 in Supporting Information S1). In all but one community, participants included more plants than animals, but animals differed from calendar to calendar, resulting in a

Table 1
Numbers of Organisms Included in Ecological Calendars Co-Generated With Communities in the Standing Rock Nation

	Bullhead	Cannon Ball	Fort Yates	Kenel	Little Eagle	Porcupine	Wakpala	All
Plants	**16**	**23**	**15**	**8**	**13**	**13**	**23**	**42**
Herbaceous	5	11	9	4	7	4	10	25
Woody	11	12	6	4	6	9	13	17
Fungi	**1**	**1**	**1**	**0**	**1**	**1**	**3**	**4**
Animals	**13**	**17**	**7**	**6**	**12**	**16**	**19**	**48**
Birds	5	8	2	3	5	7	7	19
Fish	0	5	2	2	0	0	7	9
Insects and Arachnids	2	0	0	0	1	3	2	5
Mammals	4	4	3	1	5	4	3	11
Reptiles and Amphibians	2	0	0	0	1	2	0	4
All	**30**	**41**	**23**	**14**	**26**	**30**	**45**	**94**

Note. Bold words indicate major categories (plants, fungi, animals, and all) whereas non-bolded words are sub-categories.

higher total count. Both herbaceous and woody plants (trees and shrubs) were included in all seven calendars. Although the total number of herbaceous plants was higher (25 as compared to 17), there were more woody plants in four of the calendars. Among animals, birds and mammals were present in all seven calendars. Birds were the largest group (19) and the most numerous in six of seven calendars, followed by mammals (11 overall). Although many fish were included (9), they were absent from three calendars, notably those located further from the Missouri River (Figure 1). Similarly, there were five insects and arachnids included in four of the calendars and four reptiles and amphibians included by three communities.

Although many participants referred to plants and animals using Lakota or Dakota names, workshops and interviews were conducted primarily in English, so participants tended to use common English names. Half of the names given for plants were identified to the species level, 40% refer to multiple species in the same genus (e.g., Standing Rock is home to four species in the genus *Ribes*, all known as "gooseberry"), and 2% to plants belonging to multiple genera (e.g., "melon" includes members of the genera *Citrullus* and *Cucumis*). As for animals, 54% of names refer to a single species, 15% to multiple species in the same genus, and 31% to members of multiple genera. Furthermore, the ecological calendars included general patterns about the seasonal development and/or behavior of large groups of organisms. For example, participants sometimes described the budding of trees and the migration of birds without identifying them by name. Such statements were deliberate generalizations and do not indicate a lack of knowledge, as evidenced by information about specific trees or birds in other parts of the calendar. Furthermore, participants often used generic names to refer to the most familiar member of a group (Berlin, 2016). For example, over the course of multiple workshops and interviews, the research team learned that "geese" referred to Canada geese, the species most frequently observed in Standing Rock, and participants would be more precise if they were referring to other species (e.g., snow geese).

Most of the plants included in Standing Rock's ecological calendars (69%) are consumed as food (Table 2). The high proportion of food plants reflects the diversity of plants that are consumed, as well as the research team's stated interest in food sovereignty. Altogether, 15 of the plants in the calendars are domesticates planted in fields and gardens, and the remaining 27 are non-domesticates gathered from various parts of the landscape. Most (14) of the domesticated plants are herbaceous, and 79% of these are consumed. By comparison, slightly more than half (54%) of the non-domesticated herbaceous plants included in the calendars are consumed. Of all herbaceous plants, the most frequently mentioned (included in all seven calendars) was prairie turnip (*thíŋpsiŋla* or *thípsiŋna*, *Psoralea esculenta*), a non-domesticated native legume that produces nutritious root nodules used in Dakota and Lakota foodways (Kant et al., 2015; Ruelle & Kassam, 2011; Stahnke et al., 2008).

The only domesticated woody plant included in the calendars is apple (*Malus domestica*), which is consumed. By contrast, 16 non-domesticated trees and shrubs were included in the calendars; most of these (69%) are consumed. Four non-domesticated woody plants were included in all seven calendars: buffalo berry (*Shepherdia* sp.), chokecherry (*Prunus virginiana*), wild plum (*Prunus americana*), and wild grapes (*Vitis riparia*); another

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Table 2
Domestication Status and Consumption of Plants, Animals, and Fungi Included in Ecological Calendars Co-Generated With Standing Rock Communities

	Total number		% Consumed as food	
Category	Domesticated	Non-domesticated	Domesticated	Non-domesticated
Plants	**15**	**27**	**80%**	**63%**
Herbaceous	14	11	79%	55%
Woody	1	16	100%	69%
Fungi	**0**	**4**	**NA**	**75%**
Animals	**3**	**45**	**33%**	**51%**
Birds	0	19	NA	37%
Fish	0	9	NA	100%
Insects and Arachnids	0	5	NA	0.0%
Mammals	3	8	33%	88%
Reptiles and Amphibians	0	4	NA	0.0%

Note. Bold words indicate major categories (plants, fungi, and animals) whereas non-bolded words are sub-categories.

was included in all but one calendar: juneberry (*Amelanchier* sp.) All these produce edible fruits that are important components of Standing Rock's traditional foodways (Ruelle, 2017; Ruelle & Kassam, 2011).

Three domesticated animals, all mammals, were included in the calendars: cattle, horses, and dogs. Of these, only beef is part of Standing Rock foodways, including as a substitute for bison in foods prepared for ceremonies and important social gatherings (Powers & Powers, 1990). As for the 45 non-domesticated animals, approximately half (23) are consumed as food. These include seven types of birds, seven mammals, and nine kinds of fish, all possible to hunt, trap, or catch within the reservation. Meat from these animals is traditionally shared with Elders and other relatives and used to prepare foods for family or community gatherings.

Five of the calendars included a fungus referred to as "wild mushrooms" or frequently by their Lakota and Dakota name, *čháŋnákpa*, meaning "tree ears." These mushrooms grow on box elders and elms that grow along creeks and rivers and are widely gathered, dried, and consumed. The three other types of fungi were each included in only one calendar; two of these were described as edible, while one is used as medicine.

Many of the other plants and animals that are not consumed nevertheless contribute to food sovereignty. Some are used in food system activities; for example, fodder plants like alfalfa (*Medicago sativa*) feed domesticated animals. Still other organisms are not used (in the sense of consumption) but are included in the ecological calendars because observations of their development and/or behavior provides information about seasonal change. We will explore these contributions further in the next section.

3.2. Seasons, Months, and Seasonal Indicators

All participants and interviewees described the year according to four seasons: spring, summer, fall, and winter. In Fort Yates and Little Eagle, some participants used Dakota or Lakota names for seasons. Both communities referred to fall as *Ptaŋyétu*. In Fort Yates, spring was referred to as *Wóžu*, a word associated with planting (Ullrich, 2008) and summer as *Blokétu*. In Little Eagle, summer was named *Wétu* and winter was identified as *Waníyetu*. Members of other communities know and use Dakota or Lakota terms for seasons but chose to use English words that were familiar to all participants. Regardless, most participants described seasons in relation to the months of the Gregorian calendar. In nearly all communities, the seasons were said to be similar in duration, each lasting approximately 3 months. The sole exception was in Kenel, where participants said winter is longer (5 months), than summer (3 months), spring and fall (2 months each).

Many participants indicated they know the names of months in the Dakota or Lakota calendar; however, participants tended to refer to the Gregorian months in English. During one interview, an Elder in Wakpala shared Lakota names for months corresponding to the Gregorian calendar, and these were incorporated into Wakpala's community's ecological calendar during the validation workshop. In Porcupine, an Elder provided the Dakota names for the 13 moon cycles in a solar year, which do not correspond to the Gregorian months. In both cases, the Lakota and Dakota names for months and moon cycles refer directly to ecological phenomena, including weather (e.g., *Wióthehǩika Wí*, meaning "the sun is scarce moon", associated with January), the development and behavior of living beings (*Wasúthuŋ Wí*, "moon when things ripen", used for August), and interactions between the two (*Čhaŋwápe Kasná Wí*, "wind shakes off the leaves moon", October). Others refer to human activities, such as *Wóžupi Wí*, "planting moon", associated with May. The Elder in Wakpala emphasized that the names for months differ among Standing Rock communities living in different ecological contexts, so they would use names that were most relevant. Furthermore, she said that names for months might differ among families in the same community who live in different ecological contexts or engage in different activities, particularly for the months in winter when there are fewer social activities and families are less likely to observe their landscape collectively.

As a result of colonization, the people of Standing Rock use the Gregorian calendar and apply it to their understanding of ecological rhythms in their habitats. This adaptive response reveals how Indigenous knowledge continues through the English language and European systems of timekeeping, including sophisticated cumulative knowledge of moon cycles in relation to ecological phenomena. The ability to derive meaning from multiple ways of measuring time as an adaptive response to colonization is also found in the Pamir Mountains of Central Asia, where the fourth author has conducted collaborative research with Indigenous communities (Kassam et al., 2011). These communities share a similar history of colonization by multiple invading forces and yet maintain embodied knowledge of their environments.

Although participants at first described seasons in relation to Gregorian months, in practice they use seasonal indicators to identify the transition from one season to the next (Table 3). Most seasonal indicators (19) are associated with the transition from winter to spring, which is considered the beginning of a new year in Lakota and Dakota calendars. By contrast, there are only four seasonal indicators mentioned for the transition from fall to winter, two for summer to fall and one for spring to summer. Many indicators are unique to a single community, demonstrating how context specificity leads to diversity of knowledge within ecological calendars.

All communities mentioned multiple indicators of spring, and participants discussed how they look out for multiple signs that spring has begun. The most frequently cited indicator of spring (mentioned in six of seven communities) was the singing of a Western meadowlark (*Sturnella neglecta*). Interestingly, the meadowlark's song is one of several acoustic indicators included in the ecological calendars, along with the sound of ice breaking up in rivers and the first rumblings of thunder (Table 3).

Documented observations of birds in Standing Rock by citizen scientists parallel their reliability as seasonal indicators. The earliest observations of meadowlarks and robins are typically in mid-March, although robins are sometimes reported in February (Figures 3a and 3b). The first observations of snow buntings, who are present through the winter, begin in late October (Figure 3c), whereas observations of migrating snow geese peak in the first half of November (Figure 3d).

Seasonal indicators are used in combination with the Gregorian calendar to understand changes in the timing of ecological phenomena relative to the solar year. Seasons are said to begin earlier or later than usual based on the date an indicator is observed. For example, during our community workshops in 2016, many participants had heard a meadowlark sing in early March and told us that spring had come earlier than normal that year. Thus, seasonal indicators serve as reference points to observe climate variability and respond accordingly, ultimately contributing to food sovereignty.

3.3. Temporal Relations Within Ecological Calendars

A *synchrony* is a temporal relation in which two or more phenomena reliably occur at the same time. When a participant describes the timing of an ecological phenomenon by referring to Gregorian months or dates, they are observing a synchrony between that phenomenon and the movement of the earth around the sun, on which the Gregorian calendar is based. Most ecological phenomena were described in relation to the Gregorian calendar, with differing degrees of specificity. On the ecological calendars, these relations are illustrated by a solid line beginning and ending with open triangles to indicate the range of possible dates (Figure S1 in Supporting Information S1). Many phenomena are associated with months; for example, participants in Wakpala said that wood ticks emerge in April. In other cases, participants were more specific: in Bullhead, participants said that prairie

Table 3
Seasonal Indicators Included in Ecological Calendars Co-Generated With Communities in the Standing Rock Nation

Seasonal transition	Seasonal indicator	Calendars
Winter-spring	Meadowlarks sing[a]	BH, CB, KN, LE, PP, WP
Winter-spring	Prairie crocuses blossom	BH, CB, KN, PP, WP
Winter-spring	Breakup of ice in rivers[a]	BH, CB, KN, WP
Winter-spring	Geese fly north	BH, PP, WP
Winter-spring	Robins return	CB, KN
Winter-spring	Other birds arriving or flying north	FY, KN, PP, WP
Winter-spring	Other flowers blossom	PP, KN, WP
Winter-spring	Trees bud	CB, KN, PP
Winter-spring	Temperatures rise	FY, KN
Winter-spring	Grass appears, greens	BH, KN
Winter-spring	Rain starts	BH, PP
Winter-spring	Wind starts	BH
Winter-spring	Allergies	BH
Winter-spring	Animals ready to shed	FY
Winter-spring	Thunder returns[a]	WP
Winter-spring	Prairie chickens dance	WP
Winter-spring	Snow melts away	KN
Winter-spring	Snakes and other animals emerge from hibernation	LE
Winter-spring	Animals give birth	LE
Spring-summer	Flies appear	BH
Summer-fall	Geese migrate south	LE
Summer-fall	Leaves fall from trees	CB
Fall-winter	First snowfall	BH, FY
Fall-winter	Snow geese fly south	PP
Fall-winter	Snow buntings arrive	CB
Fall-winter	Begins to get cold	CB

Note. BH = Bullhead; CB = Cannon Ball; FY = Fort Yates; KN = Kenel; LE = Little Eagle; PP = Porcupine; WP = Wakpala.
[a]Primarily acoustic indicators.

turnips flower at the end of May. Differences in specificity may reflect the duration of phenomena, variability from year to year, or other nuances that require further explanation. For example, an interviewee in Fort Yates said he gathers chokecherries at the time of the Little Eagle powwow at the end of July. He acknowledged it may be possible to gather chokecherries earlier or later, but chokecherries are reliably ripe on those days.

Participants also described synchronies in which two or more ecological phenomena occur at the same time. This kind of synchrony can shift in relation to the solar year. On the ecological calendars, these synchronies are indicated with bidirectional green arrows (Figure S1 in Supporting Information S1). For instance, participants in Bullhead said they gather juneberries and sandcherries at the same time. Knowing these two foods can be gathered simultaneously saves effort, since they happen to be found in similar habitats. Furthermore, although these fruits typically ripen in June, knowledge of their synchrony enables gatherers to adapt to interannual variability and longer-term trends affecting the timing of their development.

Whereas synchronies occur at the same time, a *sequence* is a series of seasonal phenomena that occur in a reliable order. For example, in Cannon Ball, participants noted that juneberries ripen before chokecherries, followed by wild plums and later buffalo berries. Like the synchronies just described, sequences can shift in relation to the solar year. In the ecological calendar illustrations, sequences are identified with an orange arrow that points from one event to the next (Figure S1 in Supporting Information S1). The length of time between sequential

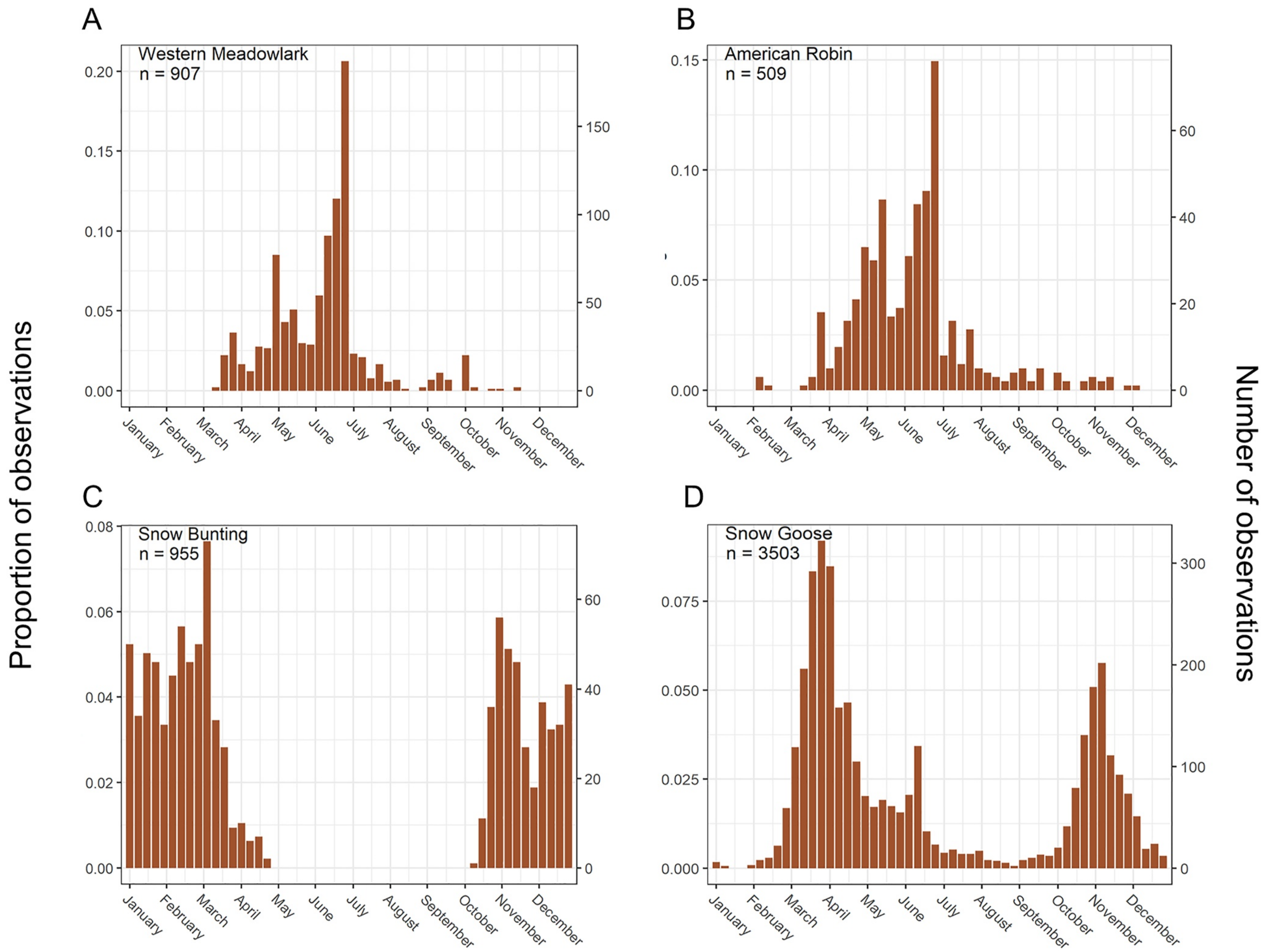

Figure 3. Documented observations of birds used as seasonal indicators in ecological calendars in the Standing Rock Nation. Observations of Western meadowlark and American robin are within the Standing Rock Nation, whereas those of snow bunting and snow goose include all of southern North Dakota and northern South Dakota. Data source: Cornell Lab of Ornithology (2021).

phenomena is unspecified, only the order. Nevertheless, knowledge of such sequences facilitates adaptation to the effects of a variable climate, because observation of one phenomenon (sweet juneberries, in this example) leads the community to anticipate the next part of the sequence (the chokecherries turning black, in this case).

The example of a sequence of gathering times is made up of independent ecological phenomena; the ripening of one type of fruit is followed by another, but the first is not causally connected to the next in the sequence. In other types of sequences, one phenomenon is directly responsible for another. For example, participants in Little Eagle said that the first sound of thunder in the spring wakes up animals that have been hibernating, including snakes that emerge from their dens. Causal sequences are distinguished from other sequences in the ecological calendar by a blue arrow pointing from the cause to the effect (Figure S1 in Supporting Information S1). As in the relations between thunder and snakes, many of the causal sequences found in the calendars describe effects of weather on plants and animals, suggesting that such relations may be impacted by anthropogenic climate change.

Another type of sequence is a seasonal cue, in which observation of a seasonal phenomenon is interpreted as a signal to initiate a particular activity. Seasonal cues differ from other sequences because they rely on human knowledge (i.e., someone must know how to observe and respond to the cue). In the ecological calendars, cues are indicated by a purple arrow pointing from the seasonal phenomenon serving as the cue to the activity initiated after observation (Figure S1 in Supporting Information S1). For instance, participants in Cannon Ball said they harvest buffalo berries after the first frost because the berries are sweeter and drop off the bush more easily. In

Table 4
Temporal Relations Included in Ecological Calendars Co-Generated With Communities in the Standing Rock Nation

Temporal relation	Bullhead	Cannon Ball	Fort Yates	Kenel	Little Eagle	Porcupine	Wakpala	Total
Synchrony	5	1	4	0	0	5	2	17
Sequence	6	12	1	0	7	5	7	38
Cause and effect	0	0	3	1	7	4	2	17
Cue	4	9	5	3	11	1	7	40
Block	0	1	0	0	2	0	2	5
Predictor	0	1	0	0	0	0	1	2
All	15	24	13	4	27	15	21	119

relation to the solar year, the first frost is highly variable, and the window of opportunity to gather buffalo berries is limited because birds will start eating them as soon as they are sweet. Therefore, gatherers must be ready to collect buffalo berries as soon as the frost is observed. Such seasonal cues are a particularly important feature of ecological calendars because they can optimize the timing of food system activities despite increasing climate variability.

In a few cases, participants mentioned seasonal cues that indicate when to stop rather than start an activity. In the ecological calendars, this kind of cue (referred to as a "block") is indicated by a red arrow that points from the phenomenon to the activity that should cease (Figure S1 in Supporting Information S1). For example, participants in Wakpala and other communities said they stop gathering *čhaŋšáša* (red willow or red osier dogwood, *Cornus sericea*), an important medicinal plant, after the first sound of thunder in the spring. Like other seasonal cues, the timing of blocks shifts in relation to the Gregorian calendar, and therefore facilitates adaptation to increasingly variable climate conditions.

Finally, some participants mentioned seasonal phenomena that provide information about future phenomena, including their anticipated characteristics or whether they will occur. For example, participants in Wakpala said that if they see crows fly south, they expect an unusually cold winter. Such sequences reflect a respect for the knowledge of other beings; in this case, crows are able anticipate a cold winter. We consider these to be another type of sequence, because one phenomenon reliably occurs before another, but they differ from causal sequences because the first phenomenon is not responsible for the second. In the ecological calendars, such sequences are indicated by a blue arrow pointing from the "predictor" to its prediction (Figure S1 in Supporting Information S1).

Altogether 119 distinct temporal relations were included in the seven calendars (Table 4). Looking across the ecological calendars, sequences and seasonal cues are more numerous than synchronies, and blocks and predictors are relatively rare. Although none of the temporal relations included in the calendars are the same, some involve the same phenomena. For example, Elders in Little Eagle described observing the blossoms of prairie roses as a seasonal cue to plant their gardens. Participants in Cannon Ball agreed that prairie roses blossom around the same time that they plant their gardens, but because they do not use these as a signal to begin planting, identified their relations as a synchrony rather than a cue.

3.4. Observations of Climate Change

Many of the ecological calendars include information about weather observed at different times of year, including temperature, precipitation (rain and snowfall), wind, cloud formations, and frost. Some calendars note recent changes in these patterns; for example, the Cannon Ball calendar notes that in the past, white, fluffy clouds were observed in spring, but have not been seen in recent years. Others point out changes in animal behavior that they associate with climate change. For example, participants in Fort Yates said that in the past, snakes returned to their dens in August, whereas recently they have been observed until September, presumably due to warmer temperatures.

Participants' attention to weather facilitates adaptation of their food systems to climate variability. As mentioned earlier, communities watch for the first frost in the fall to know when to gather certain fruits and fungi. Likewise, identifying the last frost in the spring informs decisions about when to plant a garden. However, high interannual

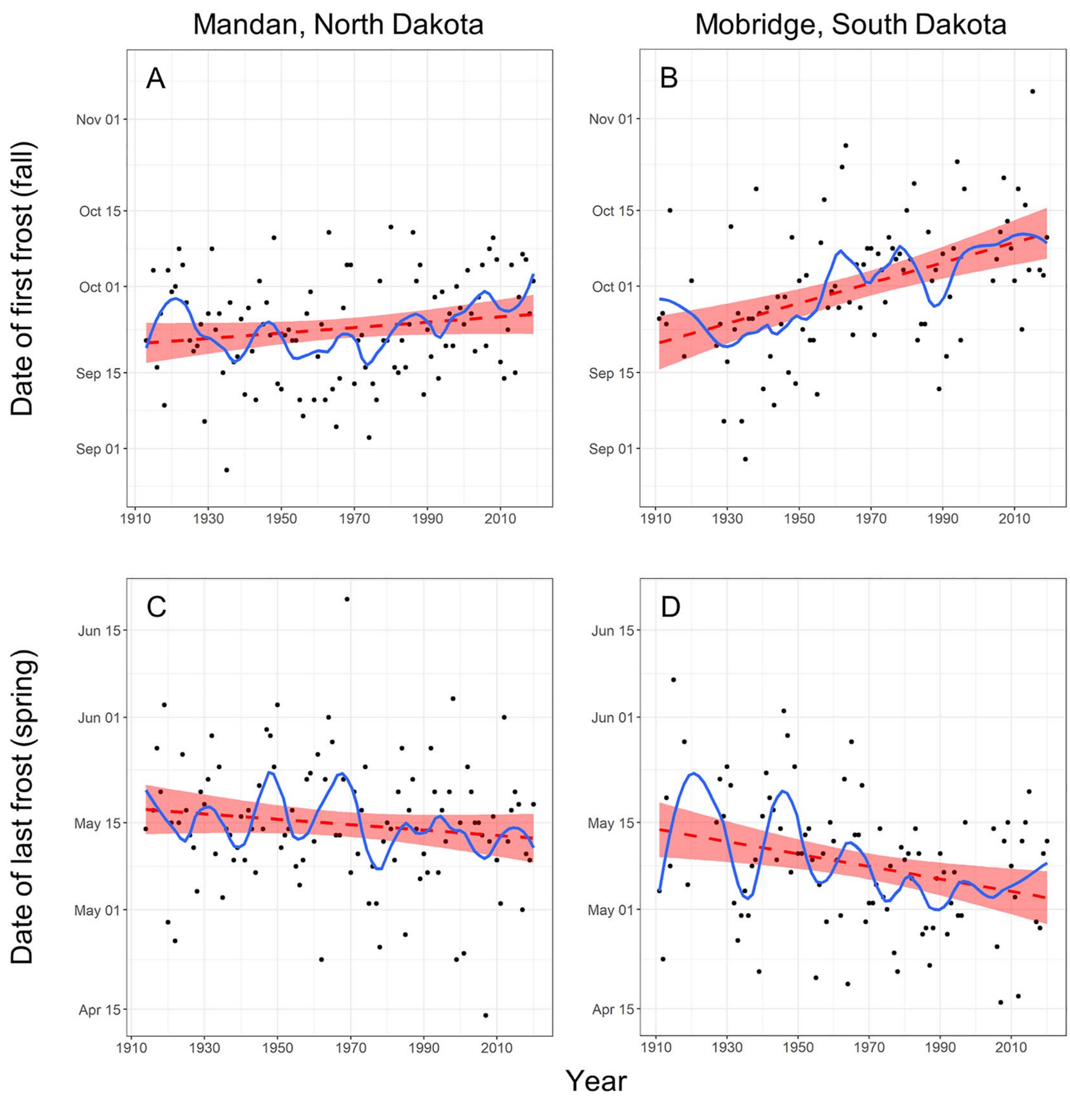

Figure 4. Change in date of first frost in fall and last frost in spring, as recorded at weather stations in Mandan, North Dakota (1914–2020) and Mobridge, South Dakota (1911–2020). The linear model (long-term trend) is depicted as a dashed red line, with confidence interval shaded red; the 10-year moving average is depicted as a blue line. Data source: NCEI (2021).

variability in the timing of first and last frosts make it extremely difficult to perceive long-term trends. Furthermore, such high variability means the average dates are largely irrelevant because they are unlikely to be observed. Not surprisingly, participants mentioned high variability in the timing of frost but did not describe long-term trends.

Nonetheless, statistical analyses of first and last frost dates suggest long-term changes that may impact local food systems. Historical data from the two weather stations closest to Standing Rock (Mandan, North Dakota, and Mobridge, South Dakota) align with participants' observations that the first frost in the fall typically occurs in September or early October, with high variability from year to year. In Mandan, linear regression did not detect significant change between 1914 and 2020 (Figure 4a, $p = 0.099$). However, in Mobridge, our analysis suggests that the first frost has been arriving significantly later between 1911 and 2020 (Figure 4b, $p = 0.001$), an average of one day later every seven years. Correspondingly, the last frost typically occurs between mid-April and early June, with even higher interannual variability. Again, there is no significant long-term trend in Mandan (Figure 4c, $p = 0.184$), but the last frost has been occurring significantly earlier in Mobridge (Figure 4d, $p = 0.005$); on average, the last frost has arrived 1 day earlier every 10 years.

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Although statistically significant shifts in the timing of frost raise concerns about effects on ecosystem processes, none of the participants mentioned long-term trends. In fact, despite the average last spring frost coming earlier, several participants remarked on unusually late frosts in the spring. These events were considered outside of the normal range because they came after certain food plants such as juneberries had already blossomed and thereby inhibited fruit production. Although unusual, participants indicated that such a reversal of the typical sequence (frost coming after rather than before the juneberry blossoms) was not unprecedented. Indeed, participants emphasized the need for close observation of frost events in spring and fall before planting a garden or gathering berries, which may prove a highly adaptive approach to increasing climate variability.

3.5. Impacts of Colonialism

Government programs have had devastating consequences for Indigenous knowledge systems, including the relations and knowledge underlying ecological calendars. Many of the Elders who participated in this research were taken to boarding schools where they were forbidden to speak Lakota or Dakota and had limited opportunities to participate in the activities included in the ecological calendars. One of the reasons participants who can speak their Native language chose to share information in English rather than Lakota or Dakota was to avoid excluding participants who did not learn their Native languages as children.

In several communities, Elders expressed gratitude for the research process as an opportunity to share memories with each other as well as the research team. In some cases, these memories revealed ecological changes, such as the disappearance of plants and animals from the landscapes surrounding their communities. Seasonal phenomena and activities from the past were included in the calendars using brown (as opposed to black) text and icons (Figure S1 in Supporting Information S1). Elders in Bullhead, for example, remembered they used to gather gooseberries, which they said are no longer available, most likely due to the conversion of land to large-scale crop and cattle production. Many other memories highlighted changes in ways of life. For example, Elders in several communities remembered gathering, chopping, and stacking firewood to prepare for winter. These activities are no longer necessary, as most families heat their homes with propane, and few families have access to firewood following the destruction of forests by the Oahe Dam.

Some of the starkest impacts of government policies were observed in the community of Kenel, where families were forcibly relocated from their homes along the Missouri to a hilltop overlooking Lake Oahe. The ecological calendar for Kenel is dominated by the memories of Elders who grew up along the river. In addition to remembering the plants they once gathered from riparian forests, participants spoke at length about their interactions with the settler community of Powell, South Dakota, located on the east bank of the river, which was accessible by boat prior to the construction of the dam. Elders recalled dances and other social events in Powell, as well as trade of food and firewood; these social relations were an important aspect of food sovereignty disrupted by the dam.

Another example of colonial policies restricting seasonal activities related to food sovereignty is the regulation of hunting seasons. In several communities, participants noted changes in the timing of hunting from summer to fall mandated by state and tribal agencies. In the past, participants' decisions about when to hunt were based on their knowledge and use of animals. For example, participants said they once hunted deer in the summer because the conditions are better for drying meat to store for the winter. By contrast, beginning as early as the 18th century, Euro-American settlers restricted hunting to the fall and winter. The adoption and enforcement of regulated hunting seasons increased as deer populations declined throughout the 19th and early 20th centuries (Hewitt, 2015). In some parts of the United States, numbers of hunters have declined and deer populations have rebounded, suggesting opportunities for authorities to reconsider their management strategies (Riley et al., 2003), including the timing of hunting seasons. In the Northern Great Plains, however, hunting remains a primary cause of deer mortality and conversion of fallow land to crop production continues to impact deer populations (Grovenburg et al., 2011). Even if restrictions remain necessary, the Standing Rock government could consider whether hunting seasons for tribal members might be modified to reflect Indigenous ecological knowledge and foodways, thereby enhancing food sovereignty.

3.6. Diversities of Ecological Knowledge

From the beginning of our collaborative research process, participants emphasized the need to develop a unique ecological calendar for each community. They pointed to differences in the timing of seasonal phenomena

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Table 5
Differences in the Time to Gather Chokecherries in Ecological Calendars Co-Generated With Communities in the Standing Rock Nation

	Early July	Mid-July	Late July	Early August	Mid-August	Late August
Porcupine	x	x	x			
Little Eagle	x	x	x	x	x	x
Bullhead		x	x			
Fort Yates			x	x		
Wakpala			x	x	x	
Kenel				x	x	x
Cannon Ball					x	

according to the location of their communities in relation to landscape features such as hills, ravines, rivers, and forests. The ecological calendars reveal the diversities of habitats to which communities have access. For example, the community of Little Eagle is close to the Grand River and some of the richest cottonwood forests; the Little Eagle ecological calendar includes plants and animals that are difficult to find in other parts of Standing Rock and therefore not included in their calendars. The four communities located close to the Missouri (Cannon Ball, Fort Yates, Kenel, and Wakpala) included fish in their calendars, which were absent from the other three.

In addition, participants emphasized the cultural diversity among their communities in terms of language and tradition. As mentioned earlier, Standing Rock is home to a diversity of Indigenous cultural identities, including the Iháŋktȟuŋwaŋna and Húŋkpatina of the Yanktonai and the Húŋkpapȟaya and Sihásapa of the Lakota. Of course, many participants trace their ancestry and cultural knowledge to multiple Native groups as well as diverse settler communities. Furthermore, individuals have moved between communities within and outside of the reservation, generating further combinations of knowledge and traditions. This was particularly evident in Fort Yates, where many participants had relocated to work for the tribal government and have incorporated knowledge from the places they grew up into the ecological calendar.

Ecological and sociocultural differences result in variation among the calendars, including phenomena that one might expect to be relatively consistent. One example is the time to gather chokecherries, which was included in all seven calendars (Table 5). Notably, communities identified different gathering times in relation to the Gregorian calendar, which may be related to the heterogeneity of microclimatic and edaphic conditions in different parts of Standing Rock, as well as use of chokecherries at various stages of maturity to prepare a variety of foods (e.g., chokecherry juice, patties, or *wasna*) following different methods (e.g., sun-drying or using an electric dehydrator). As reported in past research collaborations (Ruelle & Kassam, 2011), participants approached the diversity of knowledge among their communities as a source of strategies for adapting to climate change and other challenges.

3.7. Furthering Our Collaborative Research Agenda

The ecological calendars co-generated with Standing Rock communities remain works in progress. Due to the COVID-19 global pandemic, which disproportionately impacted Indigenous nations including Standing Rock, the research team has not reviewed the current iteration of ecological calendars with the community members who co-generated them. Many participants are Elders who are particularly vulnerable in a pandemic yet lack reliable internet services to meet virtually. When feasible, the research team plans to distribute printed copies of the community report, including large-format copies of ecological calendars, to community centers where they can be examined, discussed, and updated. Because the community report includes all seven calendars, this will be the first opportunity for participants to see the efforts of other communities and serve as a first step in knowledge exchange. Furthermore, the community report includes ecological calendars co-generated with communities in upstate New York and the Pamir Mountains of Tajikistan and Kyrgyzstan. Learning about the work of other communities is likely to inspire further development of Standing Rock's ecological calendars.

As a basis for food sovereignty, ecological calendars must continue to integrate new knowledge that is relevant to ever changing climate realities. The ecological calendars reported here are a momentary snapshot of constantly evolving temporal relations and knowledge. While the documentation of these relations aims to reinforce their significance and facilitate Elders' efforts to convey them to young people, there is some risk of their being seen as final and complete. We emphasize the need for ongoing community-driven research to engage a broader array of knowledge holders, particularly young people engaged in seasonal activities. Furthermore, we recognize that printed formats presented here are difficult to modify, and future efforts should focus on interactive digital outputs that can more easily incorporate additional knowledge.

4. Conclusions

Ecological calendars co-generated with communities in the Standing Rock Nation illustrate the significance of human ecological relations to food sovereignty, including plants (42), animals (48), and fungi (4). Of these, relations with herbaceous plants, non-domesticated trees and shrubs, birds, fish, and mammals make prominent contributions, including use as food, but also providing information to synchronize food system activities with highly variable climate conditions. Although participants rely on the Gregorian calendar to describe seasonal phenomena, workshops and interviews demonstrated knowledge of seasonal cues, sequences, synchronies, and causal relations that respond to interannual variability and shift in relation to the Gregorian calendar, thus facilitating the adaptation of food systems to climate change. Although participants noted the local impacts of climate change in Standing Rock, temporal relations were described as reliable, despite high variability, as in the case of frost. There is no denying the on-going impacts of settler colonial policies on Indigenous knowledge in Standing Rock, including the effects of habitat destruction wrought by the Oahe Dam and suppression of knowledge and values affected by residential schools. However, a diversity of knowledge among Standing Rock communities suggests important opportunities for the revitalization of food sovereignty through knowledge exchange. The ecological calendars illustrate exciting possibilities for Standing Rock youth to engage plants and animals throughout the year, forging new knowledge and relations to support the food sovereignty of their communities and Nation.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

The ecological calendars referenced throughout this article are documented in our community report (Kassam et al., 2022), which is available for download at https://cornell.app.box.com/s/d6pp5wk2p5303caotte346yu6lzgbydf.

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