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Rhythms of the Earth: Ecological Calendars and Anticipating the Anthropogenic Climate Crisis

Ecological Calendars of the Pamir Mountains: Illustrating the Importance of Context-Specificity for Food Security

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Abstract Communities in the Pamir Mountains of Central Asia are among the most vulnerable to climate change due to their geographic location and subsistence-based livelihoods. Historically, ecological calendars supported their agropastoral lifestyles which provided anticipatory capacity to seasonal changes. Due to decades of Soviet colonization and socioecological transformations, knowledge of these ecological calendars fell into disuse. In 2016, Savnob and Roshorv, two villages in the Bartang Valley of Tajikistan, began the revitalization of these calendars using a participatory action research process through knowledge co-generation. We undertook a comparative analysis to investigate the importance of context-specificity to ensure food security and reduce their vulnerability to climate change. A preliminary analysis of the temperature regime and local language terms, relating to the positioning and quality of land, framed our methods-of-analysis. We compared the villagers' ecological calendars by focusing on indicator species, potentially threatening weather events, land-use, livelihood activities, and the role of the vernal equinox. Despite their close geographic proximity, context-specificity determined by distinct microecologies influences the timing and practice of these communities' livelihood activities. These villages have different dependencies on biotic and abiotic events, crops, and land-use; all of which affect food security and survival. These differences contributed to mutual support between the two villages, increased the availability of food, and thereby, lowered their vulnerability to climate change. As Savnob's and Roshorv's ecological calendars are updated with changing climate, they can once again enhance their anticipatory capacity while reducing their vulnerability.

Plain Language Summary The villages of Savnob and Roshorv, in the Bartang Valley of Tajikistan, are vulnerable to climate change. For generations, these communities have been using ecological calendars, created through the accumulation of traditional knowledge, to anticipate changes in their environment and to inform their farming and herding practices. After a history of Soviet colonization and socioecological transformations, these ecological calendars fell out of use. Together with local knowledge holders, researchers aimed to co-create new calendars. We demonstrate the importance of Savnob's and Roshorv's distinct ecological calendars considering local conditions to achieve food security in response to climate change. We compared their use of animals, weather events, access to land, livelihood activities, and the role of the vernal equinox. Despite being located within the same valley, the villagers access food differently, work their land at alternate times, and in distinct ways. These variations between Savnob and Roshorv influence each communities' farming, herding, hunting, and gathering practices. Thus, this emphasizes the importance of place-based knowledge in achieving food security.

Key Points:

- Despite geographical proximity, a transdisciplinary approach demonstrates different micro-level ecologies in two Bartang Valley villages
- Ecological calendars illustrate the significance of context-specificity for achieving food security
- Ecological calendars can inform a community's anticipatory capacity and reduce vulnerability to future environmental change

Supporting Information:

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

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1. Introduction

Across Central Asia, surface temperatures have been significantly rising due to anthropogenic climate change, resulting in detrimental consequences for local communities (Finaev et al., 2016; Haag, Jones, et al., 2019; Hu et al., 2014). One direct consequence is food insecurity. Based on the Climate and Food Vulnerability Index, Tajikistan has high food insecurity, while being ranked among the countries least responsible for greenhouse gas emissions (Ware & Kramer, 2019). High elevations with poor accessibility and elevated susceptibility to natural hazards exacerbates the vulnerability of certain villages in the mountains of Central Asia. These communities are usually characterized by a low diversification of livelihoods, primarily being subsistence-based farmers and herders (Gentle & Maraseni, 2012; Kohler et al., 2010; Manandhar et al., 2018). Neighboring villages in the Bartang Valley of Tajikistan, Savnob and Roshorv, historically managed to ensure food security by aligning the timing of their seasonal agropastoral activities with the occurrence of biotic indicators. Knowledge about seasonal activities and their relation to indicators is embodied in the communities' ecological calendars (Kassam et al., 2011).

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Historically, the information and experience contained in the calendars was stored in people's minds and manifested through their activities. Practice and oral tradition communicated these insights to subsequent generations. A long accumulation of traditional knowledge, demonstrated by local praxis, shaped these calendars. However, Soviet colonization and collectivization forced the calendars into disuse, leading to a partial loss of knowledge. The unprecedented pace of climate change is posing new environmental challenges to these communities' livelihoods. As a result, it has become difficult for them to anticipate seasonal changes and ensure their own food security and survival (Kassam, 2009a, 2009b). In 2006, while describing climatic variation and the increasing frequency of unusual weather events, villagers consistently referenced their historic use of ecological calendars as an effective means to anticipate seasonal change (Kassam et al., 2011).

Transdisciplinary and innovative approaches are needed to address the problem of food insecurity at the scale of villages in complex topographies where high-resolution instrumental climate data is largely missing. Diverse disciplinary and participatory approaches can provide context-specific insights at the local scale. Mountain villages that are close in terms of geographic proximity are at risk of being grouped analytically as well as in the application of solutions to general problems, such as climate adaptation strategies. Community members in the village of Savnob initially raised concerns about the loss of generational knowledge and the adaptive potential of their traditional ecological calendars. In 2016, the collaborative and transdisciplinary research project entitled, "Ecological Calendars and Climate Adaptation in the Pamirs" initiated the revitalization of Savnob's and Roshorv's ecological calendars. The research team collaborated with both communities to co-create calendars through verbal, textual, and visual representations for use by the respective villagers in the form of community reports (Kassam et al., 2022). The hand-drawn icons explicitly make the embodied knowledge contained in the calendars visible. Visualization is key to research communication and impact. It underlines the importance of context-specificity for achieving food security.

We, the three authors of this paper, were members of the Ecological Calendars and Climate Adaptation in the Pamirs project. This project co-generated deeply rooted ecological calendars for Savnob and Roshorv containing detailed examples of local particularities. These two calendars provide a unique opportunity to compare two villages in close geographic proximity through biotic and abiotic events, cultural traditions, and interactions between the community members and their environment. Our paper illustrates a transdisciplinary collaborative process of expressing ecological calendar research. Building from this foundation, we explain the importance of context-specificity in ensuring food security. Therefore, our research objectives are to:

1. demonstrate context-specific differences between the ecological calendars of Savnob and Roshorv,
2. analyze the various ways the local particularities of the respective villages are meaningful for food security, and
3. discuss what our results mean in terms of these communities' vulnerability and anticipatory capacity to climate change.

2. Background

2.1. History of Ecological Calendars in the Pamirs

Ecological calendars are living knowledge systems that continuously incorporate new learnings. Calendars arise through generations of experiential knowledge and shared insights within community contexts. Various kinds of ecological calendars have been documented around the world including in the Gunungkidul Karstic region of Indonesia (Retnowati et al., 2014), among the Iñupiat in Alaska (Kassam, 2009a), the Akan of Ghana (Adjaye, 1987), the Tukano in the Amazon (Cochran et al., 2015), the Nuer people of South Sudan (Evans-Pritchard, 1939), and with members of the Yugul Mangi rangers (McKemey et al., 2020) and the Ngan'gi set of languages (Woodward & Marrfurra McTaggart, 2019) from Australia. Each of these calendars is based on an understanding of time as relational to ecological processes rather than the movement of celestial bodies, which are the primary focus of the familiar Gregorian calendar. Most ecological calendars use phenological indicators to inform subsistence activities. These calendars evolve and incorporate elements of other calendar systems. In the Pamirs, the movement of people due to Silk Roads, war, and colonization has informed the dynamic and diverse cultures in the region (Kassam et al., 2011, 2018). As a result, ecological calendars in the Pamir Mountains are diverse, varying among villages (Kassam et al., 2011). However, the Soviet Union had a tremendous impact on livelihoods due to *kolkhoz* and *sovkhoz*; collectivization and industrialization of agriculture (Bliss, 2006; Kassam et al., 2018). This disruption resulted in a loss of expertise regarding local crop production in their montane habitat, jeopardizing their food

security (Kassam, 2013). For instance, communities in the Bartang Valley used calendars of the human body, a type of ecological calendar, as the primary agricultural calendar continuing into the 1930s (Andreev, 1958). Rather than counting days according to the position of the sun and moon, specialists recognized by the community (known as *hisobdons*) kept track of time according to the movement of the sun and ecological phenomena and decided when local villagers should begin to count days on their bodies (Andreev, 1958; Kassam et al., 2011; Lentz, 1939). Each body part corresponded to ecological events and human activities (Andreev, 1958; Kislyakov & Pisarchik, 1966). An analysis of the original calendars revealed every calendar to be distinct according to different valleys and villages, reflecting the cultural and ecological context, including local climate conditions (Kassam et al., 2011).

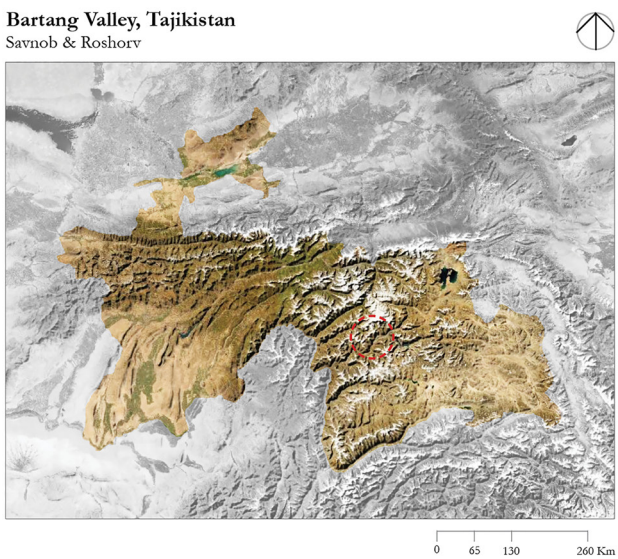
Although Soviet rule suppressed the calendars of the human body, some elements remain embedded in the local languages (Kassam et al., 2011). Analyzing language can give us insights into the importance of local praxis for understanding ecological change. Language, a key component of culture, can reveal knowledge of patterns in the landscape. Historically, the Pamir region was known for its extensive crop diversity, variable at the level of crop fields. Several dialects formed, likely due to local isolation among villages, and with these arose new names for crop varieties appearing in the farmers' fields (Nabhan, 2009). In addition to describing conditions impacting food security, local lexicons demonstrate villagers' relationship to land and each other. Over time, as people move and the climate changes, words can become modified or even irrelevant under different conditions. For instance, expressions describing agricultural patterns in one's homeland may not apply in a different agroecological zone. Identifying context-specific terms in the language can therefore be a key point of reference to understand various forms of local shifts (Kassam et al., 2011).

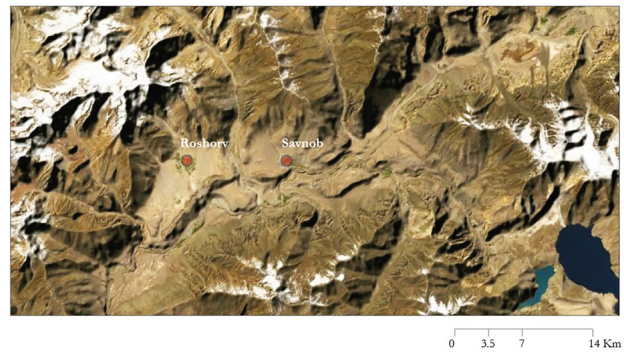
The Ecological Calendars and Climate Adaptation in the Pamirs project showed that despite historical suppression, ecological calendars and the oral transmission of knowledge remain significant in the Bartang Valley of Tajikistan. The ecological calendars of Savnob and Roshorv retain elements of the traditional calendar of the human body, blended with the communities' insights about their habitat. These calendars describe seasonal changes in the local environments and identify indicators that hold particular significance to livelihood activities, such as the cultivation of crops or the herding of livestock. To achieve food security, agropastoral practices must be carefully synchronized with specific ecological systems (Kassam et al., 2018, 2022). The calendars, therefore, underly the communities' ability to anticipate, plan, and adapt place-based observations. Furthermore, villagers' knowledge is unique in that it is embedded in a particular context and shaped through intergenerational experience.

2.2. Geographic Differences of Study Sites

The villages of Savnob and Roshorv are located approximately 8 km apart in the Bartang Valley of the Autonomous Region of Gorno Badakhshan of Tajikistan (Figure 1). At 2,692 m above sea level (masl), Savnob covers an area of 0.5 km^2, whereas Roshorv is situated at 3,139 masl with an area of 2.6 km^2. The population of Savnob is approximately four times smaller than Roshorv (Haag et al., 2021). Subsistence livelihoods, primarily small-scale farming, and herding livestock, deeply connect both communities to their habitat (Kicherer, 2018).

To ensure food security, communities have learned to align their activities with abiotic conditions. Despite their geographic proximity, the biophysical conditions differ between Savnob and Roshorv. Steep slopes encircle Savnob, which has access to spring water, while Roshorv is situated in an extensive flat terrain on the side of a mountain supported by a glacier-fed river (Kassam, Ruelle, et al., 2021). In a semi-arid area, such as the Pamir Mountains of Tajikistan, the availability of surface water is key for food security as are local climate conditions. However, little is known about climate trends at the scale of villages in the Pamir Mountains, which can differ from regional levels (Haag, Kassam et al., 2019; Haag et al., 2021). For Savnob and Roshorv only limited information about past and current climate conditions exists, based on two weather stations installed by the Ecological Calendar and Climate Adaptation in the Pamirs project and a downscaled, monthly temperature data set developed by Haag et al. (2021). The data demonstrate that both villages have experienced warming temperature trends across all seasons between 1979 and 2018. The strongest warming occurs in summer, with over 0.3°C increase per decade (Haag et al., 2021). Located at a lower elevation, Savnob is generally warmer than Roshorv, resulting in fewer frost days and a longer growing season. The absolute temperature difference between the two villages averages approximately 2.39°C. Technical information on the above-mentioned data sets, methods applied to calculate associated climate indicators, and further data on temperature variation is in Supporting Information S1.





Bartang Valley	Roshorv	Savnob
Coordinates	38°19'04"N 72°19'29"E	38°19'58"N 72°24'32"E
Elevation (masl)	3,139	2,692
Population Size	1,200	310

Figure 1. Map of Savnob and Roshorv, situated within the Bartang Valley of Tajikistan.

The interview transcripts also illustrate a temporal offset between the villages, impacting the timing of agricultural activities such as planting times. Compared to Roshorv, Savnob planted 6 and 18 days earlier in 2016 and 2017, respectively. The ecological calendars outline each events' timeframe.

Both villages culturally identify as Bartangi. Their primary dialects consist of Shugni and Rushani, which belong to the Pamiri language group of the Indo-European language family. Local languages include terms to describe the divergent characteristics of the two villages. For example, community members in Savnob and Roshorv use the terms *poytakht* and *sarad* to distinguish a village based on its geographic location and climate. Locations at low altitude, which tend to have warmer climatic conditions and fertile agricultural fields are considered *poytakht*, whereas villages at high altitudes with cold weather and limited plant productivity are termed *sarad* (Shakarshoevich, 2017). Community members refer to specific crops which grow in *sarad* and *poytakht* villages. In Savnob, a *poytakht* village, people can grow wheat, the staple food in the region, as well as cucumbers, tomatoes, apples, and apricots. By contrast, farmers in Roshorv, a *sarad* village, primarily grow barley (Ekbolsho, 2017). Furthermore, local languages include terms for climatic variability within a village, at a scale generally not captured by climate data. For example, villagers in Savnob use the phrases *wombi zamin* and *sai zamin Wombi* (or *ghumbi*) *zamin* which describe the area close to a reliable water source, emphasizing its fertility. S*ai* (or *say*) *zamin* refers to a dry, unfertile area lacking access to water. Villagers observe that "people in *sai zamin* plant and harvest some days earlier than *wombi zamin*. *Wombi zamin* has a better harvest than *sai zamin"* (Gulbahor, 2017).

In the Pamirs, language expresses an ecological outlook. Descriptions of villages highlight their ecological characteristics. Specific terminologies for air temperature, soil fertility, or geographic location of water reveal strong interconnectivity between communities and their habitat. These relationships foster their use of ecological calendars and inform the communities' survival.

3. Methods

3.1. Development of Ecological Calendars Within the Ecological Calendars and Climate Adaptation in the Pamirs Project

The Ecological Calendars and Climate Adaptation in the Pamirs project took a transdisciplinary framework and an action research approach to combine expertise from the community of enquiry (researchers from multiple academic disciplines) and the community of practice (farmers, herders, hunters, and orchardists). It brought scientists and their students from various fields together with a diverse group of local practitioners to support collaboration and the co-generation of knowledge. This project was built on a strong foundation of trust, beginning in

2006, when Karim-Aly Kassam, the lead principal investigator of the Ecological Calendars and Climate Adaptation in the Pamirs project, first learned of ecological calendars in the village of Savnob (Kassam, 2009b; Kassam, Ruelle, et al., 2021).

An iterative research process formally began in June 2017, with an inception workshop in each village to discuss the revitalization of ecological calendars as a way to enhance anticipatory capacity for climate change. The attendees in Savnob (5 women and 15 men) and Roshorv (3 women and 15 men) were invited based on their various leadership roles as well as their ecological professions, such as farming, herding, gathering, and hunting. Each participant gave their informed consent. With the approval of community leaders, the research team installed weather stations in each village. They collected phenological data and conducted individual interviews focused on agropastoral practices, climate change, and how the local landscape influences agriculture. A member of the community of enquiry facilitated the interviews, posing questions to the participants by moving through the various seasons, and asking about key characteristics and the individuals' livelihood activities. There were 20 individual interviews conducted in Savnob with 6 women and 14 men. As for Roshorv, there were 17 interviews with 3 women and 14 men. The purpose was not to attain a general agreement among individuals but to incorporate the variation and distinctiveness of each perspective to enhance insights gained about ecological calendars (Kassam, Ruelle, et al., 2021).

In July 2018, members of the community of enquiry returned to Tajikistan to organize validation workshops. These events allowed the community of practice to assess the accuracy and correct any errors in the information gathered by the researchers in the previous year. Participants included village leaders, members from the inception workshop, individuals interviewed, as well as others who were interested. There were 23 participants from the village of Savnob, 4 women and 19 men, and 19 participants from the village of Roshorv, consisting of 3 women and 16 men (Kassam, Ruelle, et al., 2021).

Under the supervision of the Principal Investigator Karim-Aly Kassam, Ullmann and Bulbulshoev collaborated in 2019 to visualize the validated traditional knowledge as an illustrated ecological calendar. Our goal was for it to be understood by the respective communities as well as the wider public. This process required translating local, shared Indigenous ecological knowledge into widely accessible forms by adding the element of durable visual documentation. We visualized the calendars through hand-drawn icons of ecological and cultural events. Such iconography surpasses language barriers, allowing for communication across cultures. Interview transcripts contextualized and conveyed the villagers' insights upon which we built the ecological calendars. The transcripts served as the basis for descriptions explaining each icon as well as its role in the local environment. The icon descriptions and ecological calendars have the potential to perform as a manual of important biotic life where the illustrations operate as a realistic field guide, making them accessible and applicable to the Bartang Valley villagers, schoolteachers, and policymakers.

To remain true to the spirit and unique characteristics of the Bartang Valley, it was essential for the local culture to inform the calendars' overall design. Therefore, the frame of the ecological calendars refers to the calendars of the human body. On either side of the calendars stand a man and a woman in traditional Pamiri dress (Figure 2). The spaces between the humans at their heads and feet, called *chillas*, correspond to the period when the sun passes through the human body, initiating a pause in counting. They are periods of rest in the calendars of the human body allowing for reflection and rejuvenation for the community at key times of the year (mid-summer and winter). Historically, calendars of the human body were embodied knowledge visually expressed through time. The artistic representation of human bodies in the ecological calendars illustrates the complex connectivity and reproduces this effect. The calendars provide a comprehensive picture, asserting and reinforcing the connection between humans and their local ecology. The visual and physical expression of the calendars in the local environment is a methodological response. Every icon emphasizes the villagers' insights, illuminating the integration of their knowledge systems in the 21st century.

The sun reappears in the center of the ecological calendars, shining through a traditional skylight into a Pamiri home. In the Bartang Valley, community members track the sun's movement, showing the passing of time across the mountains as well as within the architecture of local houses. Ecological calendars incorporate the sun due to its cultural significance and necessity for sustenance and survival. The octagonal outline of the ecological calendars serves many purposes. Not only does it refer to the communities' cyclical and spiritual character, but it assists in reading the calendars. Four colors distinguish the outline of the octagon, divided to represent the four seasons spring, summer, autumn, and winter. This allows for orientation as a reference point when reading the calendars

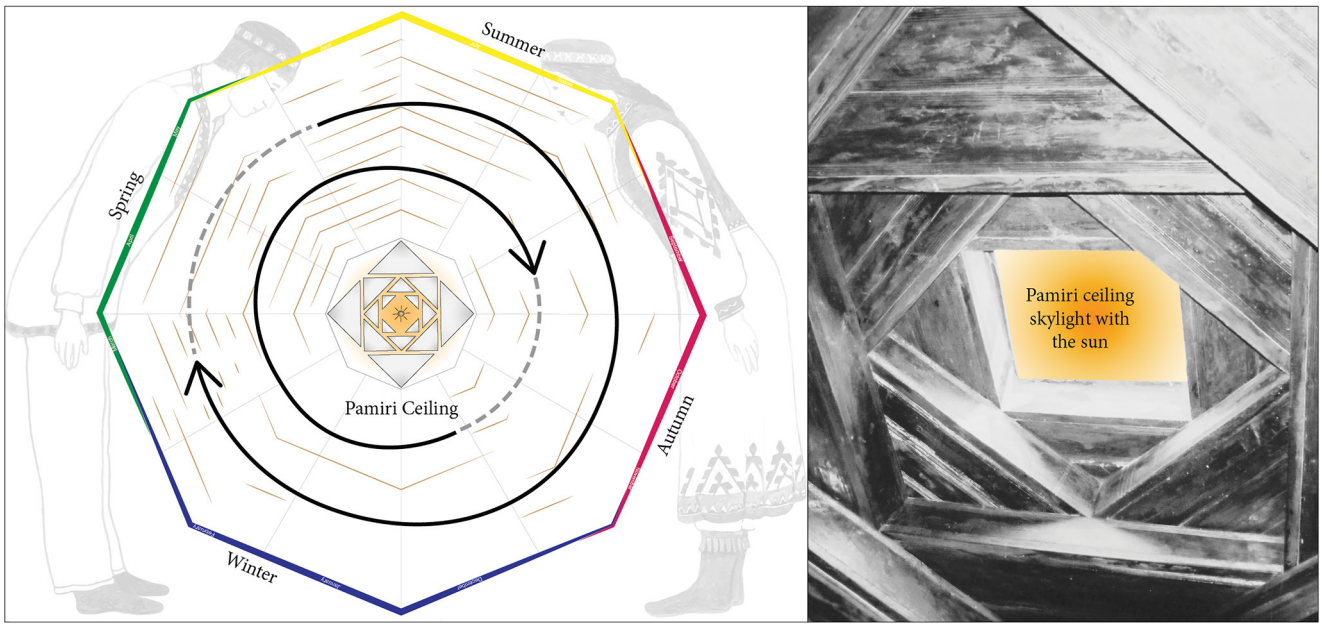


Figure 2. A depiction of the calendar of the human body, octagonal frame, and hearth. The photograph of the sun shining through a traditional skylight in Gudara, taken by Kassam in 2006, inspired the center design. The arrows illustrate how to read the calendars as well as highlight the multiple levels of content within the Bartang Valley ecological calendars.

if shifts occur. For instance, if the duration of winter shortens overtime, the corresponding blue line will visually present this reduction in length. Similarly, if the timing of events changes over time, their placement with respect to the months will be different within the ecological calendar. This means the calendars provide information across spatial and temporal scales.

While this most recent format was unfortunately unable to undergo a second validation by the community due to the SARS-CoV-2 pandemic, the research team returned the calendars to their respective communities in the published form of community reports. Furthermore, in October 2021 the research team presented these ecological calendars at an international conference with members of both villages (Kassam et al., 2022).

3.2. Analysis of Ecological Calendars

We, the authors of this paper, collaborated to conceptually interpret the data collected from the Ecological Calendars and Climate Adaptation in the Pamirs fieldwork and identify those aspects impacting local food security. We compared the Bartang Valley ecological calendars to analyze the similarities and differences between Savnob and Roshorv. The sizes of the villages determined the spatial bounds for our analysis. Therefore, this paper discusses the local context within the scale of hundreds of meters to kilometers. The challenges of anthropogenic climate change, and the specificity of our research questions, required a transdisciplinary methodology. We identified how context-specific characteristics of Savnob and Roshorv relate to the villagers' livelihoods, and how their human ecological relationships affect their food security.

Our analysis of particularities revealed how and why the calendars are context specific. Given the illustrated icons symbolize every event in the calendars, the visual contextualized the text of this paper. Our evaluation of Savnob's and Roshorv's ecological calendars also extended beyond the visual calendars to incorporate the descriptions, stemming from interview transcripts, within the accompanying icon legend. Our comparison used both documents as points of reference. Because the community members primarily engage in agricultural activities, we drew from examples relating to farming activities and corresponding crops.

The content of the Bartang Valley ecological calendars contains unique icons for abiotic and biotic aspects as well as human activities and cultural events. We selected icons for our analysis based on their relation to agropastoral activities and methods of traditional timekeeping. To demonstrate context specificity and its importance to food

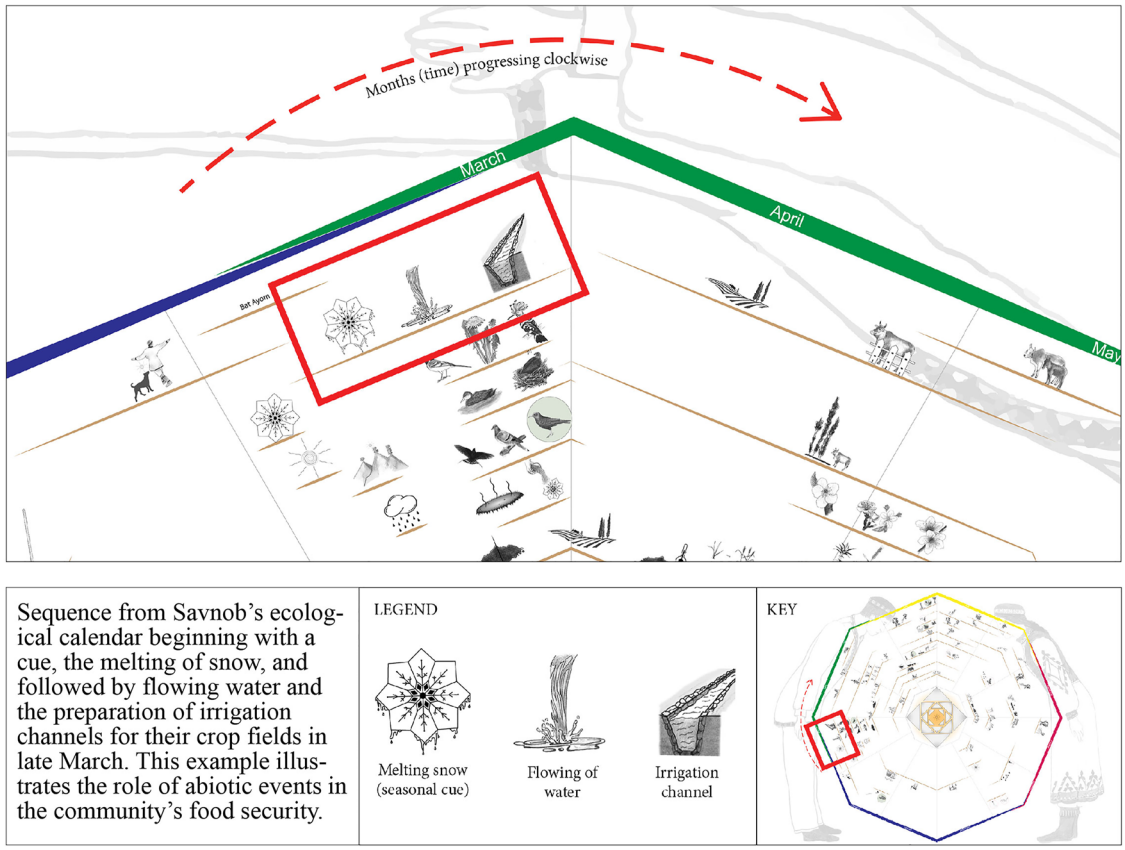


Figure 3. Savnob's ecological calendar adapted from Kassam et al. (2022) highlights a sequence in spring that informs food security.

security, we focused on the relationship between the villagers and their habitat, which included an analysis of cues, sequences, the use of landscape, livelihood activities, and events coinciding with the vernal equinox. Cues inform and prompt villagers to perform livelihood activities. Community members observe cues, which can be celestial, abiotic, or biotic phenomena. Beginning in January and moving through the year, we identified all cues as the first icon in a sequence that impact livelihoods in the respective villages. Sequences refer to a chronological series of events that occur through time. Sequences of events are displayed on the lines. Lines communicate the span of time, and their placement within the calendars refers to the timeframe in which events occur. The first event of a sequence is therefore the first icon on a line when reading the calendar clockwise, from left to right.

For instance, to demonstrate a sequence in Savnob's ecological calendar, refer to a light brown line extending from the end of February into March (Figure 3). This line holds three abiotic icons, where the first icon is a cue. The sequence begins with melting snow, followed by the flow of water, and ends with an irrigation channel. There are extensive descriptions in the icon legend describing the icons' relation to other abiotic, biotic, and cultural events. In brief, this sequence shows that melting snow is a sign that winter is ending. The melting snow causes water to collect in streams, which prompts villagers to prepare their irrigation channels to direct water to their crops.

Indicator species are a form of cue that initiate agropastoral activities. A green circle in the ecological calendars highlights these plant and animal species. For example, villagers in Roshorv identified spring rains to be associated with the call of the *tsatsao,* the Himalayan snowcock (*Tetraogallus himalayensis*). Their arrival and singing are an indicator for farmers to begin plowing their fields (Figure 4). Indicator species illustrate the relationship communities have to their habitat and their dependence on biodiversity in their local environment. We focused on the ability of indicator species to inform livelihood activities and subsequent food security in their respective communities.

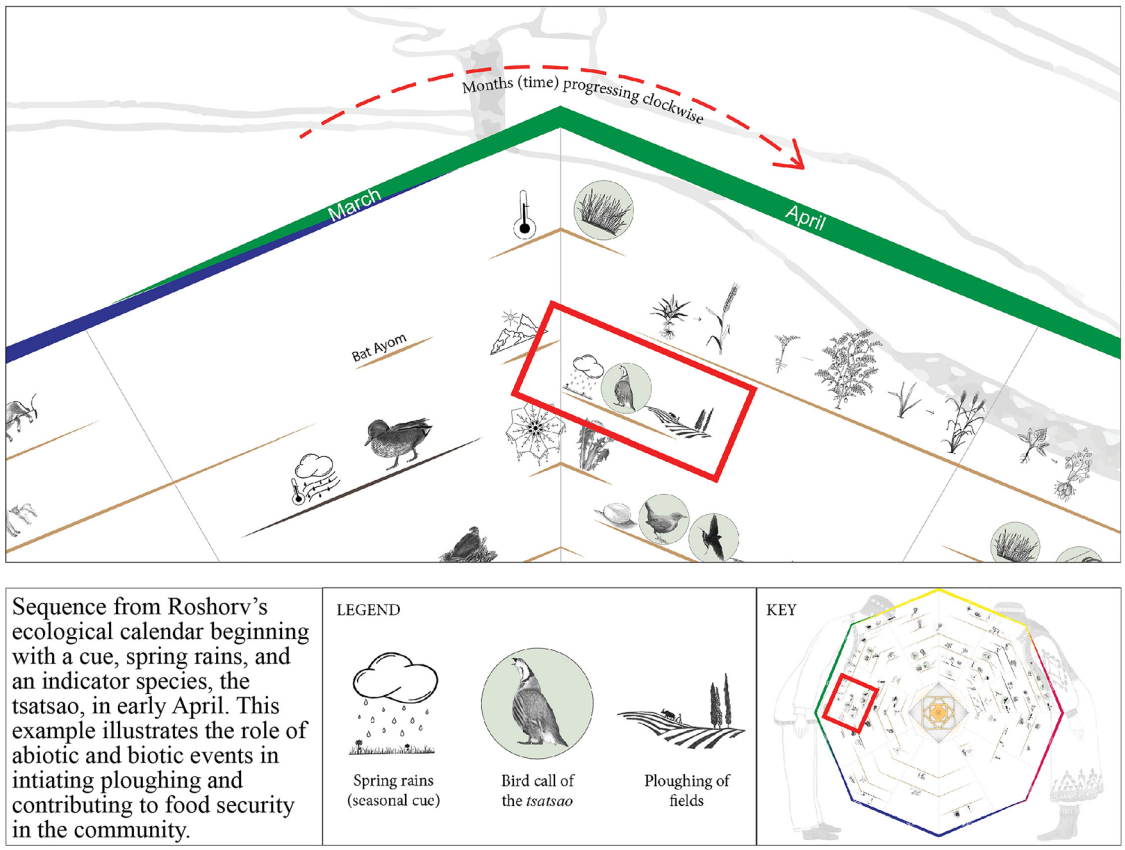


Figure 4. Roshorv's ecological calendar adapted from Kassam et al. (2022) highlights a sequence in spring that informs food security.

4. Results and Discussion

We developed a total of 134 unique icons, 49 of which are present in both Savnob's and Roshorv's ecological calendars. There are 43 icons used solely for Savnob and 42 exclusively for Roshorv. Among the two calendars, 54 organisms are referenced, including 22 plants and 32 animals. There are a total of 24 icons connected to livelihood activities, a subset of 13 relating to abiotic events, and the remaining 11 to indicator species. Of the 13 abiotic events, only the freezing streams icon occurs in both calendars. The remaining abiotic icons connected to livelihood events are unique to the respective village, with Savnob presenting six and Roshorv five. Although the calendars of Savnob and Roshorv are similar, this demonstrated distinct differences in the content.

4.1. The Siberian Ibex

The 11 indicator species consist of five birds, three mammals, two plants, and one amphibian. While the villagers of Roshorv mentioned eight species, and Savnob four, the *nakhcheer* or Siberian ibex (*Capra sibirica*) is the only indicator species identified as such in both communities. The Siberian ibex is a key example, as it corresponds to different livelihood activities in each village, illustrating the importance of context-specificity (Table 1). Savnob's ecological calendar includes one icon of the Siberian ibex, focusing on kidding in June. This occurs when the weather warms and serves as an indication it is time for the herders to move their livestock to higher pastures. This timing also relates to the increasing presence of wolves threatening livestock, corresponding to a hunting period. In contrast, the Siberian ibex appears in three icons in Roshorv's ecological calendar, all of which inform hunting practices. In the first instance, the icon communicates that ibexes are easiest to hunt during May as they follow the greening of grasses to lower, more accessible pastures. The second icon is found in June when the ibexes are seen searching for the most suitable locations for their young in the mountains. This breeding season is an indicator of a hunting season. In the final occurrence in August, the ibex is among other species including the *mekhak* or Marco Polo sheep (*Ovis ammon polii*), *khuchirf* or long-tailed marmot (*Marmota caudata*), *tsatsao* or

Table 1
Comparison of the Locally Named nakhcheer or Siberian Ibex (Capra sibirica) Indicator Species as Represented in Savnob's and Roshorv's Ecological Calendars

Livelihood Activity	Savnob	Roshorv
Herding & Hunting	 June	 May, June, and August

Note. The ibex icons are present in the summer and autumn, the yellow and red portions of the ecological calendars, respectively.

Himalayan snowcock (*T. himalayensis*), and the *zarez* or chukar (*Alectoris chukar*). The ibexes are indicators of a third hunting season as some villagers consider the best time to hunt to be autumn. If the weather remains clear and the animals are well-nourished from their summer diets, community members can hunt various mammal and bird species. The ibex informs the village's food security given its connection to hunting seasons. In short, the Siberian ibex is primarily a cue for herding in Savnob and hunting in Roshorv. Both activities reflect the food system of the respective villages.

4.2. Potentially Threatening Events

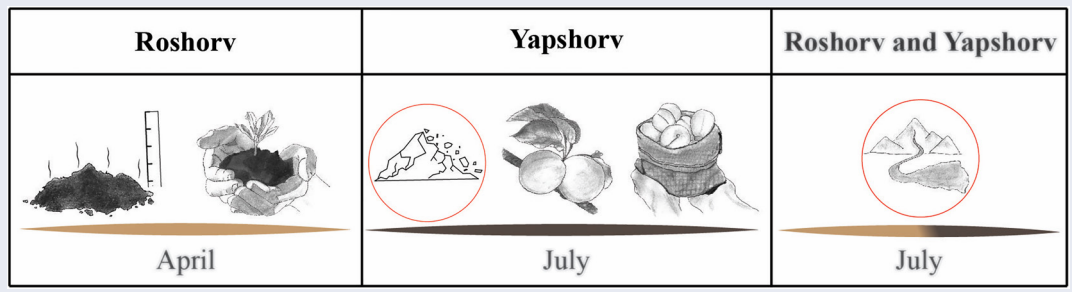
Villagers in the Bartang Valley described potentially threatening events to food security including strong winds, insect pests, heat waves, and extremely cold times of the year. However, it is important to consider the implications of such events for the livelihoods of villagers. For instance, Savnob's icon legend describes crop damages due to *mur* or caterpillars (*Pieris brassicae*), *chirum* or gray grubs, *shakarak* or green aphids (*Sappaphis piri*), and *zadetsh/zhidishk* or grasshoppers (*Caelifera* spp.). Although these species do not pose a problem for crops every year, the villages' vulnerability may increase with additional pest outbreaks. Future projections show climate change to increase pest abundance as well as lead to the arrival of additional species (Skendžić et al., 2021). Furthermore, abiotic challenges, such as particularly hot summers, also pose a problem for the village of Roshorv. Every 2 to 3 years the glaciers melt rapidly causing clay runoff to cover the crop fields and lower their crop yields (Table 2). Whether a result of biotic or abiotic threats, poor harvests put their food security at risk. A lack of food for the villagers or their livestock makes overwintering particularly demanding.

Table 2
Examples of Sequences Illustrating Potentially Threatening Events as Represented in Savnob's and Roshorv's Ecological Calendars

Livelihood Activity	Savnob	Roshorv
Farming	 June to August	 August

Note. The ecological calendars highlight these events with a red circle around the icon. The yellow frame around the livelihood activity represents summer

Table 3
The Lines Representing Time Frames in Roshorv's Ecological Calendar Are Light Brown, as Illustrated by the Sequence Relating to Planting in April



Note. If events occur in Yapshorv the line underneath the icons is dark brown, as demonstrated by the sequence related to harvesting apricots. In cases that correspond to events occurring in Roshorv and Yapshorv, such as the flooding of a river, the line fades from light brown to dark brown

4.3. Additional Land

At a coarser spatial scale, we considered the use of the landscape surrounding each village. While Savnob's calendar only applies to Savnob, Roshorv's incorporates another village known as Yapshorv, a village at a lower elevation where some residents of Roshorv have land (Table 3). Access to an additional environmental context provides the opportunity to grow different crops. Specifically, Roshorv's ecological calendar represents livelihood activities in Yapshorv, such as the plowing of land or the ripening of *nosh* or apricots (*Prunus armeniaca*), *tuth* or white mulberries (*Morus alba*), and *gilas* or cherries (*Prunus avium*). This adds an additional level of complexity given the events in both locations mutually inform each other, both through the movement of people as well as ideas. Ties to Yapshorv have historically been important for both communities' food security and could become even more valuable under the continuing effects of climate change. This connection is also significant because access to land and crops in Yapshorv offers additional opportunities for achieving food security and lowers the vulnerability of villagers in Roshorv.

Although our comparison considered Savnob and Roshorv in isolation, we recognize the communities to be socially and historically intertwined. Their practices are interwoven, each using the strengths of their respective location. For instance, villagers in Roshorv have more arable land and therefore share their surplus in barley, chickpeas, and hay with the villagers in Savnob. In turn, Savnob has better conditions to grow wheat, which community members in Roshorv gratefully receive. Many forms of exchange are practiced including trading, selling, and gifting. Differences in local conditions inform agropastoral practices, which are the foundation for the villagers' food security.

4.4. Livelihood Activities

Our comparison of livelihood activities showed how local context holds particular importance to food security and survival. An analysis of key seasonal characteristics illustrated the differences in Savnob's and Roshorv's ecological professions. Given villagers in the Bartang Valley are primarily farmers, we evaluated sequences informing plowing, planting, and harvesting stages as well as general activities such as gathering, and herding (Table 4). This provided an overview of defining seasonal events which distinguish Savnob and Roshorv from each other, as well as added insight about sequences in the ecological calendars. Sequences explained how villagers initiate livelihood activities contributing to food security.

As expected, due to the lower elevation, farmers in Savnob begin plowing earlier than those in Roshorv. Villagers also use different cues. Whereas Savnob farmers pay particular attention to soil moisture, those in Roshorv wait for spring rains and the call of the Himalayan snowcock to begin plowing in April. Not only are different biotic and abiotic events depended upon relative to the village context, but there are multiple cues initiating the same livelihood activity in Roshorv. For instance, additional sequences in Roshorv's calendar include the arrival of the

Table 4
Tabulation of Seasonal Sequences Identified in the Bartang Valley Ecological Calendars, Comparing Savnob and Roshorv

Livelihood Activity	Savnob	Roshorv
Plowing	 March to April	 April
Planting	 April to May	 April to May
Gathering	 June to July	 June to August
Harvesting	 July to August	 October
Tending Livestock	 September to October	 September to October

Note. Although these sequences may not occur every year, this table presents one example per season relating to livelihood activities. The colors frame livelihood activities according to their seasonal timing: green for spring, yellow for summer, and red for autumn. Refer to the ecological calendars' icon legends in the community reports for further descriptions (Kassam et al., 2022).

brown dipper and barn swallow in April, also informing the villagers to begin plowing. This reduces the farmers' dependency on any one of the cues.

Similarly, planting strategies in spring differ between Savnob and Roshorv. The villagers in Savnob did not mention the use of a cue to initiate planting. Rather, they described a planting sequence to begin with *gharj* or alfalfa (*Medicago sativa*) and *chush* or barley (*Hordeum vulgare*) in April and then *kilak Bartangi* or wheat (*Triticum aestivum*), followed by *joidore/kartoshka* or potatoes (*Solanum tuberosum*) and *rediska* or turnips (*Brassica rapa rapa*) in May. Roshorv's calendar has a similar sequence in April beginning with wheat, *revand* or chickpeas (*Cicer arietinum*), barley, and potatoes, however the warmth of the soil at 10–15 cm deep is an important cue for which some villagers wait prior to planting. Various approaches and the sowing of different crops may reveal one

village to be more vulnerable than the other under a changing climate. This will partially reflect crops' abilities to survive and produce new offspring.

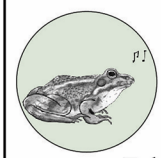
The Bartang Valley's gathering practices exhibit the same trends as demonstrated by the farming sequences. Not only are the sequences slightly different, but events in Savnob occur a few weeks earlier than in Roshorv. In Savnob, villagers gather plants in June and July, while in Roshorv these activities range from the end of June to the beginning of August. Savnob's and Roshorv's ecological calendars contain the same sequence related to the flowering of *zira* or black cumin (*Benium persicum*) followed by its collection. Details within the icon legend reveal this icon represents the general gathering activity of wild and medicinal plants. Savnob's community members specifically communicated the gathering of mint to occur when the weather is dusty during the summer solstice and one can hear *qargha* or red-billed and yellow-billed choughs (*Pyrrhocorax pyrrhocorax* and *Pyrrhocorax graculus*, respectively) calling on their nest. According to the interview transcripts, Savnob villagers listed about two times as many non-domesticated plant species relative to Roshorv, 30 to 16 respectively. These included medicinal plants as well as various forms of fodder for their livestock. Based on this diversity, we may infer that the villagers of Roshorv are more vulnerable in this regard to climate change compared to Savnob. However, in terms of anticipatory capacity, this deviation between villages may present as an asset. Ten species were listed by both villages, indicating 26 plants remain. Savnob's and Roshorv's mutual support system provides each village with further knowledge and access.

The harvest tends to come earlier in Savnob than in Roshorv, particularly for fruit. For instance, both villages have the same sequence illustrated by the collection of apricots followed by *mun* or apples (*Malus* spp.). However, this occurs in Savnob from the end of July to the beginning of August while the same sequence does not appear until October in Roshorv. Both villages have access to the same fruits, including mulberries and cherries, but ties to Yapshorv make these fruits available to villagers in Roshorv. Savnob can begin collecting fruit at the end of June through the middle of August while fruits in Yapshorv are ready at the end of July through September. Field crops, such as barley, wheat, alfalfa, and potatoes are harvested by community members from the Bartang Valley in autumn. Villagers collect them at the end of July into October in Savnob and from the end of August to the beginning of October in Roshorv. These examples reaffirm the local differences in timing. The villagers in Roshorv described three common varieties of potatoes, all of which currently grow well in the region, yet are ready for harvest at various times ranging from July to early October. Access to different varieties is likely beneficial under climate change. Simulations revealed wheat and potato yields to generally increase in Tajikistan, however, their productivity depends on the crop variety, temperature, and access to water (Bobojonov & Aw-Hassan, 2014; Sommer et al., 2013). Long-term, as the ecological calendars are continuously updated, they will contain a record of crop varieties. Therefore, applying such insights, and offering support between villages, have the potential to improve the likelihood of achieving food security in an unknown future.

Even though tending livestock is less common in the Bartang Valley relative to farming crops, small herds of *hiwanat* or cattle (*Bos taurus*), *quotos* or domestic yaks (*Bos grunniens*), *vaz* or domestic goats (*Capra aegagrus hircus*), *markab/khar* or donkeys (*Equus asinus*), and *mav* or sheep (*Ovis aries*) remain significant to the community members' livelihoods. In autumn, during late September and early October, the herders in Savnob and Roshorv bring their livestock back to the villages. In Savnob, the sequence often begins when streams freeze. This is a cue to move their livestock to lower pastures and harvest barley and potatoes. It is important for harvesting to occur prior to the return of livestock so the livestock does not damage the crops, but this may not be possible due to biotic and abiotic pressures. For instance, a very wet season or a nearby *wurj* or gray wolf (*Canis lupus*) may cause the herders to bring their livestock back to the village of Savnob. It is also important that harvest is complete in Roshorv before the return of their livestock. Like Savnob, herding in Roshorv coincides with the appearance of wolves. Villagers in Roshorv explained that the wolves' presence is connected to seasonal changes such as the grass turning yellow and the *khuchirf* or long-tailed marmot (*M. caudata*), a food source for wolves, going into hibernation. Community members in Roshorv assist their shepherds with herding their livestock back to the village before the streams freeze and the animals can no longer drink. Livestock supports the livelihoods of villagers in the Bartang Valley, irrespective of whether the animals are a direct food source, an aid for plowing fields, or a means of receiving income.

All events in the ecological calendar are interconnected. This is visually apparent in sequences when all icons are located on the same line, however, icons that do not appear in a sequence are also linked to other local events. For instance, the breeding of livestock such as cattle at the end of summer in Savnob corresponds to the timing of their

Table 5
Comparison of Spring Activities Relating to the Celebration of Navruz, the Vernal Equinox, as Represented in Savnob's and Roshorv's Ecological Calendars

Livelihood Activity	Savnob	Roshorv
Farming	 February	 February

Note. This table presents the sequences relating to *Boj Ayom* in February. The livelihood activity has a blue frame according to its appearance in the winter season.

calving season in April. Community members from Roshorv alternatively explained winter to be associated with the sheep and cattle giving birth. Winter is the coldest and darkest time of year which begins in November and lasts until March. The primary tasks in Savnob during the winter include housework and feeding the livestock. Despite the local variation, having a successful harvest and enough fodder for their livestock throughout the cold season is necessary for their animals' survival as well as their own livelihoods. The relations and interconnectivity illustrate both the robustness of their ecological system as well as its susceptibility to climate change. Even with milder winters, damaged harvests in the warmer months impact the winter food supply and outline the cascading effects of climate on all the seasons. Irrespective of the season, local conditions directly impact the livelihoods of villagers in Savnob and Roshorv.

In a further examination of the distribution of seasonal activities throughout the year, we found winter to be the quietest season as it has the fewest number of icons in Savnob and Roshorv. However, the seasons presenting the most icons are distinct. In Savnob, this corresponds to spring and summer, not tapering off until autumn. Arguably, Roshorv's ecological calendar displays a period of rest that aligns with the summer *chilla* as there are fewer events and activities in June and July compared to spring and autumn. Traditional timekeeping methods incorporated *chillas* twice a year, in the heat of summer and the coldest part of winter (Kassam et al., 2011). Although Savnob's calendar diverged from this pattern, both calendars are adjusted to the local conditions reflecting the livelihood activities and ecological professions in each respective village, and therefore, their food security.

4.5. Navruz

The vernal equinox, named *Navruz* in Persian languages, initiates the new year. In the calendars of the human body, *Navruz* is often associated with counting reaching the heart (Kassam et al., 2011). Although Savnob's and Roshorv's icon legends mention *Navruz* at a similar frequency, 5 and 6 times respectively, there are slight differences in corresponding events. In Savnob, community members began the discussion of *Navruz* with a "small *Navruz*," called *Boj Ayom*, occurring from 8 to 12 February. The croaking of *kharbirj* or lake frogs and green toads (*Rana ridibunda* and *Bufo viridis*, respectively) initiates this period, dedicated to spring tasks such as the preparation of tools for their fields (Table 5). Exactly 1 month later, the celebration of *Bat Ayom* occurs. Villagers honor the day by wishing their neighbors *Shogun Bahor*, a happy new year and spring, and by preparing a porridge from *rushtak* or red wheat (*Triticum* spp.) flour, milk, and water. Community members associate the vernal equinox on March 21st with the arrival of bird species. Based on their visual and auditory observations, they mentioned the *khofta* or hill pigeons (*Columba rupestris*), the *mandozaks* or barn swallows (*Hirundo rustica*), the *qargha* or red-billed and yellow-billed choughs (*P. pyrrhocorax* and *P. graculus*, respectively) as well as hearing the calls of the *zhon* or golden eagle (*Aquila chrysaetos*). The appearance of these birds coincides with using oxen to plow fields.

Comparatively, although spring-related events such as the arrival of birds and plowing are similarly central to villagers in Roshorv, details about *Navruz* are nonetheless distinct. For instance, community members recalled how hunting used to be important for *Boj Ayom* in early February. They also referred to a *varmoi* or landmark

in the mountains to assist in determining the location of the sun in their calendar of the human body. When the sun is in the shins it corresponds to spring preparations, such as preparing the plow and assembling seeds. After the celebration of *Boj Ayom,* villagers from Roshorv go to plow the land in Yapshorv. Community members mentioned the importance of *hiwanat* or an ox (*B. taurus*) for plowing, especially when working with *chush* or barley (*H. vulgare*). The celebration of *Bat Ayom* occurs in mid-March, a week before *Navruz*. *Navruz* is generally characterized by warming temperatures, light rain, and fog. The *kurak* or common teal (*Anas crecca*) arrives in Yapshorv, closely followed by the *babůb* or Eurasian hoopoe (*Upupa epops*) as well as the *mosY(kh)* and *kabitsor* or mallards (*Anas platyrhynchos*) in Roshorv. Community members also emphasized the sun reaching another *varmoi* in the mountains, 9 days after *Navruz*. This landmark, termed *bthanak*, is located between two mountain peaks symbolizing a period of balance. If all the snow has melted, *bthanak* initiates planting in Roshorv.

The ecological calendars highlight *Navruz,* a robust example of complex connectivity. This single event ties together cultural features and multiple calendar and knowledge systems such as the calendar of the human body with the Gregorian calendar and solar movement. It integrates abiotic environmental conditions, celebrations, the behavior of local species, and farming activities. The events support and provide the content of the ecological calendars. *Navruz* shows the link between local language and weather data, while simultaneously demonstrating the variation between Savnob's and Roshorv's local context. The icons, as modern depictions of context-specific praxis, illustrate examples where community members stated the importance of particular abiotic conditions and biological phenomena to their livelihood and cultural practices. The difference in the timing of plowing and sowing activities between the villages of Savnob and Roshorv facilitates cooperation. Villagers in Savnob often borrow oxen from Roshorv to plow their lands. Thus, one community contributes to the food security of the other. The Food and Agriculture Organization of the United Nations pillars of food security include availability, access, utilization, stability, agency, and sustainability (FAO, 2021). Evidence of the communities' agency and sustainable practices that do not compromise future generations are available (Kassam, 2021; Ullmann & Kassam, 2022), and based on our results from the communities' ecological calendars, we concluded that very local contexts must be considered to inform villagers' access to food.

Climate change can impact the culture and food security of villagers in the Bartang Valley. For instance, the date of the vernal equinox will stay the same, however previous links to ecological processes may become offset or disconnected. Unmet expectations about timing regarding the arrival of migratory species or the warming of soil after winter will be a clear indication of changes. Community members are already adjusting their agropastoral activities accordingly and will need to continue to do so when they prepare their plows in spring. Misjudgments and bad decisions can threaten household food supplies. Ecological calendars can be a robust and valuable source of information capable of informing one's anticipatory capacity for future environmental uncertainties (Kassam et al., 2022; Ullmann & Kassam, 2022). An analysis of ecological calendars can identify where and how communities are vulnerable. When these findings inform targeted efforts, they can increase the communities' resilience by means of anticipatory and adaptive capacity. Every calendar recorded in the Pamirs may be unique, even within a single valley. This context-specificity directly displays the historical adaptive capacity of local communities and remains significant today.

4.6. Future Directions

Currently, the Bartang Valley ecological calendars capture generations of community insights extending until 2018, the year the community of practice validated the interview findings. If these calendars are to remain contemporary and reflect current ecological conditions, repetition of a transdisciplinary approach like the Ecological Calendars and Climate Adaptation in the Pamirs project is necessary. Updating the calendars with the most recent empirical observations can guide future decisions. Over generations, older versions document changing phenology and could have a significant role in achieving anticipatory and adaptive capacity. They can help communities to anticipate imminent shifts as they are a record of timekeeping that display transformations in the local context. Ecological calendars are unique in that they benefit from insights of multiple generations drawing on the knowledge of any, and potentially every, individual within a community. The dimensions of these calendars, therefore, simultaneously offer temporal breadth and spatial depth. Their graphical form is an available document that unites each offered perspective. Individuals contemplating the information in the calendar have the freedom of choice when considering what content or approach may be best suited for their given situation.

Ecological calendars present numerous opportunities for future research directions and implications. Regarding the villages of Savnob and Roshorv, efforts can include updating the calendars with insights generated since 2018 as well as interviewing women to incorporate more female perspectives. Their unequal representation was due to a variety of sociocultural factors, including cultural norms and the fact that the summer season corresponds with their highest workload (Kassam, Ruelle, et al., 2021). Not only is their participation necessary for a transdisciplinary approach, but given women engage in different activities than men, they offer additional knowledge regarding food security. Furthermore, a quantitative analysis of seasonal activities from the High Arctic of North America recently assessed the vulnerability of indicator species to climate change (Kassam & Bernardo, 2022). This method could also be applied in the Bartang Valley as it would highlight where conservation efforts and governance structures need to be tailored. Moreover, by following the Ecological Calendar and Climate Adaptation in the Pamirs methodology, anyone can create ecological calendars in any context to address food security. The significance of this approach resides within the framework; to gather insights from a combination of various data sets, lived experiences, and specific expertise for the local circumstances under consideration.

5. Conclusion

The objective of our paper was to illustrate the importance of context-specificity for food security in the Bartang Valley of Tajikistan. Due to climate change and the precision of our research question, we required a transdisciplinary methodology, with an Indigenous knowledge foundation offering site-specific insight. We compared their local human ecologies, focusing on the relations between the community members with their habitat as subsistence agropastoralists. Our analysis and creation of icons for the visual ecological calendars of Savnob and Roshorv revealed differences in ecological conditions, demonstrated by the variation in icons as well as their applications. The altitudinal difference accounts for some of the divergences. This is evident when the communities conduct the same sequences or events at separate times. Apart from a temporal offset, our results suggest that the ecological calendars differ due to local microecological conditions. Their differences facilitate inter-village mutual support, where sharing their harvests increase the availability of products. They communicate, assist, and influence each other. The comparison of Savnob's and Roshorv's ecological calendars was necessary to illustrate the significance of context-specificity. This remained unchanged irrespective of whether we considered plowing, planting, gathering, harvesting, or hunting activities. The particularities between Savnob and Roshorv, despite their close geographical proximity, are of paramount importance to the communities' survival and response to change. This is partially attributed to their ecological professions, exhibiting considerable connectivity to their habitat.

Environmental shifts caused by climate change disconnect villagers from their local ecosystems. This poses a real threat to their food security. The villagers' traditional knowledge systems, represented through their ecological calendars, are becoming ever more vulnerable to climate change. Yet, their knowledge systems are proving more valuable, which may lead to greater interest in their continuation. As updated ecological calendars include current conditions, they will remain dynamic, providing sustainable and place-based information to anticipate rising climate uncertainty. They could be immensely useful if recognized and accepted by local communities, researchers, schoolteachers, policymakers, related interest groups, or the like. This case illustrated the importance of ecological calendars: ecological calendars are the result of transdisciplinary collaboration engaging local praxis as well as a strategy to achieve food security in a changing climate.

Conflict of Interest

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

Data Availability Statement

We used the ethnographic data from Kassam et al. (2022) for our analysis. It is available in the form of community reports cited in this publication and available at: https://cornell.app.box.com/s/d6pp5wk2p5303caotte346yu6lzgbydf. Temperature data was analyzed with RStudio, a free statistical computing software, and the original data from Haag, Kassam, et al. (2021) has been cited in the references of this publication and is accessible at: https://doi.org/10.1007/s10584-021-02988-3. Figures were designed with Adobe Illustrator 2022 version 26.4.1, Adobe

Photoshop 2022 version 23.4, Adobe Indesign 2022 version 17.0 under Cornell University Adobe Creative Cloud license (https://www.adobe.com/education.html).

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References

Adjaye, J. K. (1987). Time, the calendar, and history among the Akan of Ghana. *The Journal of Ethnic Studies*, *15*(3), 71.
Andreev, M. S. (1958). Tadzhiki doliny Khuf: verkhovyev Amu-daryi (A. K. Pisarchik Ed., 2nd ed.).
Bliss, F. (2006). *Social and economic change in the Pamirs (Gorno-Badakhshan, Tajikistan)*. Routledge.
Bobojonov, I., & Aw-Hassan, A. (2014). Impacts of climate change on farm income security in Central Asia: An integrated modeling approach. *Agriculture, Ecosystems & Environment*, *188*, 245–255. https://doi.org/10.1016/j.agee.2014.02.033
Cochran, F. V., Brunsell, N. A., Cabalzar, A., van der Veld, P.-J., Azevedo, E., Azevedo, R. A., et al. (2015). Indigenous ecological calendars define scales for climate change and sustainability assessments. *Sustainability Science*, *11*(1), 69–89. https://doi.org/10.1007/s11625-015-0303-y
Ekbolsho, D. (2017). Savnob interview [Interview]. Conducted by Talia Chorover.
Evans-Pritchard, E. E. (1939). Nuer time-reckoning. *Africa*, *12*(2), 189–216. https://doi.org/10.2307/1155085
FAO. (2021). The State of Food and Agriculture 2021. In *Making agrifood systems more resilient to shocks and stresses*. FAO. https://doi.org/10.4060/cb4476en
Finaev, A. F., Shiyin, L., Weijia, B., & Li, J. (2016). Climate change and water potential of the Pamir Mountains. *Geography, Environment, Sustainability*, *9*(3), 88–105. https://doi.org/10.15356/2071-9388_03v09_2016_06
Gentle, P., & Maraseni, T. N. (2012). Climate change, poverty and livelihoods: Adaptation practices by rural mountain communities in Nepal. *Environmental Science & Policy*, *21*, 24–34. https://doi.org/10.1016/j.envsci.2012.03.007
Gulbahor, I. (2017). Savnob interview [Interview] Conducted by Talia Chorover and Kayla Scheimreif.
Haag, I., Jones, P. D., & Samimi, C. (2019). Central Asia's changing climate: How temperature and precipitation have changed across time, space, and altitude. *Climate*, *7*(10), 123. https://doi.org/10.3390/cli7100123
Haag, I., Kassam, K.-A., & Samimi, C. (2019). Ökologische Kalender im Pamir: Anpassung an den Klimawandel auf dem Dach der Welt. *Geographische Rundschau*, *71*(12), 26–31.
Haag, I., Kassam, K.-A., Senftl, T., Zandler, H., & Samimi, C. (2021). Measurements meet human observations: Integrating distinctive ways of knowing in the Pamir Mountains of Tajikistan to assess local climate change. *Climatic Change*, *165*(1), 5. https://doi.org/10.1007/s10584-021-02988-3
Hu, Z., Zhang, C., Hu, Q., & Tian, H. (2014). Temperature changes in Central Asia from 1979 to 2011 based on multiple datasets. *Journal of Climate*, *27*(3), 1143–1167. https://doi.org/10.1175/jcli-d-13-00064.1
Kassam, K.-A. (2009a). *Biocultural diversity and indigenous ways of knowing: Human ecology in the Arctic*. University of Calgary Press.
Kassam, K.-A. (2009b). Viewing change through the prism of indigenous human ecology: Findings from the Afghan and Tajik Pamirs. *Human Ecology*, *37*(6), 677–690. https://doi.org/10.1007/s10745-009-9284-8
Kassam, K.-A. (2013). Keeping all the parts: Adaptation amidst dramatic change in the Pamir Mountains. In L. R. Lozny (Ed.), *Continuity and change in cultural adaptation to mountain environments* (Vol. 7). Springer New York. https://doi.org/10.1007/978-1-4614-5702-2_12
Kassam, K.-A. (2021). Anthropogenic climate change, anxiety, and the sacred: The role of ecological calendars in the Pamir Mountains of central Asia (chapter 6). In D. Haberman (Ed.), *Understanding climate change through religious lifeworlds* (pp. 153–179). Indiana University Press. https://doi.org/10.2307/j.ctv21hrh8r.10
Kassam, K. A., & Bernardo, J. (2022). Role of biodiversity in ecological calendars and its implications for food sovereignty: Empirical assessment of the resilience of indicator species to anthropogenic climate change. *GeoHealth*, *6*(10), e2022GH000614. https://doi.org/10.1029/2022gh000614
Kassam, K.-A., Bulbulshoev, U., & Ruelle, M. (2011). Ecology of time: Calendar of the human body in the Pamir Mountains. *Journal of Persianate Studies*, *4*(2), 146–170. https://doi.org/10.1163/187471611x600369
Kassam, K.-A., Kaziev, D., Louis, L., Ruelle, M., & Ullmann, A. (2022). Rhythms of the land: Indigenous knowledge, science, and thriving together in a changing climate (Community Reports). Retrieved from https://cornell.app.box.com/s/d6pp5wk2p5303caotte346yu6lzgbydf
Kassam, K.-A., Ruelle, M., Haag, I., Bulbulshoev, U., Kaziev, D., Louis, L., et al. (2021). Engaging transformation: Using seasonal rounds to anticipate climate change. *Human Ecology*, *49*(5), 509–523. https://doi.org/10.1007/s10745-021-00269-2
Kassam, K.-A., Ruelle, M., Samimi, C., Trabucco, A., & Xu, J. (2018). Anticipating climatic variability: The potential of ecological calendars. *Human Ecology*, *46*(2), 249–257. https://doi.org/10.1007/s10745-018-9970-5
Kicherer, S. (2018). Blessed people in a barren land: The Bartangi and their success catalyser barakat 1. In *Identity, history and trans-nationality in central Asia* (pp. 173–192). Routledge.
Kislyakov, N., & Pisarchik, K. (1966). Tadzhiki Karategina I darvaza, Dushanbe.
Kohler, T., Giger, M., Hurni, H., Ott, C., Wiesmann, U., von Dach, S. W., & Maselli, D. (2010). Mountains and climate change: A global concern. *Mountain Research and Development*, *30*(1), 53–55. https://doi.org/10.1659/mrd-journal-d-09-00086.1
Lentz, W. (1939). *Zeitrechnung in Nuristan und am Pamir* (Vol. 7). Akademie der Wissenschaften in Kommission bei Walter de Gruyter & Co.
Manandhar, S., Xenarios, S., Schmidt-Vogt, D., Hergarten, C., & Foggin, M. (2018). *Climate vulnerability and adaptive capacity of mountain societies in central Asia, research report 1*. Mountain Societies Research Institute, University of Central Asia.
McKemey, M., Ens, E., Rangers, Y. M., Costello, O., & Reid, N. (2020). Indigenous knowledge and seasonal calendar inform adaptive savanna burning in northern Australia. *Sustainability*, *12*(3), 995. https://doi.org/10.3390/su12030995
Nabhan, G. P. (2009). *Where our food comes from: Retracing Nikolay Vavilov's quest to end famine*. Island Press.
Retnowati, A., Anantasari, E., Marfai, M. A., & Dittmann, A. (2014). Environmental ethics in local knowledge responding to climate change: An understanding of seasonal traditional calendar PranotoMongso and its phenology in Karst area of GunungKidul, Yogyakarta, Indonesia. *Procedia Environmental Sciences*, *20*, 785–794. https://doi.org/10.1016/j.proenv.2014.03.095
Shakarshoevich, S. L. (2017). Roshorv interview [Interview]. Conducted by Kayla Scheimreif.
Skendžić, S., Zovko, M., Živković, I. P., Lešić, V., & Lemić, D. (2021). The impact of climate change on agricultural insect pests. *Insects*, *12*(5), 440. https://doi.org/10.3390/insects12050440
Sommer, R., Glazirina, M., Yuldashev, T., Otarov, A., Ibraeva, M., Martynova, L., et al. (2013). Impact of climate change on wheat productivity in Central Asia. *Agriculture, Ecosystems & Environment*, *178*, 78–99. https://doi.org/10.1016/j.agee.2013.06.011
Ullmann, A. L., & Kassam, K.-A. S. (2022). Has the adaptation-mitigation binary outlived its value? Indigenous ways of knowing present an alternative. *Community Science*, *1*(2), e2022CSJ000008. https://doi.org/10.1029/2022CSJ000008
Ware, J., & Kramer, K. (2019). *Hunger strike: The climate and food vulnerability index*. Waterloo.

Woodward, E., & Marrfurra McTaggart, P. (2019). Co-developing indigenous seasonal calendars to support 'healthy Country, healthy people' outcomes. *Global health promotion*, *26*(3_suppl), 26–34. https://doi.org/10.1177/1757975919832241

References From the Supporting Information

Feng, S., & Hu, Q. (2004). Changes in agro-meteorological indicators in the contiguous United States: 1951–2000. *Theoretical and Applied Climatology*, *78*(4), 247–264. https://doi.org/10.1007/s00704-004-0061-8

Frich, P., Alexander, L. V., Della-Marta, P., Gleason, B., Haylock, M., Tank, A. K., & Peterson, T. (2002). Observed coherent changes in climatic extremes during the second half of the twentieth century. *Climate Research*, *19*(3), 193–212. https://doi.org/10.3354/cr019193

Rosenberg, N. J., Blad, B. L., & Verma, S. B. (1983). Frost and frost control. In *Microclimate: The biological environment* (2nd ed., pp. 368–390). John Wiley & Sons.