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Ilemchane Transhumant Pastoralists' Traditional Ecological Knowledge and Adaptive Strategies: Continuity and Change in Morocco's High Atlas Mountains

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Mountain rangelands are critical resources for mobile pastoralists, and they provide benefits to humankind broadly. Yet mountain pastoral social–ecological systems (SESs) face challenges that affect both mountains and rangelands. Herders' traditional ecological knowledge (TEK) underpins their adaptive strategies and serves as a resource for future adaptation. This holistic case study of Ilemchane transhumant herders in Morocco's High Atlas Mountains applies a simple framework to explore how herders' biophysical TEK, practices, and institutions interrelate and how climate and social changes affect the SES. Using participant observation, interviews, and surveys, we find Ilemchane climate, plant, and ecological knowledge shape their practices and institutions, which in turn reinforce or alter TEK. Building on a recent synthesis of mountain SES, we identify a paradox of remoteness, wherein Ilemchane remoteness both maintains traditional transhumant culture and TEK and threatens it. Overcoming this paradox may require internal organization, collective action, and external support.

Keywords: *adaptive strategy;* agdal*; Amazigh;* amskou*; climate change; grazing reserve; indigenous knowledge; transhumance.*

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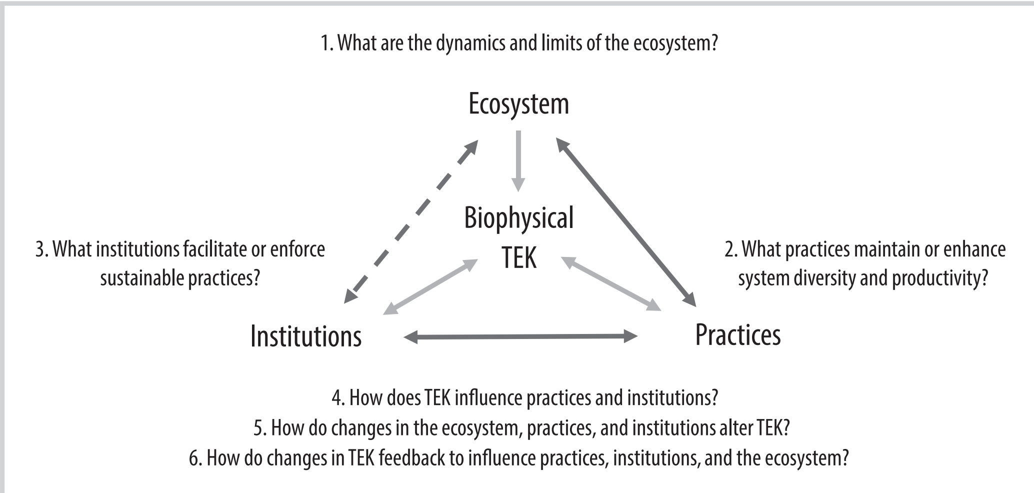
Introduction

Mountain pastoralists' traditional ecological knowledge (TEK) and adaptive strategies may serve as key resources in facing multiple social and environmental changes. Mountain rangeland or pastoral systems are the nexus of 2 social–ecological system (SES) types: rangeland SES and mountain SES. Both mountain and rangeland SES afford key benefits to humanity (water, carbon storage, pollination, wildlife habitat, and livestock forage, among others) (Sala et al 2017; Bengtsson et al 2019) and experience multiple interacting stresses and paradoxes. Klein et al (2019) identify 5 features of mountain SES that challenge sustainability: complexity, cross-scale ecosystem services, hazards, isolation, and marginalization. They also find 6 paradoxes: (1) policies made by outsiders, (2) resource rich and income poor, (3) in- and outmigration, (4) lack of needed data, (5) remote but vulnerable to global changes, and (6) remote but attract actors. Pastoral SESs share similar characteristics and face similar paradoxes (Reid et al 2014). Interacting land use, climate, and sociocultural changes threaten pastoral SESs (Galvin 2009; Dong et al 2011), yet few studies focus on mountain pastoralists' TEK and adaptive strategies under changing conditions.

TEK includes biophysical observations, management practices, institutions, values, and beliefs (Berkes 1999). Created and maintained through active use and culturally transmitted, TEK evolves over time (Fernández-Giménez and Fillat 2012) and serves as social or cultural memory and a resource for adaptation and innovation, buoying SES resilience (Berkes et al 2003; Wilson et al 2017). Pastoralist TEK supports rangeland monitoring (Reed et al 2008; Jamsranjav et al 2019), management (Castillo et al 2020; Molnar et al 2020), and climate change adaptation (Soma and Schlecht 2018). Past work describes Moroccan pastoralist TEK from the Middle Atlas (Gobindram et al 2018) and High Atlas (Linstadter et al 2013) Mountains but omits remote groups like the Ilemchane.

Pastoralists' biophysical TEK underlies their adaptive strategies, including practices and institutions. Pastoralist adaptive strategies are often conceptualized as risk-management measures (Mijiddorj et al 2019) or reliability-seeking measures (Roe et al 1998). Fernández-Giménez et al (2015) identified 5 key pastoralist adaptive strategies, encompassing the practices of mobility and storage (eg grazing reserves), diversification (eg multispecies herds and diverse habitats), and the institutions of resource pooling (eg grazing commons and labor sharing) and reciprocity (eg sharing pastures with outsiders in a disaster). Fernandez-

FIGURE 1 Conceptual framework depicting the relationship of biophysical TEK (traditional ecological knowledge) to ecosystem dynamics, management practices, and institutions, as well as associated guiding questions for a holistic TEK study. Gray lines connecting TEK to ecosystem, practices, and institutions show the hypothesized mediating role of TEK.



Gimenez and LeFebre (2006) proposed a framework for assessing sustainability in pastoral SES that focuses on understanding ecosystem dynamics, practices that allow use while maintaining ecosystem diversity and productivity, and institutions (policies, rules, and norms) that promote these practices. We build on this framework and posit that TEK, as biophysical observations, mediates among ecosystem dynamics and TEK as expressed in practices and institutions, leading to a set of guiding questions for studying the role of TEK in SES (Figure 1). Here, we present a holistic case study of Ilemchane transhumant herders in Morocco's High Atlas Mountains that applies this framework to explore how herders' biophysical TEK, practices, and institutions interrelate and how climate and social changes affect the SES. Our objectives are to (1) document herder knowledge of forage plants, rangeland ecology, and observations of environmental change; (2) investigate key pastoral practices (mobility and storage), their perceived benefits and challenges, and the institutions (*agdal*) that support these practices; and (3) explore how herder biophysical TEK, practices, and institutions are interrelated (Figure 1, Q4–Q6). Specifically, we investigate how TEK is reflected in practices and institutions (Q4); feedback between changes in the ecosystem, practices, and institutions to TEK (Q5); and feedback from changes in TEK to practices and institutions (Q6).

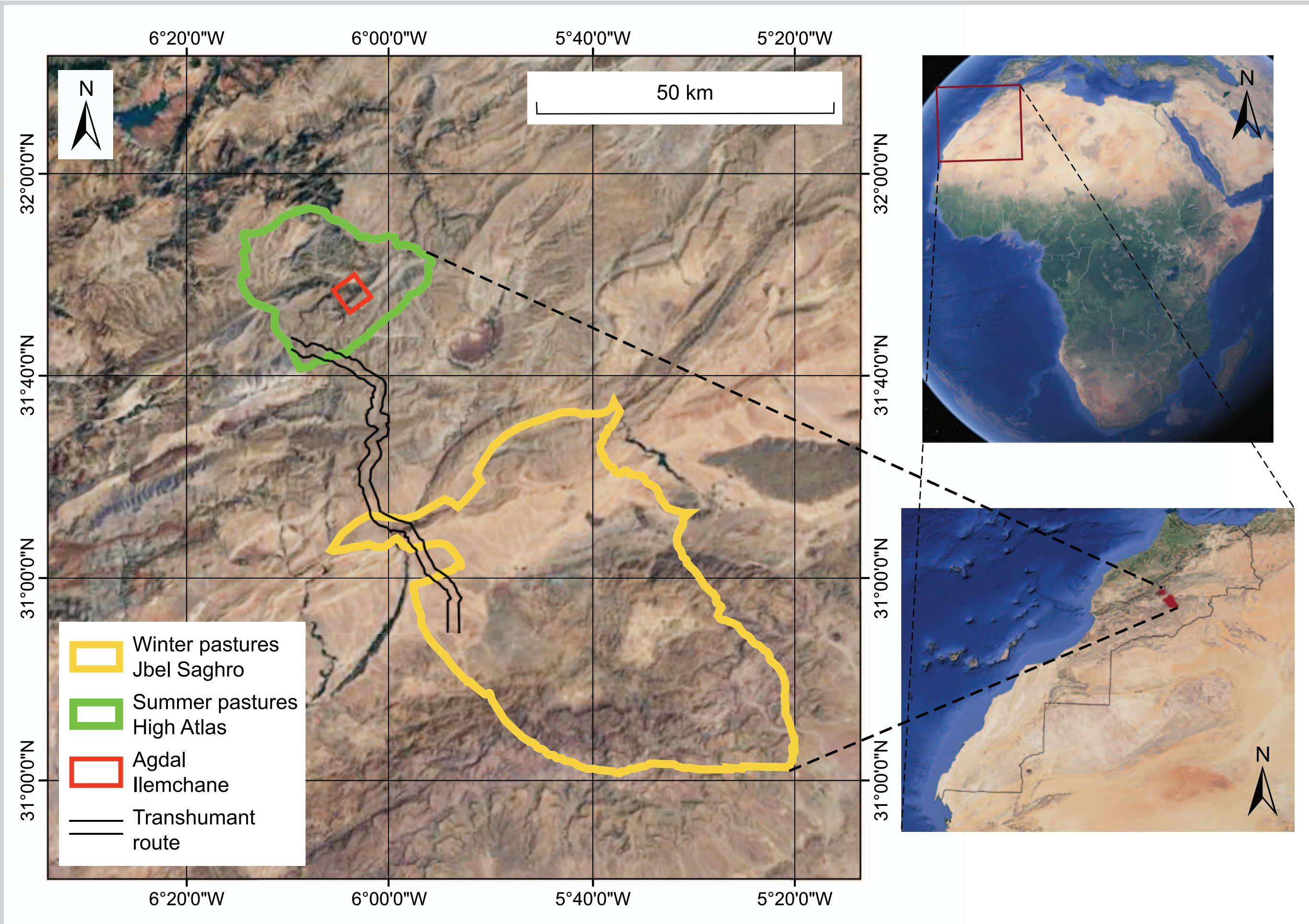
Here, we focus on the adaptive strategies of mobility, specifically the practice of transhumance, and storage, specifically the institution of *agdal*. Transhumance is repeated seasonal migration wherein herders track forage availability by moving, for example, from lowland pastures in winter to alpine pastures in summer (Niamir-Fuller 1999; Starrs 2018). Water availability, disease, and social factors also influence movement (Akasbi et al 2012; Fernandez-Gimenez 2000). As a distinctive cultural practice that enhances biological diversity (Bunce et al 2004), transhumance contributes to biocultural diversity (Dominguez 2016), defined as "the dynamic, place-based aspect of nature arising from links and feedbacks between human cultural diversity and biological diversity" (Bridgewater and Rotherham 2019: 12). Transhumants' TEK may be lost as mobility declines due to fragmented landscapes, lack of services, and rural depopulation (Niamir-Fuller 1999; Galvin et al 2008; Oteros-Rozas et al 2013). In Morocco, changing policies and land use forced most Middle Atlas transhumants to settle, causing a cycle of degradation, poverty, and vulnerability (Bencherifa and Johnson 1991; Kouba et al 2018).

Agdal is a generic Amazigh (Berber) term used throughout North Africa, which Auclair and Alifriqui (2012: 27) define as "a community management practice based on the protection of specific resources within a defined territory. These protections, most often seasonal, occur at times key to the biological cycle of the plants." *Agdal* can encompass various resources (forests, orchards, and rangelands) and is likely an ancient practice that represents "a holistic ecological, social, cultural and institutional phenomenon" (Auclair et al 2011: 3). Pastoral *agdal* exemplifies successful governance of communal pastures (Gilles et al 1992) and may serve as Indigenous Community Conservation Areas (Dominguez and Benessaiah 2017), reservoirs of biocultural diversity, and resources for SES resilience (Auclair et al 2011). Governance of High Atlas *agdal* is often tied to religious beliefs (Gilles et al 1992; Dominguez et al 2010). Thus, changes in these beliefs could undermine *agdal* function.

Ilemchane social–ecological system

As Amazigh people, the Ilemchane are descended from a cultural group that arrived in North Africa around 2000 BC and are considered indigenous peoples (Champs 1995). Despite outside influence from Arab expansion in the 7th century, French colonization in the 20th century, and assimilation pressures from the postindependence Moroccan government, Amazigh communities maintain distinct languages and cultural identities. The Ilemchane belong to the Ait Atta confederation, which consists of 5 segments that settled in the Saghro Mountains during the 13th century, later expanding toward the High Atlas Mountains (Cuzin and Benabid 2004). Ilemchane territory encompasses winter pastures in the Saghro (31°09′14.3″N, 5°38′57.5″W) and summer pastures in the High Atlas (31°44′39.4″N,

FIGURE 2 Map of the study area, including Ilemchane winter pastures in Jbel Saghro, summer pastures in the High Atlas Mountains, and the transhumant route between the 2 seasonal pasture areas.



6°11′06.4″W) (Figure 2). In 2018, the Ilemchane population numbered 673 individuals over age 7, of whom 183 were transhumants. In total, transhumant households herded 14,500 goats, 9050 sheep, and 200 camels, with an average herd size of 516 head of small stock.

The diverse topography and elevations of the Ilemchane territory (from 1400 masl in Saghro to more than 3500 masl in the High Atlas), as well as the associated climate gradient and soil variations, give rise to 4 main vegetation types: *Hammada* semidesert and *Artemisia* steppe in the Saghro, juniper woodsteppe on the southern slopes of the High Atlas, and Oromediterranean shrubland in the high mountains, dominated by cushionlike shrubs (Cuzin and Benabid 2004; Linstadter and Baumann 2013). Saghro average temperatures range from 6°C in January to 28°C in July, with mean yearly precipitation of 168 mm and a coefficient of variation (CV) in annual precipitation of 37%. In the High Atlas study area, average temperatures range from 4°C (January) to 24°C (July), with annual precipitation of 400 mm and a CV of 35%.

Methods

Our mixed-methods study used qualitative and quantitative methods during 5 field trips of 7–28 days each from September 2018 through June 2019. Data collection included (1) participant observation with herders, (2) 1 focus group and 21 semistructured interviews (13 with women), (3) 7 free lists of plants (3 with women), (4) 3 pile sorts of plant photographs, (5) a structured survey on herder observations of environmental change over 25 years between 1993–2018 ($n = 23$, 7 with women), and (6) a structured survey of 30 households on herd dynamics and production. In addition to Ilemchane, we interviewed 4 herders from the Ait Bougemez Valley who use the same summer pastures.

Except for the livestock production survey, all data collection was conducted under Colorado State University Institutional Review Board protocol 350-18H with participants' free, prior, and informed consent. The livestock production survey was led and implemented independently by the Institute Agronomique et Vétérinaire Hassan II. A detailed description of data collection methods and copies of data collection instruments are available in the *Supplemental material* (Appendices S1–S5, https://doi.org/10.1659/MRD-JOURNAL-D-21-00028.1.S1).

Audio recordings of interviews in Tashelhit were transcribed and translated into English for analysis. We coded interview notes and transcripts thematically in NVIVO (QSR International 1999). We postcoded qualitative data from open-ended survey questions and calculated

TABLE 1 Plants elicited via 7 free list activities, listed in order of the cognitive salience index.

Tashelhit name	Family	Genus	Species	Growth form	Indicator of	Observed trend	Frequency	Average rank	CSI
Ilibi (Tilibit)	Poaceae			Grass	Good quality	Decreasing	4	0.86	0.67
Azemaroy	Fabaceae	*Erinacea*	*anthyllis*	Shrub	Good quality		4	1.43	0.40
Tifisiit	Brassicaceae	*Alyssum*	*spinosum*	Shrub			6	4.43	0.19
Tazemaroyt	*Fabaceae*	*Cytisus*	*pungens*	Shrub	Good quality	Decreasing	5	3.71	0.19
Tiwechket	Fabaceae	*Astragalus*	*ibrahimianus*	Shrub	Good quality		6	5.00	0.17
Amersid	Apiaceae	*Bupleurum*	*spinosum*	Shrub			6	5.57	0.15
Iwichket (iouchked)	Brassicaceae	*Zilla*	*spinosa*	Shrub			2	1.86	0.15
Adolfsa	Apiaceae	*Bupleurum*	*spinosum*	Shrub		Decreasing	4	3.86	0.15
Imouman	Poaceae	*Poa*	*bulbosa*	Grass			3	3.29	0.13
Awchked (ochked)	Fabaceae	*Astragalus*	*armatus*	Shrub			2	2.29	0.13
Ouzra	Caryophyllaceae	*Arenaria*	*pungens*	Shrub	Poor quality		4	4.71	0.12
Auzhdem	Asteraceae			Forb		Decreasing	2	2.43	0.12
Awrubia	Poaceae			Grass	Good quality		4	5.29	0.11
Awri	Poaceae	*Stipa*	*tenacissima*	Grass	Good quality	Decreasing	2	2.71	0.11
Agassis	Poaceae	*Dactylis*	*glomerata*	Grass		Both	3	4.29	0.10
Ikhardn	Asteraceae	*Centaurea*	*marocana*	Forb			2	2.86	0.10
Tiraut	Juncaceae	*Juncus*		Rush		Decreasing	4	6.14	0.09
Igersel	Poaceae			Grass	Good quality	Decreasing	3	5.00	0.09
Adil nuushin	Rosaceae	*Crataegus*	*oxyacantha*	Shrub	Good quality		3	5.14	0.08
Tanahgout	Euphorbiaceae	*Euphorbia*	*nicaeensis*	Forb			2	3.43	0.08
Tigherdayn (tighourdain)	Poaceae	*Hordeum*	*murinum*	Grass			2	3.43	0.08
Timengwert	Asteraceae			Forb		Decreasing	4	7.00	0.08
Balfech (belfch)	Malvaceae	*Malva*	*parviflora*	Forb			2	3.71	0.08
Amenzal	Poaceae			Grass			2	3.86	0.07
Awrubia	Fabaceae	*Adenocarpus*	*bacquei*	Shrub	Good quality	Decreasing	2	5.00	0.06
Azazr	Buxaceae	*Buxus*	*balearica*	Shrub			2	5.29	0.05

Note: Cognitive salience index (CSI) = freq/($n \times$ ave rank), where freq = number of times a plant was mentioned out of 7 free lists, n = total number of lists (7), and ave rank = average rank of the plant over all lists. Only plants appearing in 2 or more lists are included. Information on the plant's use as an indicator of pasture quality and its status as increasing or decreasing were obtained from the survey and semistructured interviews. Free list participants included (1) an 18-year-old woman and a 12-year-old boy; (2) 3 women; (3) 10 men; (4) 2 boys, 12–15 years old; (5) a man in his 40s; (6) a woman in her 40s; and (7) 3 men, 45–60 years old.

descriptive statistics for all questions. We calculated a cognitive salience index (Sutrop 2001) from free list data. We used climate data for the Saghro and the High Atlas Mountains from the National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC) Prediction of Worldwide Energy Resources (POWER) project (Stackhouse 2021) to compare with herder-observed changes and assessed trends using the nonparametric Mann–Kendall test and Sen's slope estimates (Salmi et al 2002). Following Fernández-Giménez and Ritten (2020), we used data from the livestock production survey to construct typical annual budgets for settled, transhumant, and long-distance transhumant households.

Findings

Herder TEK: plant, pasture, and climate knowledge

Forage plant TEK: Free lists yielded 11–24 plants, with 57 taxa across 7 lists. Of these, 26 plants were included in 2 or more lists (Table 1). Lists generated by women and men included similar numbers of plants (average women = 15, average men = 17). Participants shared knowledge of plant uses and

TABLE 2 Indicators of pasture quality from an open-ended question on a survey of 23 current and former transhumant herders.

Good-quality indicators		Poor-quality indicators	
Indicator	**Frequency**	**Indicator**	**Frequency**
Amskou (pasture characteristic that makes sheep rest well and gain weight—see text)	9	*Imurtz* (opposite of *amskou*)	8
Amount of forage or plants	7	Lack of forage or plants	2
Presence of specific plants	4	Makes sheep sick or lose weight	2
Water source nearby; quality water source	3	Animals don't want to stay	2
Fog; low-intensity, long-duration rains (at the right time for plant growth)	2	Water far away/lack of water	2
Topography/slope (steep for goats, gentle for sheep)	2	Topography/slope (too steep)	2
Space between neighbors	2	Presence of specific plants, especially toxic plants	2
Where animals stay healthy	1	Specific place names	2
Cool temperature	1	Intense rain	1
No snow	1	Snow	1
Good soil	1	Close to cultivated land	1
Rain-use efficiency	1		

ecology through pile sorts, interviews, and surveys. In pile sorts, herders knew most or all plants and sorted them first based on forage value. Other sorting criteria were plant toxicity, plants eaten only under certain conditions (eg when dry or green), plants that cause bloat, preference by specific livestock species, abundance, habitat (eg riparian plants), and nonforage uses (eg firewood).

*Conceptions and indicators of pasture quality—*amskou *and* imurtz*:* Participants identified various criteria and indicators to distinguish good- and poor-quality pasture (Table 2). The most frequent criteria referenced in both interviews and surveys were expressed in Tashelhit as *amskou* and *imurtz*. *Amskou* is the most important indicator of good or desirable pasture, and *imurtz* is its opposite. Participants consistently described the meaning of *amskou* as related to the characteristics of the bedding ground where sheep sleep and their quality of rest. One participant described it as follows:

> *It's like these 2 tables. On this one you sleep one night and wake up in good shape. This other one you sleep a long time but don't feel good when you wake up. Ants and scorpions [are found where there is* amskou*]. The soil color should be red. If it's white, it's not good. This place has* amskou. *The village on the other side of the river has no* amskou.*... In Issaughar I have an* azib *[stone summer dwelling] with* amskou. *All of Issaughar is good. Some places have higher and some have lower* amskou *... If one place has* amskou*, it will never go away. You can't gain it if [the place] doesn't have it. A place can only lose* amskou *if a river comes through it [flood/runoff]. The runoff will take the* amskou *with it.*

One herder described *amskou* as energy or "waves" associated with particular places. The main way to determine whether a pasture possesses *amskou* is the performance and comportment of the animals, specifically sheep. Herders described sheep on pastures with *amskou* as healthy, at ease, playful, and energetic.

Participants repeatedly said that *amskou* is unrelated to the amount or type of vegetation at a site; even if forage is scarce, if a place has *amskou,* animals do well. Participants used the term *imurtz* to describe places where animals do poorly. As one participant said, "If they sleep in a place, and we notice that [the animals] lose weight, and so when they lose weight, we know that we have to move. When they lose weight in a particular place, we call it an *imurtz* place, a place that's bad for them."

Observations of environmental change and causes: Most survey participants reported declining pasture conditions compared with 25 years before (Table 3). The most often mentioned causes of pasture change were drought or lack of rain, late rains, intense rain or high runoff, erosion, less snow, more hail, and higher temperatures. Only 2 herders cited overgrazing and 3 mentioned overharvest of *azgar (Ziziphus lotus)*. Several said that God caused the changes, and one thought that the rangelands are "getting old." Participants varied on whether degraded pastures could recover. Those who believed that pastures could recover discussed increased rainfall and protection from use as mechanisms for recovery and believed pastures could recover in time spans of months to several years.

Herders' observations of climate changes over 25 years aligned with their views on the causes pasture change (Table 4). Most observed that rainfall amount declined, rainfall intensity increased, and rainfall duration decreased. Climate data showed a nonsignificant declining trend in total annual precipitation for both High Atlas and Saghro sites. Participants also observed a decrease in snow and declining river flows, lake levels, and spring flow.

Participants' observations of temperature changes were more varied (Table 4). Between 22 and 40% of participants observed no change in seasonal temperatures, and some found temperatures cooler now in spring and winter. Yet for all seasons, the largest fraction of respondents observed

TABLE 3 Herder observations of changes in pasture conditions over 25 years (1993–2018) ($n = 23$).

Variable	Herder observations, % (number) of survey respondents					
	Much less	Less	No change	More	Much more	Don't know/ don't recall
Pasture production (forage amount)	73.9 (17)	8.7 (2)	17.4 (4)	0	0	0
Number of types of plants (richness)	30.4 (7)	30.4 (7)	34.8 (8)	0	0	4.3 (1)
Forage quality	31.8 (7)	22.7 (5)	45.5 (10)	0	0	0
Bare ground	0	4.5 (1)	36.4 (8)	22.7 (5)	31.8 (7)	4.5 (1)
Erosion	0	13.6 (3)	9.1 (2)	13.6 (3)	59.1 (13)	4.5 (1)

warmer temperatures. Climate data showed significant warming trends in spring, summer, and mean annual temperatures in the High Atlas and in spring and mean annual temperatures in Saghro. There was a slight, nonsignificant cooling trend in High Atlas winters.

Practices: transhumance

Adapting to spatiotemporal variability: Ilemchane transhumant seasonal pasture use patterns typically follow the availability of forage over the year, adapting specific grazing locations based on annual conditions. Herds winter in the lowlands where rain falls in the fall, supporting winter forage growth. In May, herders "follow the green" as temperatures warm and snow melts in the high mountains, walking their herds upward for 7 to 10 days (Figure 3). Arriving in the high mountain pastures, Ilemchane graze in several areas outside the *agdal* Ilemchane until the *agdal* opens in mid-July (Figure 4). They use *agdal* Ilemchane from July until October and then move back to the Saghro. Herders vary the mountain and Saghro pastures they use depending on each year's forage. In poor years, about 30% of herders reported longer-distance migrations in winter. As one explained:

> *Before, the droughts were not so frequent. Now droughts are more frequent. So we have to move farther. We are obliged to leave here [the high mountains] because of the snow. To move we have to rent a truck to go to Zagora and it may cost MAD 5000 [US$500] for 150 ewes. If*

TABLE 4 Herder observations of climate changes 1993–2018 as reported in the survey ($n = 23$), and analysis of climate data over a similar time series (1988–2017).

Variable	Herder observation						Meteorological data			
	% (number) of survey respondents						High Atlas Mountains		Saghro Mountains	
	Much less	Less	No change	More	Much more	Don't know	Sen's slope	Sig	Sen's slope	Sig
Rainfall amount	60.9 (14)	17.4 (4)	17.4 (4)	4.3 (1)	0	0	−1.687	NS	−0.198	NS
Rainfall intensity	13.0 (3)	0	30.4 (7)	17.4 (4)	39.1 (9)	0	No data		No data	
Rainfall duration	47.7 (11)	26.1 (6)	8.7 (2)	8.7 (2)	4.3 (1)	4.3 (1)	No data		No data	
Snow amount	34.8 (8)	21.7 (5)	26.1 (6)	8.7 (2)	0	8.7 (2)	No data		No data	
River volume	56.5 (13)	21.7 (5)	21.7 (5)	0	0	0	No data		No data	
Lake levels	68.4 (13)	5.3 (1)	10.5 (2)	0	0	15.8 (3)	No data		No data	
Spring flow	39.1 (9)	34.8 (8)	17.4 (4)	0	8.6 (2)	0	No data		No data	
Well water levels ($n = 16$)	18.8 (3)	25.0 (4)	31.3 (5)	0	0	25.0 (4)	No data		No data	
Variable	**Much colder**	**Colder**	**No change**	**Warmer**	**Much warmer**	**Don't know**	**Sen's slope**	**Sig**	**Sen's slope**	**Sig**
Spring temperature	4.5 (1)	31.8 (7)	22.7 (5)	31.8 (7)	9.1 (2)	0	0.063	<0.05	0.058	<0.05
Summer temperature	4.3 (1)	21.7 (5)	26.1 (6)	34.8 (8)	13.0 (3)	0	0.035	<0.05	0.024	NS
Fall temperature	4.3 (1)	13.0 (3)	39.1 (9)	39.1 (9)	4.3 (1)	0	0.014	NS	0.005	NS
Winter temperature	17.4 (4)	13.0 (3)	26.1 (6)	43.5 (10)	0	0	−0.008	NS	0.001	NS
Mean annual temperature	No data	No data	No data	No data	No data	No data	0.031	<0.05	0.026	<0.05

Note: Climate data sourced from the NASA LaRC POWER project (Stackhouse 2021). Sen's slope is a robust, nonparametric slope estimate for a set of pairs (j, x_i), where x_i is a time series. Significance (sig) is determined using the Mann–Kendall test in the MAKESENS package for annual trend data (Salmi et al 2002). NS, not significant.

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FIGURE 3 Transhumance from the Saghro Mountain winter pastures to summer grazing in the High Atlas Mountains. (A) Departing the Saghro; (B) camels carry Ilemchane transhumants' belongings; (C) donkeys carry goat kids too young or tired to walk on their own; (D) arrival at the early summer campsite in the High Atlas. (Photos by O. El Aouni)

it is a good weather year, we go to Ouarzazate, Bouma, or Zagora. If it is a drought, we have to go farther.

Pastures in Saghro are used in common with other Ait Atta fractions, and those in the High Atlas are used by others as well, except for *agdal* Ilemchane. When herders move to distant locations, they rely on longstanding relations of reciprocity, not formal access rights. One person goes ahead to scout for pastures. As one transhumant described, "You never ask [permission]. You go and if they accept you, you stay. If not, you move again… For example, this year I am going to visit places and afterward decide where to go. Others will stay here. I have to see if there is vegetation or not."

Although most herders' first response to drought is to move, they also reduce herd size in long droughts (El Aouni 2019). Rarely, they supplement their animals, prioritizing lactating and pregnant females, followed by breeding males.

Rationale for transhumance: For most participants, transhumance is the only life they have ever known, and they lack education or training to do anything else. Herders' second main reason for transhumance is its relative profitability. Transhumants graze their herds on natural vegetation year-round, with minimal supplementation, avoiding the cost of purchased feed. Even accounting for the lower productivity of transhumant flocks, spending less on feed makes transhumance more profitable than settled management (Table 5). On a per-100-animal basis (Moroccan zootechnical unit), assuming identical herd compositions (60% goats and 40% sheep) and accounting for differences in herd productivity, net revenue for middle-distance transhumants (80–200 km/y) is 30% greater and for long-distance transhumants (>200 km/y) is 37% greater than for settled herders. Transhumance also allows larger flocks.

Transhumants also see that mobility benefits pasture. As one participant said, "It's good for the pastures because it gives them some rest and also because if you put animals all year round in one place there are no seeds." Participants recognized both pros and cons to livestock health and productivity. As one said, "It's good for the animals if you go slowly. Don't make the animals go fast. The butcher comes and puts his hand on the back of the animals and says, 'This one has a lot of kilometers on it.' The meat won't be tender."

FIGURE 4 Life in Ilemchane summer pastures in the High Atlas Mountains. (A) Sheep graze early summer pastures outside of *agdal* Ilemchane; (B) typical Ilemchane *azib* (stone corral or dwelling) and tent in early summer pastures; (C) Ilemchane transhumants sometimes travel more than 2 hours (round trip) to refill water jugs for domestic use; (D) grasses in *agdal* Ilemchane grow undisturbed before the July opening of the grazing reserve. (Photos A, B, and D by M. Fernández-Giménez and C by O. El Aouni)

Finally, several participants expressed affinity for the transhumant way of life. One woman said, "It's a good life. [I like] being settled and doing my daily chores, and also the animals. I like the animals when I'm herding and watching them." A former transhumant who longs to resume that life reminisced, "My mind is still in my *azib*. I like to go with my sheep. I like the space. Nobody to bother you." His wife shared:

> *The transhumant life is a difficult and tough life, but what I like about it is to be far from other people and have time alone. There, if it's a good year with rain and snow and grass for the livestock, we didn't need to buy extra feed and we saw the livestock get fat and healthy.*

Challenges of transhumance: Transhumants most often mentioned challenges of remoteness and lack of services, especially in High Atlas summer pastures, which are inaccessible by vehicle and lack cell phone service. One woman shared, "It feels like you fell into a well with no connection to the world." Participants bemoaned the distance to medical services; one nearly died in childbirth. Most participants had little formal education, especially the women. Today, more children go to school, including girls. This change brings new challenges, because families often must split up, with children staying behind. Women worried about leaving their children in the care of others. Children gain formal education, expanding their livelihood options, but lose the chance to learn herding TEK through observation, practice, and knowledge exchange with elders. Few young people and no unmarried women interviewed wanted to continue transhumance.

Finally, participants reported that transhumant treks on foot are exhausting and dangerous. They described places along their route where animals sometimes fall to their deaths. Some said it is getting harder to find water and pasture along the route, especially where cultivation and settlement are expanding, and that conflicts with people whose lands they pass by have increased.

Institutions: *Agdal* Ilemchane

Agdal Ilemchane encompasses 2500 ha used only between July 15 and October. Bourbouze (1981) writes that the *agdal* was granted as a reward by Sidi Said Ahensal, religious

TABLE 5 Annual revenue, expenses, and relative profitability of settled, middle-distance, and long-distance Ilemchane transhumant households per 100 zootechnical units, assuming a herd of 40% sheep and 60% goats for an average year.

Item	Price or cost per unit in US$	Number of units			Revenue/expense (US$)		
		Settled	Transhumant	Long-distance transhumant	Settled	Transhumant	Long-distance transhumant
Ewe lambs	70	13	12	12	910	840	840
Wether lambs	120	17	16	16	2040	1920	1920
Cull rams	150	1	1	1	150	150	150
Cull ewes	60	3	2	2	180	120	120
Wool (average per animal)	0.35	41	41	41	14	14	14
Female goats	30	7	7	7	210	210	210
Male goats	40	18	16	16	720	640	640
Cull male goats	100	1	1	1	100	100	100
Cull female goats	80	4	4	4	320	320	320
Total revenue					***4644***	***4314***	***4314***
Livestock feed	Settled: 17.98 Transhumant: 8.40 Long distance: 2.00	100	100	100	1798	837	200
Veterinary	1.20	100	100	100	120	120	120
Paid employee	600				600	600	600
Shearing (per animal)	0.30	41	41	41	12	12	12
Transport (to market)	0.37	100	100	100	37	37	37
Transport (long-distance transhumance)	5.00				0	0	500
Total expenses					***2567***	***1606***	***1469***
Net revenue					**2077**	**2709**	**2846**
Profitability relative to settled herding (%)					**100**	**130**	**137**

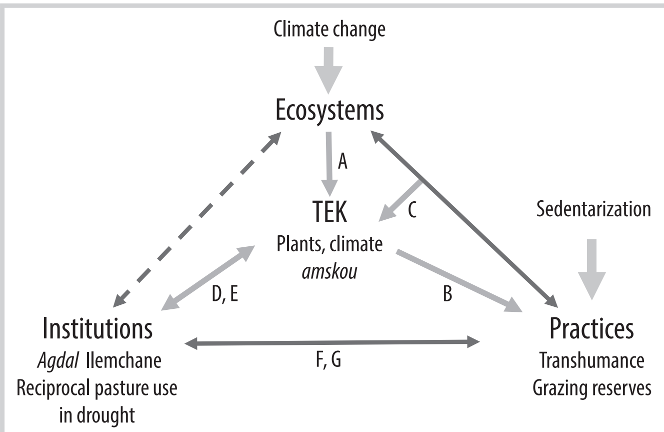
Note: Values represent typical values for each type of household and are based on a household survey and interviews. Surveys recorded the average amount of supplemental feed per animal per day (in kilograms), feed cost per kilogram, the number of days feed was provided, and the number of animals fed. For comparability, we assumed identical ewe replacement rates of 10% for all operation types.

founder of Zaouiat Ahensal, to Dada Atta, ancestor of the Ait Atta confederation, in return for military support. In a different account, one interviewee reported that the first 5 Ilemchane families purchased the *agdal* from the village of Taghia 500 years ago. Interviewees denied that religion plays a role in current *agdal* management. One interviewee expressed the *agdal*'s purpose as "to allow grass and other plants to grow so animals can eat them in July" (Figure 4D). As such, the *agdal* is a classic example of the grazing reserve as a storage strategy.

Only men born into the Ilemchane subfraction may use the *agdal*. Access cannot be gained by marrying an Ilemchane woman. Ilemchane may only bring their own animals to graze; they cannot bring animals of any non-Ilemchane. The *agdal* is closed from March 25 until the opening date in mid-July. Herders leave in September when the forage runs out and cold weather begins. There is no limit on the number of animals a family may bring or on the total number of animals allowed on the *agdal*. Each family that brings animals pays a fee that goes toward paying a guard to monitor the *agdal*. This non-Ilemchane guard is hired from the nearby village. According to interviewees, the number of families using the *agdal* has declined over time. In the 1980s, some 160 households used the *agdal* each summer, each bringing 200 sheep and goats. In the 2000s, about 60 households came, bringing an average of 400 animals. Today, fewer than 50 households come, each with about 600 animals.

The *agdal* is governed by a *jmaa* (council) made up of a male representative of each household using the *agdal*. Each year the council chooses a different *m'kdem* or leader to oversee the *agdal*. The *jmaa* selects the *m'kdem* via discussion (not a vote) at a meeting in Saghro before the spring migration, seeking a person of humility, good reputation, and wealth, in case he needs to pay expenses in advance of collecting fees. The *m'kdem*'s responsibilities include paying the guard and collecting users' fees and fines for violations of

FIGURE 5 Conceptual framework applied to the Ilemchane case. Herders gain ecological, plant, and climate TEK through interactions with ecosystems (A). This biophysical TEK informs practices like transhumance and grazing reserves (B). Herders observe how these practices affect ecosystems and livestock (C), further developing TEK. *Agdal* Ilemchane is founded on and reinforces TEK (D), and the concept of *amskou* influences *agdal* governance (E). The institutions of *agdal* and reciprocal pasture use support practices of transhumance and grazing reserves (F), which in turn are hypothesized to strengthen these institutions (G). See text for further explanation and supporting evidence.



agdal rules. Interviewees said that the *agdal* rules are "very old" and have not changed for centuries, but the amount of the fines sometimes changes. Each year when the *jmaa* meets, it goes over the rules and agrees on the amount of the fines for that year. When someone does not agree with or repeatedly violates rules, the *m'kdem* and *jmaa* may refer that person to the *Makhzen* (government administration). The person who disagrees may file a complaint with the *Makhzen*. If a person refuses to pay their fines, the *m'kdem* can confiscate livestock to cover the fine. Interviewees reported no major conflicts among users but recalled a dispute with another group in the 1980s that closed the *agdal* for 2 years and ended in a court decision. Since then, only Ilemchane use the *agdal*.

The Ilemchane use a lottery to allocate *azib* and water sources to the members each year. Each year the *jmaa* meets at a central place in the high mountain pastures the day before the *agdal* opens. At the meeting, each man puts one shoe in the middle of the tent. Someone mixes up the shoes and covers them with a blanket. One man randomly choses shoes from the pile without looking at them. The man whose shoe is picked first is assigned the first *azib,* and so on. In this way, the allocation of the *azib* is fair and transparent. This is important because half of the *azib* are in places with *amskou* and half are not. After dawn on the following day, families enter the *agdal* one by one with their flocks, in the order of the lottery, and move toward their assigned *azib* on a prescribed path.

During the grazing period, several rules guide use of *agdal* resources. Each *azib* is associated with a specific water source and the user assigned to a given *azib* must use only that water source. Upstream water is reserved for drinking and cooking; washing is confined to sites downstream. Wood-gathering areas are assigned to each user, and gathering outside of the assigned area is prohibited. There are specific routes for herd movements; when entering and leaving the *agdal,* a family must use their assigned route. Blocking another's way when they are moving is prohibited. Violation of any rule is punishable by a fine. Before the opening of the *agdal* each year, the *m'kdem* orally recites the rules to the *jmaa* to remind users of the rules and fines.

Transhumants' views of the future

Participants were pessimistic about the future of transhumance. Most perceived that Ilemchane youth have more options and little interest in continuing transhumance. Some said that the main advantage of transhumance—its profitability—is waning as the cost of transportation increases. In contrast to such pessimism, one interviewee from Ait Bougemez noted that the number of transhumants in his village has recently increased due to the increased availability of nearby high mountain pastures as others leave the sector.

Transhumants suggested several measures to support them in continuing their mobile lifestyle. Transportation support for movement and infrastructure, such as roads; solar panels to provide electricity; and cell phone services to enable communication would make travel and life in remote regions safer and easier, as would mobile schools and clinics. One participant suggested tree planting to halt erosion. Several proposed potential policies, like government subsidies for transhumance. An Ilemchane leader opined that transhumants must organize and form a federation to advocate for their needs: "For sustainable development we need examples, and to organize. They need to organize and lobby if they want help. They are more organized now than in the past." One woman stated, "The work of the women is harder than men's. They take care of the children, the house, the herds, everything. In every place in the world, there are rights for women, except for here."

Synthesis: exploring interactions among TEK, practices, and institutions

Figure 5 depicts the observed relationships among Ilemchane biophysical TEK and Ilemchane practices and institutions (ie adaptive strategies). Herders gain plant, rangeland, and climate TEK through interaction over time with the ecosystems they inhabit and use (Figure 5A). This TEK informs practices (Figure 5B), as seen when herders explain the rationales for transhumance and *agdal,* and describe how *amskou,* weather, and rangeland conditions drive movement decisions. Herders also observe the outcomes of their practices on ecosystems and livestock (Figure 5C), feeding back to the evolving TEK. For instance, they observe the benefits of grazing reserves and seasonal movement on plant growth and reproduction and the impact of transhumance movements on animal condition. *Agdal* Ilemchane both arises from TEK and reinforces it via feedback (Figure 5D) as herders note how the *agdal* benefits rangelands, leading to productive herds. *Amskou* shapes *agdal* governance (Figure 5E) via a lottery that ensures equitable access to the best campsites—those with *amskou.* Finally, the institutions of *agdal* and customary reciprocal pasture use with other pastoral groups support the practices of transhumance and grazing reserves by creating an incentive to move (access to lush *agdal* pastures) and opportunity to access distant pastures in drought (via reciprocal use norms) (Figure 5F). We hypothesize that these practices will in turn strengthen institutions (Figure 5G). For example, we expect repeated interactions with distant hosts from other pastoral groups to reinforce social networks of mutual obligation.

Climate change and sedentarization drive changes in the Ilemchane SES. Herders experience climate change as more frequent droughts, loss of plant species and rangeland productivity, and declining water sources. Mobility, especially distant movements in drought years, remains their main adaptive strategy in the face of these changes. Pressure to settle driven by needs for accessible health, sanitation, education, and communication services threatens the continuity of transhumance, *agdal* Ilemchane, and the TEK that created and maintains this mountain rangeland management system.

Discussion and conclusions

We found that Ilemchane transhumant women and men hold detailed knowledge of specific plants, in line with past TEK studies in Morocco (Linstadter et al 2013; Gobindram et al 2018), and beyond (Fernandez-Gimenez 2000; Molnar 2017). Yet like other Moroccan studies, our work stops short of a rigorous ethnobotanical inventory of herders' forage plant knowledge. More in-depth studies that definitively correlate Tashelhit vernacular plant names and forage uses with scientific nomenclature could help preserve this TEK and support communication and management.

Ilemchane herders relied on the concepts of *amskou* and *imurtz* to assess pasture quality. Although Moroccan experts were familiar with these terms, we found no reference to *amskou* in the literature. Chiche et al (1991) describe the idea of *mraoud* (an Arabic term for *amskou*) without reference to the Tashelhit word. Hammoudou (1988) sampled soils and vegetation in places with and without *mraoud* and found no differences. *Amskou* merits further study and consideration in conservation and management.

Herders observed changes in pastures over time, such as declines in many plant species, increasing bare ground and erosion, and declining water flows or levels, and believed climate drives most such changes. These findings align with ecological studies in low-elevation sites, where rainfall is the major driver (Finckh and Goldbach 2010). Yet herders' *agdal* experience has shown them that protecting plants during key growth periods allows recovery. The scant ecological research from similar High Atlas sites supports these views (Ouhammou 1996; Linstadter and Baumann 2013). Thus, Ilemchane TEK could inform community-based monitoring to track changes related to climate and management (Reed et al 2007, 2008; Jamsranjav et al 2019), supporting adaptation.

Scholars have described *agdal* governance (Gilles et al 1992; Dominguez et al 2010, 2012; Auclair et al 2011; Auclair and Alifriqui 2012), but *agdal* Ilemchane seems to differ from other High Atlas grazing *agdal* in key ways. Ilemchane hire a guard external to the group, and interviewees insisted that current management of *agdal* Ilemchane is not linked to saints or religious beliefs. Given that governance of some High Atlas *agdal* relies heavily on religion (Gilles et al 1992; Dominguez et al 2010), it is interesting to find a well-functioning secular *agdal*. Further investigation into *agdal* Ilemchane's history could help clarify when, why, and how it transitioned from a religious to a secular institution and verify the current regime.

We applied a simple framework (Figures 1 and 5) to investigate the interactions of Ilemchane biophysical TEK, as described earlier; its expression in practices (transhumance and grazing reserves) and institutions (*agdal* Ilemchane and reciprocal pasture use norms); and how herders' observations of the outcomes of these adaptive strategies feed back to further develop TEK and strengthen practices and institutions. This analysis reinforces findings from other mountain pastoral SESs that emphasize how TEK maintenance depends on its use (Kassam 2009; Fernández-Giménez and Fillat 2012). Given the exploratory nature of this case study, the framework remains a working hypothesis that we hope will inspire more in-depth work to validate and refine it.

As Figure 5 depicts, multiple factors—especially climate change and sedentarization—drive change in the Ilemchane SES. Thus, despite strong *agdal* governance, Ilemchane views on the future of transhumance are pessimistic and prospects for its continuity seem tenuous. On one hand, Ilemchane use and maintain TEK through transhumance to *agdal* Ilemchane. This way of life supports the sustainable development goals (SDGs) of poverty reduction, food security, and land health, among others. For instance, our budget comparison shows that Ilemchane transhumance is more profitable than settled management, similar to the findings of other studies (Fernández-Giménez and Ritten 2020). Transhumants also keep larger herds, which buffer against drought, and are able to respond flexibly using a suite of strategies, including mobility, storage, destocking, and supplemental feed. Our results align with those of Martin et al (2016), who found that Moroccan pastoralists' mobility correlated with decreased vulnerability to climate change and increased livelihood security. Similarly, mobile pastoralists in Kenya were more resilient to drought and herders who settled had poorer nutrition (Fratkin 2013).

On the other hand, interviewees see transhumance as incompatible with other SDGs, like gender equity and access to education, clean water, and infrastructure. Ilemchanes' limited access to schooling, medical care, hygiene, and infrastructure is a challenge shared by mobile pastoralists globally (Galvin 2009; Catley et al 2013; Khazanov 2013), as is gender equity in many pastoral SESs (Kipuri and Ridgewell 2008; Kohler-Rollefson 2012). The extreme remoteness of pastoralists in mountain rangelands intensifies these challenges. For Ilemchane, some deficits exacerbate others. For example, the lack of cell phone and radio services precludes use of these technologies to support remote schooling and health care. Interviews with Ilemchane women suggest that lack of medical care and hygiene disproportionately affects women, whose child-bearing role makes them especially vulnerable to health emergencies. Women's work in nomadic households often prevents them from taking part in the rare educational opportunities available to them. This results in high rates of illiteracy and monolingualism that further limit access to markets and information, hindering economic autonomy. Ilemchane women also remain excluded from formal decision-making roles in the *agdal* Ilemchane *jmaa*.

In summary, transhumance both supports and thwarts Ilemchane pastoralists' wellbeing, especially that of women. This apparent contradiction highlights another mountain paradox (Klein et al 2019), wherein Ilemchane remoteness and associated lack of education, health care, and alternative livelihood opportunities both maintain traditional transhumant culture and TEK and threaten to end it. For instance, lack of communication infrastructure limits Ilemchane exposure to homogenizing globalized culture, supporting continuity of their unique transhumant culture and TEK. Ilemchane women, like other Amazigh women (Sadiqi 2007), play a key role in transmitting transhumant culture. However, young Ilemchane women's disinterest in continuing transhumance suggests they contribute to abandonment of this lifeway. Women pastoralists in other mountain rangeland SESs also hold multiple roles in system conservation, transformation, and abandonment (Fernández-Giménez et al 2019). The remoteness paradox that this case study illustrates likely applies to other mountain pastoral SESs (Kreutzmann 2012). As Kreutzmann (2012) suggests, the remoteness of mountain pastoral SESs, despite hindering access to services, may create spaces for locally driven development approaches that avoid top-down modernization projects. Mountain pastoralist TEK and adaptive strategies could serve as vital foundations for such locally driven approaches (Kassam 2009; Wilson et al 2017).

In conclusion, this exploratory case study of Ilemchane TEK advances a simple integrated framework for examining how TEK as biophysical observations, management practices, and institutions interrelate and reinforce one another. Drawing on their TEK system, Ilemchane transhumants use a full suite of pastoralist adaptive strategies—mobility, storage, resource pooling, reciprocity, and diversification—to sustain their livelihood and the health of their herds and pastures. Ilemchane TEK and adaptive strategies inherently contribute to biocultural diversity (Dominguez 2016) and offer resources for future innovation and adaptation (Kassam 2009; Wilson et al 2017). Yet as in other mountain pastoral SESs, both climate and social change challenge the future of this SES and its TEK (Kreutzmann 2012; Reid et al 2014). To overcome the paradox of remoteness, Ilemchane need greater internal organization and external support to achieve SDGs of equity and access while maintaining their TEK system, adaptive strategies, and the transhumant way of life they sustain.

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Supplemental material

APPENDIX S1 Detailed data collection methods.
APPENDIX S2 Traditional ecological knowledge, management practices, and governance interview questions.
APPENDIX S3 Ethnobotanical interview questions.
APPENDIX S4 Survey questionnaire on observations of environmental conditions and changes.
APPENDIX S5 Household production survey.

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