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

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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 (Linstalder 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 (Roé 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). Fernández-
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; Stairs 2018). Water availability, disease, and social factors also influence movement (Akashi et al. 2012; Fernández-Gimenez 2000). As a distinctive cultural practice that enhances biological diversity (Bunce et al. 2004), transhumance contributes to biocultural diversity (Domínguez 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; Koubal et al. 2018).

Agdal is a generic Amazigh (Berber) term used throughout North Africa, which Auclair and Afifriqui (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 (Domínguez and Benessiaia 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; Domínguez 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 Kouba et al. 2018). 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, 5°57’14.3”W).
In 2018, the Ilemchane population numbered 673 individuals over age 7, of whom 183 were transhumants. In total, transhumant households herded 14,500 goats, 9,050 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

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.

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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

| 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         |       |
| Tifisit           | 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         |       |
| Ameuris           | Apiaceae     | Bupleurum| Spinosum      | Shrub       |                        | 6              | 5.57      | 0.15         |       |
| Iwchek (Iouchked) | Brassicaceae | Zilla    | Spinoso       | Shrub       |                        | 2              | 1.86      | 0.15         |       |
| Adolphsa          | Apiaceae     | Bupleurum| Spinosum      | Shrub       | Decreasing             | 4              | 3.86      | 0.15         |       |
| Imouman           | Poaceae      | Poa      | Bulbosa       | Grass       |                        | 3              | 3.29      | 0.13         |       |
| Awchek (Ochched)  | Fabaceae     | Astragalus| Armatus       | Shrub       |                        | 2              | 2.29      | 0.13         |       |
| Ouzra             | Caryophyllaceae| Arenaria| Pungens       | Shrub       | Poor quality           | 4              | 4.71      | 0.12         |       |
| Auzechem          | 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           | 2              | 2.71      | 0.11         |       |
| Agassiss          | Poaceae      | Dactylis | Glomerata     | Grass       | Both                   | 3              | 4.29      | 0.10         |       |
| Ikhardn           | Asteraceae   | Centaurea| Marocana      | Forb        |                        | 2              | 2.86      | 0.10         |       |
| Tbaarau           | Juncaceae    | Juncus   |              | Rush        | Decreasing             | 4              | 6.14      | 0.09         |       |
| Igersel           | Poaceae      |          |               | Grass       | Good quality           | 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        | 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         |       |
| Amenaz            | Poaceae      |          |               | Grass       |                        | 2              | 3.86      | 0.07         |       |
| Awrubia           | Fabaceae     | Adenocarpus| Bacquei      | Shrub       | Good quality           | 2              | 5.00      | 0.06         |       |
| Azazr             | Buxaceae     | Buxus    | Balearica     | Shrub       |                        | 2              | 5.29      | 0.05         |       |

Note: Cognitive salience index (CSI) = freq/(n × 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.
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 bloating, 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/runner]. The runner 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

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

| Indicator Description                                                                 | Frequency | Indicator Description                      | 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         |                                           |           |

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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 until the agdal opens in mid-July (Figure 4). They use agdal 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.

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

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

**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 | Sagho Mountains |
|               | Much colder | Colder | No change | Warmer | Much warmer | 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 |
| Spring temperature | Much colder | 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, xi*), where *xi* 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.
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.”

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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)
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. 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 fell 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
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

| 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                    | 2077    | 2709        | 2846                    |
| Livestock feed       | Settled: 17.98                | 100     | 100         | 100                     | 1798    | 837         | 200                     |
|                      | Transhumant: 8.40             |         |             |                         |         |             |                         |
|                      | Long distance: 2.00           |         |             |                         |         |             |                         |
| 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                    | 2077    | 2709        | 2846                    |
| Net revenue          |                               | 2077    | 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.
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 chooses 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 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.
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 (Fernández-Giménez 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 imurts 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 Alifrigui 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. Ilemchane’s 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
livelhood 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 knowledge. 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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