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Horseflies, wolves and wells: biophysical and socio-economic factors influencing livestock distribution in Kazakhstan's rangelands

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ABSTRACT

There have been studies on how pastoralists assess and choose the resources required for their livestock, but little research analysing whether livestock are matched to the available resources in a seasonal migratory system by an entire pastoral community over a year. This paper reports a case study of pastoralists in Kazakhstan which shows how the inter-relation of biophysical, institutional and economic factors results in the imperfect matching of livestock numbers to the distribution of forage resources. The research is based on a three-year study using anthropological interviews, formal survey data, and remotely sensed data covering all livestock (25,000 smallstock and approximately 2300 cattle, horses and camels) in a study area of 60,000 km^2 for an entire annual cycle; a combination of methodologies and geographical coverage that provides a comprehensive estimation of the factors that influence the pastoral exploitation of this human-managed, complex ecosystem. The research finds that the pastoralists are subject to a number of limitations in using biophysical niches which might otherwise provide the best feed and water resources for their animals at a particular season and site. Different ecozones offer seasonally-shifting advantages and disadvantages for the livestock, but livestock owners are also economically differentiated. The interplay between economic and biophysical factors exemplifies the multi-faceted character of pastoralists' decision-making about site selection within a relatively open rangeland tenure system. Only those with the largest livestock holdings distribute their livestock to take advantage of the best seasonal resources. Despite the wide availability of biophysically suitable sites, most livestock owners' choices are compromised and therefore frequently suboptimal, prompting the conclusion that natural resource matching is constrained.

1. Introduction

Pastoral production systems typically prevail in environments where natural resources are scattered, intermittently productive or unproductive—at extreme latitudes, high altitudes or in semi-arid regions (Ellis et al., 1993). In the attempt to match livestock feed demand to feed supplies in these heterogeneous and harsh environments, pastoral herds track ephemeral and highly seasonal resource concentrations (Ellis and Swift, 1988; Fernandez-Gimenez and Allen-Diaz, 1999; Niamir-Fuller, 1999; McAllister et al., 2006). From a biological perspective, this freedom of movement by pastoralists should make optimal use of available resources and sustain larger populations than would be possible if herds were not allowed to track fleeting resource concentrations (Behnke and Scoones, 1993; Niamir-Fuller, 1999; Boone et al., 2005).

The analysis of pastoralism as resource matching by mobile domestic livestock parallels ecological theories with reference to wild animals, of the ideal free distribution (IFD) or density dependent habitat selection (DDHS) which link individual choices to overall population distributions (Fretwell and Lucas, 1970; Sutherland, 1983; Wade, 1987). The fundamental idea behind these theories is that resource consumers respond both to the distribution of resources and to the shifting distributions of other consumers. These spatial ecological models predict that the free movement of individual animals—enabled by open access to resources—results in the optimal distribution of resource con-

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sumers in temporally and spatially heterogeneous landscapes, relative to available resources. This matching of animal numbers to resource density enables landscapes to support larger consumer populations than systems in which access is constrained (Pulliam and Danielson, 1991; Jonzen et al., 2004; Hancock and Milner-Gulland, 2006).

Our study examines the proposition that the distribution of domestic livestock in a mobile pastoral system matches the resource concentrations. While this notion is not new, we note that empirical studies on how certain animal species are distributed in relation to food resources and other factors have shown that there is often an imperfect match between the population of consumers and the available food resources, termed by some as "undermatching" (Gray, 1994; Spencer et al., 1996; Houston and Lang, 1998; Shochat et al., 2002; Bai et al., 2009). Some of the main explanations of undermatching from studies of wild animal species is ignorance, poor navigational skills, lack of knowledge, poor cognitive ability or memory on the part of individual animals (Shochat et al., 2002; Hancock and Milner-Gulland, 2006; Bai et al., 2009). Our study seeks evidence on whether undermatching is also occurring in a pastoralist setting in central Kazakhstan, where we have detailed multidisciplinary material from three years of ethnographic research, remotely sensed data and quantitative surveys. If undermatching is occurring, we need to explain why and how the interposition of human managers' interests alters the expression of optimal resource matching for livestock.

When humans are responsible for the decisions regarding resource use by domestic livestock, there are likely to be trade-offs between the biophysical site attributes and socio-economic and institutional site suitability from the humans' perspective (e.g., Abernethy et al., 2007 on the distribution of fish stocks and fishing effort). The balancing of these factors in pastoral decision-making regarding herd mobility and resource use has long been recognized by social and ecological anthropologists (Stenning, 1959; Cunnison, 1966; Gulliver, 1975; Dyson-Hudson and Dyson-Hudson, 1980; McCabe and Fratkin, 1994; see also reviews in Coppolillo, 2000). One early scholar of pastoralist livestock management strategies reflects that while "Anthropologists can produce generalised patterns of movements...empirically on the ground irregularity in response to highly variable reality is characteristic of on-going nomadic life" and he emphasizes that "each occasion for movement is for the nomads an occasion for *choice*: the assessment of information and needs, the exercise of opinion, and the making of decision...this choice is not in practice simply a matter of reaching a decision through the assembly and assessment of information on resources, for usually there is no obvious single best choice but a variety of possibilities...there is a range of opportunities of roughly equal pastoral advantage" (Gulliver, 1975: 371–372; italics in original). We return to this starting point but now with new tools, such as remote sensing, for assessing the variable biophysical environment, which were not available to social anthropologists decades ago.

There have been numerous close studies of how grazing animals (herbivores) disperse over landscapes which vary in space and time at relatively small scales (e.g., an early review in Coughenour, 1991; Bailey and Provenza, 2008). With the advent of digital and remote sensing technology, studies have also been able to record where sentinel herd animals move, and to correlate those movements with environmental features gleaned from remotely sensed data and field interviews with the pastoralist owners of the livestock (Turner and Hiernaux, 2002; Butt, 2010a, 2010b; Moritz et al., 2013).

At the larger scale, rangeland ecologists and modelers have also sought to detect determinants of livestock distribution at the landscape level (see for example McAllister et al., 2006; Behnke et al., 2011). There are recent pastoralist studies which explicitly benefit from ecological theories to explain how pastoralists perceive, value and use different parts of their available environment for grazing and moving their livestock (e.g., Schareika, 2003; Krätli, 2008; Moritz et al., 2013; Sayre et al., 2013). These studies can explain (often with a great degree of precision) where some groups of a pastoral community's livestock are at any particular time and why these animals might be there rather than somewhere else, typically in terms of their consumption of forage and water. But such studies rarely indicate why some socio-economic groups of pastoralists make certain decisions in contradistinction to others, but within the same set of environmental options, a limitation noted by Baker and Hoffman (2006: 775) in a South African case study:

> "The existence of different herding strategies within the same environmental context suggests that individual herders may consider non-environmental factors more important when choosing a herd management strategy than has been suggested in ecologically focused papers . . .".

One study which does attempt to comprehend the criteria used by pastoralists with different socio-economic profiles, by Akasbi et al. (2012), tracked flocks over a year in the Atlas Mountains of Morocco, to identify the factors that influence decision-making of herders regarding accessing resources. They concluded that "The transhumant migration decisions of the three studied tribes are dependent on both ecological and socioeconomic conditions...". While it is not surprising that "the key ecological factor that drives decision-making of transhumant pastoralists is fodder availability" they also conclude that "Individual decisions allow for flexible adaptation within the framework of the tribal and ecological settings, taking into account risk control, social networks (proximity to central tribal settlement and larger family), the arrangement of tribal territories and access to local markets"(Akasbi et al., 2012: 318). Similar conclusions on the effects of socio-economic differentiation for herd management decisions have been reached by Hendricks et al. (2004) in a South African case study. In the forefront of these analyses is the realization that it is not animals making the decisions of where to congregate to obtain resources at the landscape scale, but the people who manage the animals (e.g., Coppolillo, 2000).

This case study of mobile pastoralism in semi-arid Kazakhstan uses the matching hypothesis of IFD and applies multi-disciplinary research methods to assess the extent to which resource matching is a compromise between biophysical imperatives and the social, economic and institutional conditions within which the humans operate their livestock. Our case study allows us to assess not only the tension between biophysical optima and socio-economic feasibility but to reveal the further mediation due to the differential attributes of individual pastoralists.

2. Scope and aims of the study

The assessment considers what constitutes "resources" for different types of pastoralists, in order to evaluate the extent to which they are matching their livestock to available resources. The assessment is based on comparing the apparent advantages and disadvantages of particular ecozones with the recorded distribution of livestock by their owners in each season of an entire annual cycle. This empirical analysis, using remote sensed and survey data, is then interpreted with rationales from pastoralists, gained by anthropological methods, on why certain ecozones are useful or not, at particular times of year. The resulting distribution patterns suggest there are a variety of biophysical and socio-institutional factors that constrain or attract and thus influence forage resource matching (Butt, 2010b; Behnke et al., 2011).

The study site is in Kazakhstan's south central rangelands in two settlements of one administrative district (Moiynkum). It is based on a re-examination in 2012–2014 of a pastoral rangeland system which has previously been intensively studied (Behnke, 2003; Kerven et al., 2004, 2006, 2008; Milner-Gulland et al., 2006; Alimaev et al., 2008). This case of Kazakhstan's pastoral management systems is notable for several reasons. In the former soviet collective farms, the management of livestock distribution was highly regulated and supported, but in the post-Soviet era since 1991, newly-privatised pastoralists have had to make their own decisions on livestock distribution, under rapidly and profoundly altered economic and institutional conditions. These new livestock management systems in Kazakhstan's pastoralist hinterland are largely unrecorded by researchers. From being closely observed and managed in the Soviet period, the remote pastures have become *terra incognita* for the urban policy-makers in the present day—very rarely visited and even less understood.

A novel element of this case study is that the entire livestock population distribution of several pastoralist communities over a complete annual seasonal cycle is mapped on a large scale and then illustrated with individual strategies of livestock owners, who are able to articulate their reasons for making certain decisions. The results focus on livestock owners within the current national economic and policy conditions, rather than their responses to the changes in the macro conditions that have taken place in the last decade, which will be considered in subsequent publications.

An initial challenge when examining whether resource matching is taking place is to define what constitutes "resources" for pastoralists. Partly, these are the recognized biotic and abiotic factors of vegetation or water. However, other non-biophysical factors highly influence pastoralists' choices of which patches to occupy, at what time of year (Baker and Hoffman, 2006; Behnke et al., 2011). In a heterogeneous environment in which livestock can be moved seasonally between sites in different ecozones, in certain ecozones resource suitability or attractiveness plummets at some seasons of the year and shoots up in others, for a variety of sometimes unrelated reasons. From the livestock manager's perspective, the consideration of "site suitability" must encompass more holistic factors than would be included in resource density expressed only as feed resources.

Our hypothesis is that factors other than feed resource density (measured for example as forage biomass) have a strong influence upon pastoralists' choices of which sites, in terms of ecozones, to occupy and in what season. A corollary of our hypothesis is that since livestock owners are differentiated in terms of their personal resource endowments, their choices will not be uniform, but rather will be a trade-off between their particular limitations and abilities. In this paper we focus on land tenure and flock/herd size, which emerged as the principal socio-economic and institutional factors limiting or enabling pastoralists' choices. There will consequently be a range of criteria among livestock owners as to what constitutes a resource. To examine our hypothesis, the research sought answers to the following broad questions:

- What are the major different biophysical differences between ecozones in terms of matching resources suitable for livestock, which may explain the resulting distribution patterns?
- What are the advantages and disadvantages of keeping livestock in each type of ecozone within each season, for different socio-economic groups of pastoralists?

Firstly, we outline the features of the main ecological zones in the study site, based on secondary source, and the overall distribution of livestock which our study recorded in different ecozones throughout an annual cycle. Next, we describe the distinctive biological and physical factors that underpin this livestock management and migratory system, seeing how various push–pull factors—including prevalence/absence of predators and pests, temperature, forage quantity and quality or water availability—do not necessarily add up neatly to an unequivocal signal as to where livestock should be located at a particular season. We proceed to summarize the formal land tenure conditions, the major institutional factor which may be shaping the pastoralists' choices of which ecozones to use in different seasons. The paper then assesses whether there is a discernible relationship between the current livestock ownership patterns and patterns of seasonal mobility. We ask if economic stratification and the land tenure system may influence livestock owners' perception and use of each type of biophysical resource. In conclusion, the paper discusses whether pastoralists' decision-making on site selection is resulting in constrained natural resource matching and what national policy implications arise from the observed patterns.

3. Material and methods

Since we had to consider the main biophysical, socio-economic and institutional factors influencing livestock distribution, assessment required the application of methods from different disciplines. We developed three sets of data, to assess the extent to which pastoralists were matching their livestock to the available resources. These data sets comprised firstly, open-ended interviews with local residents using social anthropological techniques; secondly, formal questionnaire surveys analysed with statistical techniques, and thirdly, analysis of remote-sensed data by reference to published material in Russian from the Soviet period. All the data sets were geo-referenced as far as possible. Each of these methods alone could not provide complete explanations for the livestock distribution patterns, so that data derived from one line of analysis was then integrated and compared with data from the other sets, in order to generate a fuller picture. For example, while some biophysical indices could be obtained from available remote sensed and published geo-botanical data, additional biophysical influences were reported verbally through our interviews with livestock owners. Similarly, while interviews with residents suggested reasons why livestock might be distributed at particular sites, only by conducting our quantitative surveys and referring to geo-botanical published data could these reasons be cross-checked for validation.

Field research in the study area used social anthropological approaches, as described below, to elicit some of the complex management practices used by pastoralists, currently and in the recent past, for gaining access to key resources for raising livestock in the study area. In two small desert settlements (respectively containing 250 families and 87 families in 2012), 167 open-ended interviews were conducted with 97 individuals (many interviewed more than once), in five fieldwork periods in 2012–2014; April and October 2012, April and June 2013 and March–April 2014.

The respondents were familiar with the international and national research team members, who had previously conducted fieldwork in this same study area between 2000 and 2005. The researchers stayed in pastoralists' family homes, which generated opportunities for unforeseen lines of enquiry to arise informally. Interviews were open-ended but followed a check list of central questions. The aim of the interviews was to uncover people's rationales on site suitability and resource matching. Whenever a respondent brought up a spontaneous explanation, such as presence of insects, livestock market prices, or land tenure, they were encouraged to elaborate on these topics. Interviewees frequently expressed their opinions and raised new issues, in response to the interviewer's questions. In such cases, secondary and tertiary lines of enquiry would be pursued. This is a standard method for social anthropological field research. New topics introduced by respondents were also followed up in subsequent interviews with other respondents.

Notes were taken in each interview, with the respondent's prior permission, and were recorded verbatim in english translation, as a Kazakh interpreter was used. Interviews were conducted in people's homes or on the open rangelands, and not all topics were asked in a single interview, as repeat visits were often made. Interviews could last a minimum of 30 min and up to 3 h or more, depending on the respondent's loquaciousness and leisure time at their disposal.

The central questions revolved around the purpose of the study, which was to understand the choices made by different types of pastoralists on what constituted resources and site suitability for their livestock. A detailed list of the questions raised is provided in Supplementary materials, in the section on "Methods". Interviewees included livestock owners, as well as their close family members, though not necessarily co-resident (e.g., spouses, sisters, brothers, sons and fathers), hired shepherds, former livestock owners, village mayors, veterinary officers, former professional employees of the state livestock farm, and those responsible for the state forestry department. All interviews are anonymized and individual statements cited here from informants are identified by their ID number in the data set.

A second method relied on formal questionnaires and field surveys. Following several field trips in which open-ended investigative interviews were conducted, two short formal questionnaire surveys were designed, tested and conducted. The first survey was on livestock monthly movements of 64 livestock owners. This survey aimed to be a complete census, and was asked of all livestock owners present at the time of the survey in the entire study area. The survey was limited to four questions, asking about pasture locations and water sources for the owners' large stock and separately for their small stock in each month of the preceding year, and the type, quantity and cost of supplementary winter fodder purchased or harvested. The data on winter fodder is not presented in this paper. We recorded only where each livestock owner located their livestock in each month of the year. We did not attempt to record adhoc opportunistic movement decisions made by owners or indeed, hired shepherds, although from interviews we learned that such unplanned movements can occur if well water or forage becomes depleted at a particular site in the course of a season.

Overall 118 unique livestock owners were recorded between 2003 and 2012. Of these owners, full livestock ownership information was available for 80 owners in 2003 and 84 in 2012; of which 58 were owners who appeared in both years. A second questionnaire survey was limited to 25 well-occupiers who had semi-privatized pasture land and previously or currently used 42 wells. This survey asked about well sites and dates when each well was occupied or abandoned by the respondent, reasons for stopping use of a well, the annual dates when pests and predators appeared and the number of days when livestock were unable to graze due to snow in winter. Two separate field surveys were also carried out in 2012 and 2014 of 57 used and abandoned accessible wells formerly under the state farm control, with the vegetation being recorded at 43 well sites, and taking GPS measures. Since the surveys were conducted over three years and five field trips, some surveys included all livestock owners in the study area, while some were surveys of all livestock owners who were present at the time of the field work, or only those in the larger of the two study villages. This is indicated in each table or graph.

While there is a growing literature on pastoralists' indigenous knowledge of pasture characteristics (e.g., Schareika, 2003; Oba and Katira, 2006), it was not the aim of this study to investigate this aspect of ecological knowledge about grazing management. Instead we use formal vegetation classifications from remote-sensed and Soviet era geo-botanical data to characterize pasture, data which was corroborated by pastoralists' explanations of their livestock distributions, derived from anthropological interviews. The coordinates of grazing locations used by interviewees over 12 months of the year were recorded using a mixture of interview and survey information, maps and site verification by GPS.

Our third method used a remote-sensed data set consisting of a classified Landsat image from 2001 (Alimaev et al., 2008), which was analysed with forage maps of the study areas' three former livestock Soviet collective farms (Rus. *sovkhoz*) which were disbanded in 1996. The forage maps were at a scale of 1:50,000, produced in 1977 and 1978 by the State Institute for Land Management (Giprozem) (Ministry of Agriculture of the Kazakh SSR, 1969; Ivanov, 1973). The current validity of the Giprozem maps was verified by fieldwork in June 2013. These sources were used by our team to produce maps of vegetation type and forage availability in the study region. We identified a set of 13 major vegetation classes by a combination of fieldwork and quantitative comparisons between the major types described in Giprozem polygons and those identified in the 2001 Landsat classification.

For each vegetation class, edible biomass values were calculated from the averages (weighted by area) of values for the Giprozem types associated with that class. Both data sources were used to produce a map simplified into major zones, with estimates of edible biomass in each season. This approach was chosen over the use of the Normalized Difference Vegetation Index (NDVI), commonly used as an index of biomass (Pettorelli et al., 2011) because NDVI is unlikely to be usable in the winter months when vegetation is brown or hidden under snow. Moreover, the Soviet vegetation maps provide information on the fraction of total biomass which is edible by livestock. The vegetation maps did not cover the entire study area, but were generalized to a larger area through the use of satellite images using methods to be published in detail elsewhere and which we summarize briefly here. A more detailed description of the remote sensed methods is provided in Supplementary materials, in Section 3.

4. Study area

The case study is based on two locations in a system of semi-arid rangelands in south central Kazakhstan; Moiynkum district (Rus. *raion*) in the northern part of Dzhambul Province (Rus. *oblast*') (Fig. 1) where the main livelihood has been raising livestock extensively, due to the low average annual precipitation of 170 mm, mostly falling in spring (March–May) but can fall as snow from late November to March; there is annual variability with CVs of over 0.30 (Coughenour et al., 2008). Temperatures are extreme, falling to −45 °C in winter (December–February) with a maximum of 46 °C in summer from June to August (Kerven et al., 2006). Nucleated villages are located along the Chu River that runs through the desert. No rainfed or irrigated crops are grown, due to aridity.

The study area comprises three former state collective farms (*sovkhoz*) each of which used to raise up to 80,000 livestock, principally sheep, in the Soviet period from the 1950s to 1991. The first former farm is centered on a large village called Ulan Bel with coordinates of 44°49′38.52″ N and 71°67′30.68 E, and for the last decade, amalgamates the people from a second adjacent sovkhoz which was centered at Malye Kamkale. The third former *sovkhoz* is located 90 km east of Ulan Bel, and contains two smaller linked villages of Sary Ozek and Yeske Baital at coordinates 44°35′20.18″ N and 72°10′56.46″ E.

4.1. Major ecozones

Nomadic Kazakh pastoralists in the region formerly used five large-scale ecozones for seasonal grazing since before the Soviet farm collectivization in the 1950s (Borodyn, 1950; Mateev and

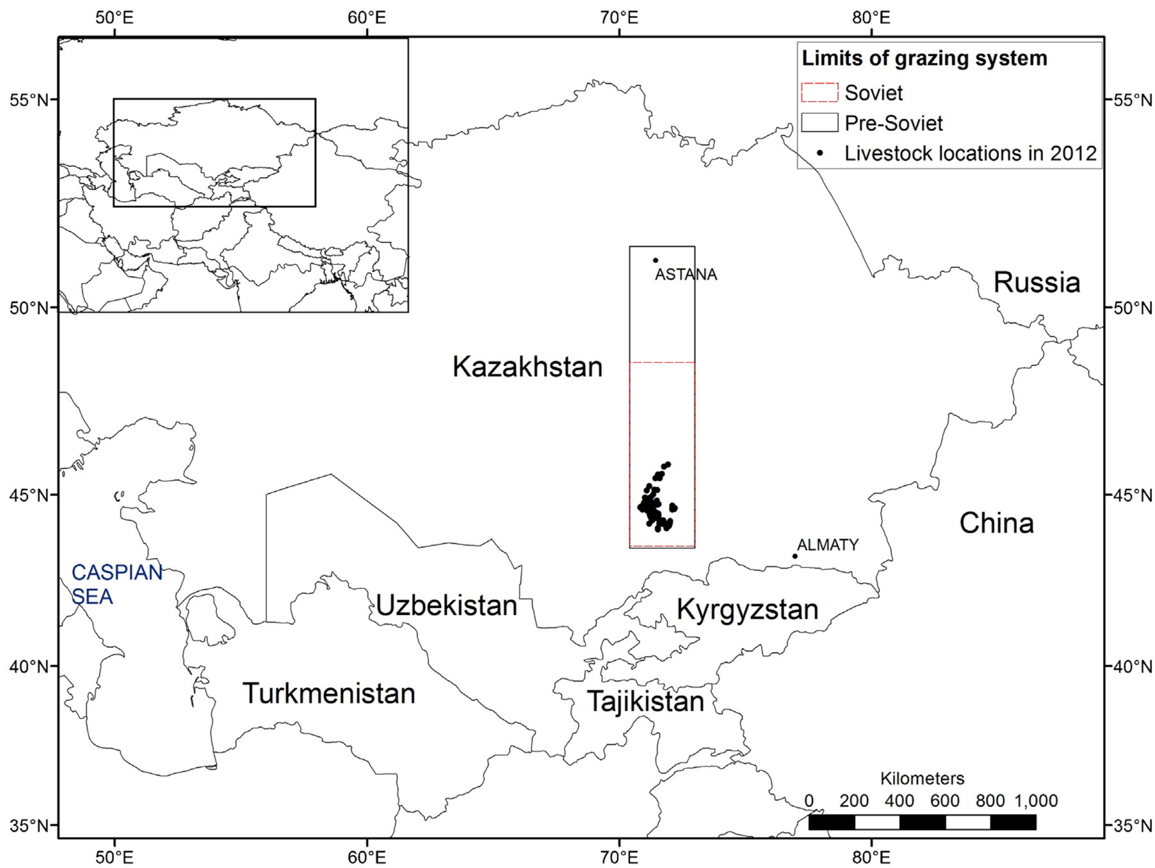

Fig. 1. Study area location within Kazakhstan and Asia.

Table 1
Major Ecozones used by pastoralists in the study area, from north to south.

Ecozone type	Biophysical characteristics
Clay desert: Betpak dala plain(most northern zone)	Betpak dala in Kazakh means "hungry steppe", and consists of a huge semi-arid plain on clay soils. During the Soviet and pre-Soviet periods, Betpak dala was a spring-autumn transition pasture crossed by livestock on their way to and from the Sary Arka summer pastures to the north (Borodyn, 1950). In spring numerous ephemeral plant species appear, a rich source of protein for herbivores following the winter period of vegetation dormancy (Mynbaev, 1957; Alimaev and Behnke, 2008)
Riverine area: Chu river valley	Riparian land above the river's many channels is termed *shabandyk* in Kazakh, and contains coarse reeds which can be grazed mainly by cattle and are cut as hay for winter feed. Vegetation on recession flood plain in spring may be grazed by sheep
Salty clay desert: plain south of Chu River	Extending up to 35 km south of Chu river a flat clay salty plain classified in Kazakh as *sor* and sometimes referred to as *shabyr*. Sparse vegetation but further south is a transition zone in which the soil starts to become sandier
Sandy desert: Moiynkum (most southern zone)	The sandy dunes (Rus. *peski*; Kaz. *kum* = sand) begin about 40 km south of the Chu river valley, and the vegetation becomes highly diverse. The dunes were the preferred ecozone in the Soviet state farms for maintaining livestock in winter, based on observed former use by Kazakh pastoralists in the pre-Soviet seasonal migratory system (Mateev and Polyakov 1950; Alimaev and Behnke, 2008)

Polyakov, 1950; Alimaev and Behnke, 2008). Circulatory movements between the ecozones covered up to 600 km each way from north to south. Following the collapse of the state farms (*sovkhoz*) in the mid 1990s, only four of these ecozones have continued to be used and only by a minority of private livestock owners (Kerven et al., 2004, 2006, 2008) summarised in Table 1. These ecozones span a north-south latitudinal axis. Since some pastoralists choose, and are able, to move their animals between these ecological zones; in this sense the zones together comprise a single potential grazing system (Fig. 2).

4.2. Livestock populations and seasonal locations

The official figures on livestock species kept in the study villages in 2012 were 20,300 sheep, about 5000 goats, 2125 cattle, 260 horses and 77 camels. These numbers were double checked, in our research, with the former livestock farm managers from the Soviet period and current village veterinarians. Most of the large livestock owners admitted that they understate the number of their animals. This is confirmed by the government veterinarians in both study sites. While absolute numbers are undoubtedly higher, the relative proportions between species and villages are realistic. The larger village of Ulan Bel has many more sheep compared to Sary

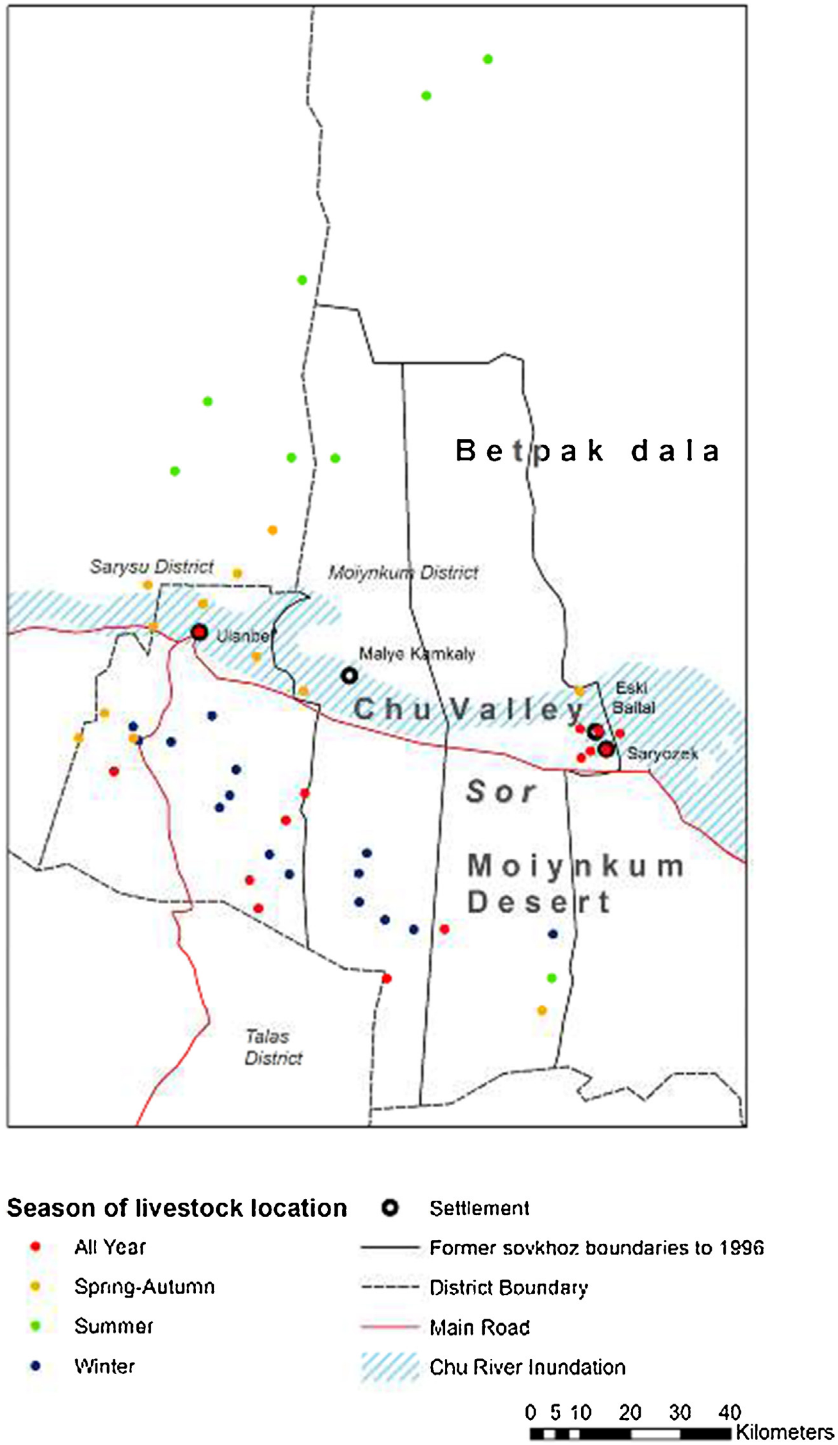

Fig. 2. Major ecological zones and livestock locations by season, 2011–2012, showing administrative boundaries. Based on a total of 30,772 livestock units of which 56% comprised cattle and horses, and 44% comprised sheep/goats in livestock units.

Ozek, where the vegetation is more suitable for goats. Some flocks and herds are moved between different locations in various seasons, while others are kept in only one or two locations all year round (Fig. 2).

4.3. Human population

In 2012, in Ulan Bel (UB) there were 1200 people (662 males and 538 females). Ulan Bel has many "nationalities" (Rus. *narod*—Soviet terminology for ethnic groups), but is predominantly Kazakh. Sary Ozek (SO) has 344 people and Yeske Baital (YB) has 67 people.

5. Results

5.1. Livestock management options

Livestock owners can choose one or more of the following management options for locating where their livestock graze, can access

Table 2
Grazing management options for livestock owners.

Type of grazing management	Variations and characteristics
Sedentary, daily grazing and return to village every night for safety	Horses and camels can stay out overnight as less loss to wolves
Chu river flood plain 5–20 km from villages, usually only seasonal	Larger-scale owners or hired shepherds move out from villages and stay in wagons or yurts, to shepherd animals
Entrustment to owners at remote grazing site(s) in desert, away from villages. Can be all year or for some seasons	Requires trusted relationship between owners or hired shepherds and payment of about 1 USD per head per month
Grazed at distant pasture sites more than 20 km from village and river	Livestock can stay at one site all year or be moved between sites. Requires housing for people, barns and wells

drinking water and are protected from predators and pests. These are summarised in Table 2.

5.2. *Seasonal livestock distribution*

The livestock owners decide each year which of the possible management options to pursue, and the ecozones in which to place their livestock, and for how much time. These moves are apparent from Fig. 2 previously, showing livestock locations in each season. More detail on these individual decisions is represented in Supplementary materials, Fig. A. The principal change in the locales of the combined livestock population occurs between winter and summer, when a quarter of the livestock are moved away from the Moiynkum sands to the northern clay desert of Betpak dala. Some pastoralists move their herds between 50 and 200 km between wells, and the net result is that around 17% of the total livestock are found in Betpak dala in the summer, where none are found in the winter. A smaller locational change occurs from winter to spring, with some pastoralists moving their livestock between 17 and 120 km from Moiynkum sands to the Chu riverine pastures, with the net result of an increase in the proportion of livestock in the Chu pastures from winter to spring. The sedentary livestock population in the villages remains stable throughout each season, at around one quarter of all the livestock.

However there are major differences between the locations of small stock (mainly sheep and some goats) and large stock (mainly cattle, some horses and a very few camels) in each of the four seasons in 2011–2012. This is particularly the case for Ulan Bel, where two thirds of the cattle in the study area are kept around the Chu river valley all year, compared to less than one third of sheep and goats, which are more likely to be kept in one or more of the other ecozones. Detailed figures are given in Supplementary materials Fig. B. It is clear that livestock owners are making different choices about the most suitable sites for their livestock, both large and smallstock in each season. There are a number of factors that influence their choices, each of which are now considered.

5.3. *Biophysical characteristics of the locations used for grazing and watering livestock*

The following sections describe the physical characteristics include climate, soils, surface and below-ground water, and topography. The biological characteristics consist of vegetation, pests and predators. These factors historically influenced seasonal livestock movements between the zones, prior to, during and after the Soviet period (Borodyn, 1950; Mateev and Polyakov, 1950; Mynbaev, 1957; Alimaev and Behnke, 2008). Following the end of state farm infrastructure and subsidized input support, some of these factors may still be important drivers of livestock movement, others less so.

5.3.1. *Climate*

For herbivores including livestock, the most limiting climatic factors occur in winter from early December to March, when temperatures drop to well below freezing and vegetation growth ceases. Although precipitation is meagre, the depth of snow in winter can then cover any accessible vegetation, rendering grazing very difficult. In some winters a climatic disaster, termed *dzhut* in Kazakh, occurs when melting snow re-freezes to form an icy layer covering the grass or due to unusually heavy snow falls (Zhambakin, 1995), which prevents livestock from accessing forage (Sludskii, 1963). However, the important factors for raising livestock are the climatic differences between the ecozones (details shown in Supplementary materials, Table A). The northern-most ecozone now used, Betpak dala, has double the number of snow-covered days (up to 120 days) and a mean January temperature of −12 °C, compared to Moiynkum in the south, with a mean of 58 snow-covered days and a mean January temperature of −8 °C. Betpak dala is also susceptible to frost-snow disasters. The Chu river floodplain has few snow-covered days in winter, while the most southern ecozone of Moiynkum has light snow and warmer winter average temperatures.

5.3.2. *Forage quantity and quality*

Each of these three major ecological zones contains different types of vegetation associations, influenced by the climate, subsurface, drainage and soil (Fig. 3). Also shown on Fig. 3 are areas of low vegetation cover which are affected by long-term grazing around wells (Type 5).

In determining the relative attractiveness of the vegetation types to livestock (and thus their human owners) at different periods of the year, two relevant indices can be considered for which secondary data is available:

- The proportion of biomass which is actually available to livestock (edible biomass);
- The quality of the edible fraction measured by digestible protein.

Fig. 4 presents maps of edible biomass for the 11 vegetation associations identified in Fig. 3, for four seasons.

Edibility essentially means that an animal may eat a plant, but does not mean that the plant is especially nutritious at a particular season of its phenology. Although data on the combined forage quality of each major vegetation association were not available, there is evidence on the variation in protein contents of the major species in the different ecozones over a year (details shown in Supplementary materials, Fig. C). The annual dates of emergence and senescence of leaves and flowers—the phenology—of the pasture plants follows a latitudinal trend from south to north, as the snows first melt and temperatures warm up initially in the southern ecozone of the Moiynkum sands and later northwards. The ephemerals (bulbs and short grasses) which highly nutritious with concentrated protein, start growing first in mid-April in the sands of the Moiynkum desert but have dried out by the end of May. Further north, in Betpak dala the ephemerals start their growth later in the middle of April. Further north in the former migratory destination of Sary Arka, the pasture plants only start growing at the end of May (Ilya I. Alimaev 1999 pers. com.).

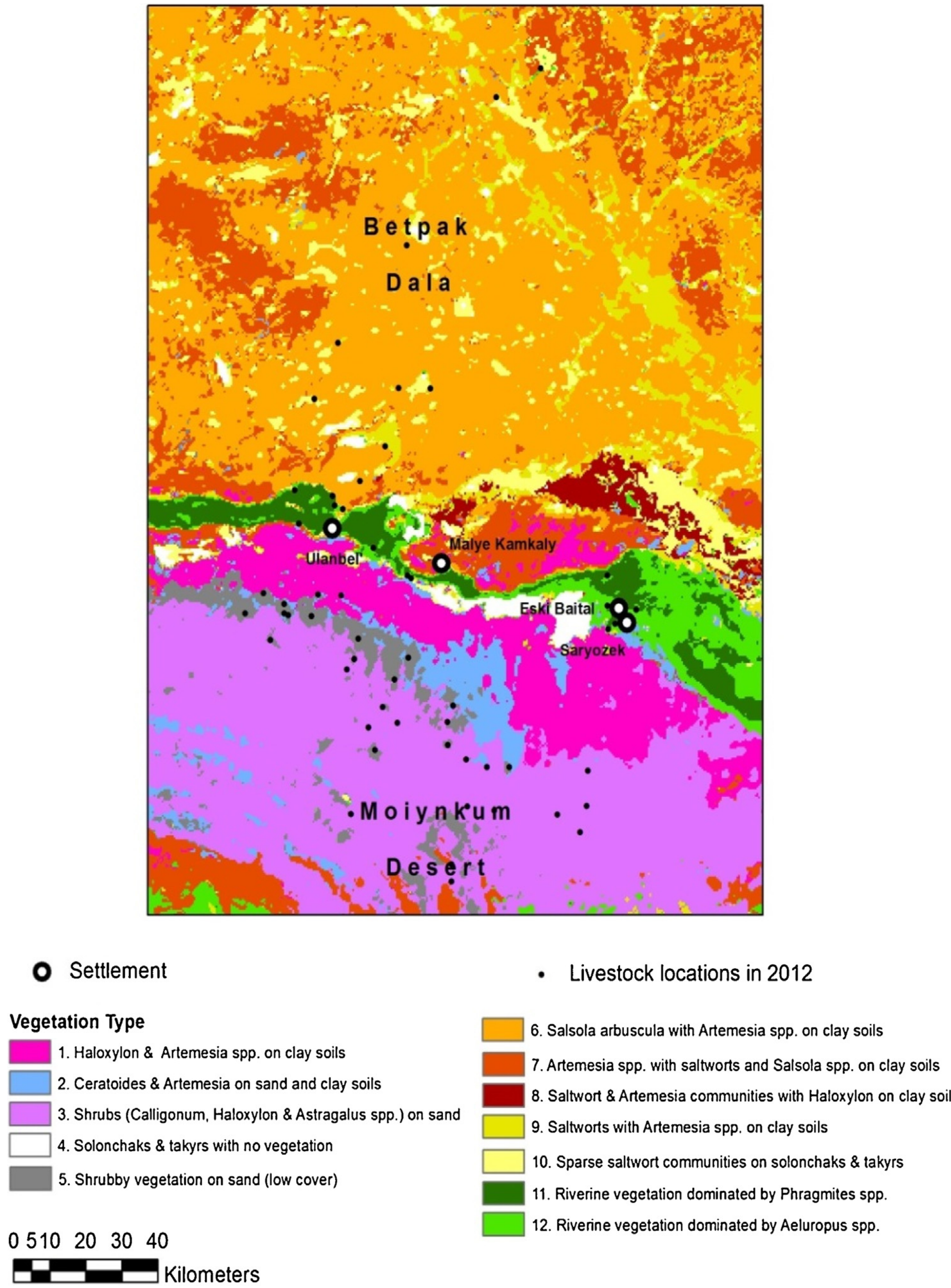

Fig. 3. Major vegetation types in the currently grazed parts of the study area.

5.3.3. Site selection according to livestock species

The vegetation associations found in each ecozone offer diverse kinds of forage not only seasonally, but also in terms of palatability to the different livestock species of sheep, goats, cattle and horses, which are kept by the pastoralists in the study area. The pastures of the Chu riverine valley are mainly suitable for cattle which can graze the coarser reeds; this is confirmed by the pastoralists in Sary Ozek village who cite the practice of the Soviet farm in keeping cattle on the extensive Chu riparian pastures around Sary Ozek most of the year. Currently nearly two thirds of the large stock, (mainly cattle), are pastured year round on Chu riverine area. For sheep, the shorter herbs and finer, shorter grasses of the Moiynkum sands can more readily be grazed all year, compared to the Chu riverine area. Therefore village-based livestock owners with smaller flocks of up to about one hundred sheep try to entrust these animals to larger-scale owners who maintain shepherding outposts at wells in the Moiynkum sands and also sometimes move to Betpak dala in the summer.

5.3.4. Vegetation characteristics and livestock distributions

The evidence presented so far on pasture vegetation characteristics in the ecozones, indicates that there is no clear matching of the population of livestock consumers to the seasonal pasture resources, either in terms of vegetation quality or quantity. In examination of Figs. 2–4 (and Supplementary material Fig. C), a discernable relationship cannot be adduced between the concentrations of livestock, edible biomass or digestible protein in each season. It is apparent, for example, that some livestock are kept year-round in areas of lower edible biomass and protein, while others are moved for summer away from sites with higher edible biomass. We now consider how biotic factors other than forage resources may account for these patterns of livestock distribution.

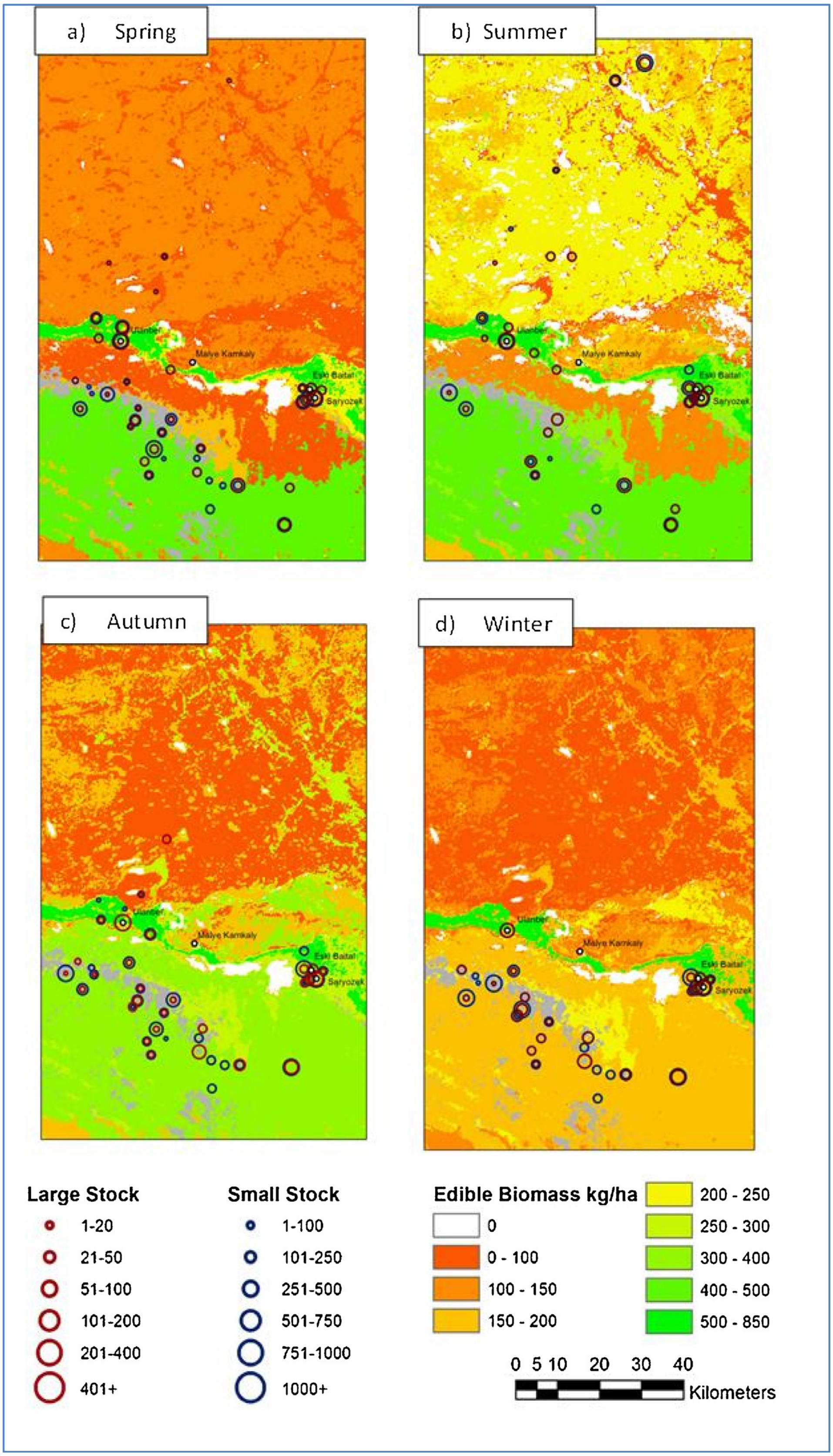

Fig. 4. Edible biomass and livestock distribution by season.

5.3.5. Other biotic factors: pests and predators

Flies, mosquitos and ticks: The pastures along the Chu are very unattractive to humans and livestock from March onwards when the weather gets warmer, throughout much of summer, due to mosquitos, botflies and horseflies in the boggy reed beds (Borodyn, 1950; Nagornyi, 1957). A large biting horsefly (Kz. *sona*) of family *Tabanidae* (Shevchenko, 1961) greatly bothers animals. According to our informants, the horseflies are not disease vectors for livestock or people, but the livestock are bothered by the biting and lose their appetite as a result. Mosquitos are also troublesome, though more to people than to animals, appearing earlier than the horseflies and disappearing by October when the weather turns colder. Livestock keepers who have to use the Chu riverine pastures for grazing their livestock in spring and summer only take the animals out to graze after dark, when the insects are not active.

Several informants noted there has been an increase in the population of horseflies and mosquitos since the end of the Soviet state farms, and they explained the reasons. The former state farm used to mechanically harvest reeds for livestock winter feed (for 80,000 sheep) on a large scale along the Chu river, starting in springtime. Harvesting removed much of the insects' breeding habitat. Secondly, the state farms used to spray the swampy reed beds with insecticide to reduce the insect population. There were also locust control spraying programs, which have since ceased. Nowadays, according to one older pastoralist (No. 2) flies and mosquitos "appear in their millions", unlike during the state farm period.

In the Moiynkum sands, ticks also appear by the beginning of March, according to our survey of pastoralists, and are usually gone by June when the sand gets too hot. The livestock must be treated by the local veterinarians against ticks. The informants emphasized that some types of ticks cause a dangerous tick typhus disease in humans, and vaccination is not regularly carried out by district (Rus. *raion)* medical staff. Pastoralists keeping their livestock in the Moiynkum sands over winter stay there for early spring lambing and so are knowingly exposed to the risk of tick disease.

Wolves: Pastoralists using the flood plain pastures around the Chu river or using pastures in the Moiynkum desert assert that since the end of the Soviet state farms, wolf attacks on livestock have become a major problem, especially from autumn (September) through winter to spring in April. Apparently wolf attacks on livestock decrease during summer when the adult wolves stay close to their cubs in the dens and instead hunt mainly small mammals. We were told that the "wolves travel with the livestock", moving to the Moiynkum sands in winter where they can rely on snow for water, and back to the Chu valley in spring when they need drinking water over the hot summers. For example, one pastoralist (No. 15) lost 8 cows to wolves in 2011 and 10 cows in 2012. Another large-scale owner (No. 2) lost up to 100 small stock to wolves in the winter of 2013–2014 at his pasture site in the Moiynkum sands, and a third pastoralist (No. 76) lost 10 sheep and several foals to wolves over the 2013–2014 winter.

Pastoralists cite the following reasons why wolf attacks are a more serious threat to livestock at the present time. During the *sovkhoz* time, state farm authorities encouraged shepherds to shoot wolves, awarded prizes for wolf skins and organized wolf hunts. Nowadays, people have to license guns or else are fined; it is also expensive to pay for bullets and motor transport to go out and hunt wolves. Secondly, since the reeds around the Chu river are no longer cut over summer, this means that when the wolves move in spring to access drinking water from the river in the hot summers, the reeds provide screens for them to hide near the villages and attack livestock. As one pastoralist wryly commented, "they are like partisans".

Pastoralists state that wolves these days come nearer to settlements because there are a lot of livestock around the villages, but in the *sovkhoz* times animals were grazed away from the villages. There were also more wild animals such as saiga antelopes present in the Soviet era, which offered an alternative ample food source for the wolves. Saiga have greatly decreased due to poaching (Kühl et al., 2009), and pastoralists recently using the Betpak dala summer ranges stated they had not seen saiga for years. Cows belonging to villagers are let out daily to graze around the Chu and Arna riverbank, but in winter the village owners in each street take turns shepherding, because there are a lot of wolves in packs then. Horses can stay out even overnight, as wolves do not usually attack them, though we heard several cases of foals being taken by wolves.

5.3.6. Summary of biophysical determinants of site selection for livestock

Presented so far have been the main physical and biotic factors which may influence people's decisions on matching resources needed for their livestock each season. These factors comprise precipitation, snow depth, temperature, soils and topography, and the associated vegetation in each ecological zone, and pests and predators in different ecozones.

We conclude this analysis of how biophysical characteristics interact to influence site selection for livestock distribution, based on how the pastoralists assess the environmental variables, in Table 3. The paper next turns to some of the formal legal and economic factors which livestock owners also consider when deciding where and when to select sites for their livestock each season.

5.4. Resource matching in terms of grazing land options and tenure arrangements

A crucial parameter for deciding how to match resources to livestock is the legal framework for acquiring access to the different kinds of pasture land for livestock. Each of these types of grazing land is governed by formal land tenure rules with associated costs, summarized in Table 4. Moreover, each type of land tenure has distinctive advantages and disincentives, sometimes requiring out-of-pocket expenses—which can be considerable—to graze and water livestock. These variables influence owners' decision-making on resource matching, as previously shown in Table 2. We next review the legal framework and costs implied in using different types of grazing land. In terms of resource matching options, the legal framework for land tenure is not coterminous with the pre-existing natural resource ecozones. Rather, the boundaries set by the legal framework cut across some of the ecozone divisions of the landscape shown in Table 1. Here we do not consider the informal access arrangements made among pastoralists and between pastoralists and officials having authority over land access. Further information on these arrangements is provided in Kerven et al., 2016.

According to the mayor of UB, before 2010, no authorities came to check the number of animals grazed by owners on Leskhoz land, but people from the district local government (Kz. *akimat*) have been coming since 2010 and charge rent per head of livestock kept. Payment per year per sheep is USD 0.36. However, a large-scale livestock owner (No. 28) in UB said that "*Leskhoz* always say they will come and count our animals, but they never do". Another livestock owner (No. 4) who manages livestock belonging to himself and three brothers (No. 83), is renting pasture around two wells in *Leskhoz* blocks, one used for winter/spring and the other for summer. In total the brothers pay annual rental to *Leskhoz* of USD 667 per year for both pasture sites. In another example, a livestock owner (No. 29) paid USD 173 in 2012, and admitted that they pay much less than the actual number of about 2000 sheep which they own, (requiring some USD 720 at 0.36 per head).

Table 3
Environmental factors influencing site selection in each ecozone. Green boxes indicate optimal period for livestock. (For interpretation of the references to colour in this table legend, the reader is referred to the web version of this article.)

MONTH	Betpak dala up to 130 km north from villages along Chu river	Chu river upland floodplain 5-20 km distant from Ulan Bel village	Chu river inundated flood plain 1-5 km distant from villages	Clay saline plain up to 30-40 km south of Chu river	Sands more than 40 km south from Ulan Bel or 70 km south from Sary Ozek villages
Jan	No pasture, very cold and windy	No pasture, very cold and windy	Some grazing if not frozen but risk from wolves	Very cold, no shelter, little pasture Salty veg and wells. Available wells all occupied	Good pasture, less accessible by road, shelter from cold winds and less snow. Animals need less water from wells.
Feb	As above	As above	As above	As above	As above, but snow starting to melt on south-facing slopes and exposing green vegetation
Mar	As above	As above	As above	As above	As above; and early green up of ephemerals
April	Begin green up of ephemerals	Spring floods creates good short pasture for sheep and cattle; no ticks	Spring floods creates good long stemmed pasture especially for cattle; no ticks	Salty veg good for livestock. Little variety of pasture plants	Ticks and horseflies. Animals and people bothered and health risk.
May	Green up ephemerals, shallow wells with cool water	Green up, good pasture but horseflies and mosquitos bother people and animals	As above	As above	As above
June	Some pasture but not very good. Cool well water good. No flies or ticks	As above	Coarse tall plants good for cattle but not for sheep/goats. Flies and mosquitos	Dried up pasture and salty water	Less pasture, dried up or woody. Sand too hot. Some wells salty, not good for livestock. Expensive to pump from wells. Ticks gone
July	As above	River water hot and polluted; bad for animals	As above	As above	As above
Aug	As above	As above	As above	As above	As above
Sept	Little pasture; dried up	Good pasture, as seed maturation of coarser plants	As above	As above	As above
Oct	No pasture, all dried up; very cold and windy	As above	Some grazing but risk from wolves	Salty pasture good for livestock	Better pasture (some seeds)
Nov	As above	Little pasture, risk from wolves	Some grazing if not frozen but risk from wolves	Very cold, snowy, some salty pasture good.	Good pasture (seeds), warmer, shelter from cold winds and less snow. Animals need less water from wells.
Dec	As above	As above	Some grazing if not frozen but risk from wolves	Very cold and snowy.	As above

5.5. *Resource matching according to water points*

The entire study area is semi-arid with less than 200 mm annual precipitation. Water is therefore a key resource to which livestock must have access, except in winter when livestock can consume snow. In the study area, there are three main sources of water: the perennial Chu river, seasonal ponds and thirdly, man-made wells from the Soviet *sovkhoz* era. Each of these types of water source has advantages and disadvantages from the livestock-keepers' viewpoint, for matching livestock to this necessary resource. We briefly review the trade-offs of using the different water points.

The Chu river flows all year but in summer, the river water becomes warm and more polluted from the waste and chemicals originating in the irrigated regions of northern Kyrgyzstan and southern Kazakhstan. While there is open and cost-free access to the Chu river and to seasonal ponds in Betpak dala, access to wells is much more complicated. The livestock owners have to carefully weigh up the suitability of dissimilar types of wells, according to their other capabilities and requirements for livestock management.

The suitability of wells varies between the different ecozones previously described in Table 1. In Betpak dala, there are currently no restrictions on a livestock owner picking a well around which to

Table 4
Legal classification and conditions of using pasture land types.

Pasture land type (from north to south)	Legal classification	Costs and conditions of using
Betpak dala	Part allocated to a parastatal hunting management body called Okhokzooprom, as a protected wildlife area under the Committee on Forestry and Hunting	Open access grazing. Hunting bans on some species (e.g., saiga antelope); seasonal bans on hunting other species (e.g., ducks, boars); seasonal bans on fishing in lakes and rivers
	Part remains as state fund land (gosfond)	Open access grazing, no rental fee
Circum-village on Chu river, 3 km radius around villages	Under control of village administration (Kaz. *akimshylyk)*	Communal access exclusively for all village residents, no rental fee
Chu river flood plain, 5–20 km width	Provincial Forestry Department, (Rus. *Leskhoz*) under district (raion)	Open access, no rental fee
	Under control of district administration	49 year lease, rental paid
Salty plain and sand desert of Moiynkum	Provincial Forestry Department, (Rus. *Leskhoz)* under district (Rus. *raion)*	Controlled harvesting of *Haloxylon* (common name saxaul). Block size ranges from 1,500 to 3,500 ha. Private annual pasture usage Starting in the early 2000s, the *Leskhoz* formally charges these pasture users an annual fee on contract, based on a per animal rate

graze his livestock. Access is unconstrained from a legal and financial aspect, so the cost of using these wells is minimal, as most are shallow of just a couple of meters deep, such that powerful but more expensive pumps are not needed. At present, those livestock owners who move north in spring to Betpak dala only use 9 or 10 wells every summer. Two deep boreholes are used by two of the largest-scale livestock owners who have new powerful but expensive pumps.

While all wells belong to the government and cannot legally be owned in current Kazakh law, they can be effectively privatized by an individual who gains *de jure* control over the pasture land surrounding a well, as noted in Section 5.4. This has occurred in the Moiynkum ecozone where pasture blocks, which also contain deeper wells, must be rented from the forestry department (Table 2). However, in the Moiynkum desert, effective resource matching is quite dependent on the access to, extraction cost and quality of well water. There are numerous unoccupied wells with surrounding suitable pasture quantity and quality, which has also regenerated from being ungrazed for more than two decades. But many of these wells are broken, or very deep, so that rehabilitating or using these wells takes relatively high amounts of capital investment which not all livestock owners are able or willing to undertake. There is a current trend toward occupying more of the remote pasture sites which require extensive repairs to the wells. Analysis of this trend is presented in Kerven et al., 2016.

The criteria of resource matching from the aspect of water points are thus quite different in each ecozone and land tenure system.

6. Resource matching according to livestock owners' socio-economic differentiation

The biophysical and institutional factors presented so far imply that livestock owners must calculate a number of trade-offs when evaluating the extent to which they can match their livestock to available resources. We have noted that there are advantages and disadvantages of particular ecozones in terms of climate, edible forage biomass and protein, pests and predators, land tenure regulations and cost of occupation, and cost of different water sources. However, when assessing available resources for their livestock, livestock owners do not start from an equal base. There is also the issue of scale, as larger flock owners can economize on the fixed costs of managing their livestock, as the unit cost per head is scaled back (Kerven et al., 2006). Meanwhile, less well-off owners do not have these economic resources, so the less attractive biophysical site options must suffice for them.

Livestock owners with larger flocks were much more likely to match their livestock to the more optimal forage resources by season and ecozone. They do not graze their sheep all year on the less nutritious reeds around the Chu valley settlements, compared to owners of small flocks with less than 100 smallstock, over 2011–2012 (Fig. 5). Large flock owners also more likely to move their livestock between at least two and sometimes three different ecozones (40% of owners who also have larger flocks). As our previous data has indicated, moving livestock to different ecozones allows the livestock to capture the best seasonal pastures, avoid some of the insect pests, but will require owners to negotiate and pay rent to government authorities and expend more capital resources for water extraction. Fig. 5 indicates that flock and herd size is a factor in ecozone selection and thus resource matching. It is now possible to express these push–pull factors based on the criteria cited by the livestock owners in selecting suitable sites, in Table 5.

7. Discussion

This paper has sought to show the extent to which pastoralists distribute their livestock to match the distribution of different types of resources in their environment. Resource matching should occur, provided two conditions are met according to IFD: if there is perfect knowledge of the location and nature of the resources and if resource consumers are free to access the resources (Fretwell and Lucas, 1970). Our case study finds that the distribution of livestock is not well matched to forage resources and there are multiple and interlinked causes of this lack of matching. The pastoralists have themselves identified a wide range of biophysical factors that influence their selection of sites and their movement within and between the main ecological zones. These factors include: Climate (precipitation, snow depth, temperature, wind); soils; pasture vegetation types and phenology; micro-topography; predators; pests; and water points. They also mention an equally wide range of non-biophysical factors that further shape their decisions on site suitability, including formal and informal land tenure; costs of vehicle transport; market prices for livestock; availability of shepherding labour; telecommunications; social services; and scale of livestock operation (livestock wealth). In this analysis we have not attempted to quantify the contribution of these various factors to the decision-making process. Assigning measurable values to determine the relative weights of each factor would be an immense though worthwhile endeavor, but well beyond the scope of the present study. What we can learn from are pastoralists' accounts

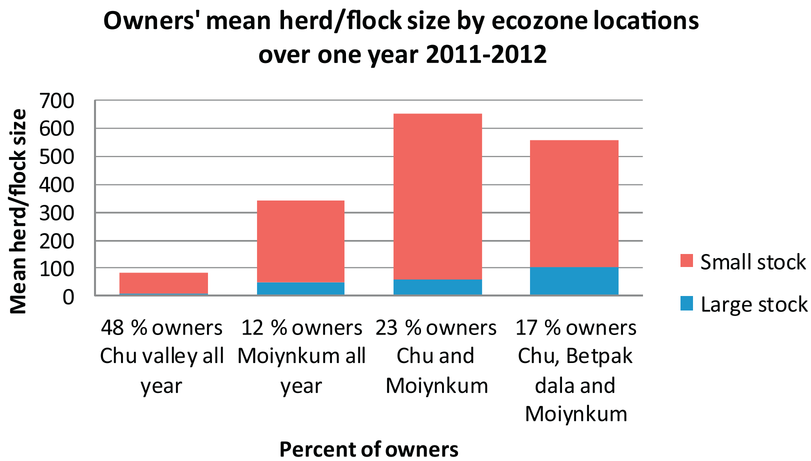

Fig. 5. Livestock owners' mean herd/flock size by ecozone locations over one year 2011–2012.

Table 5
Advantages and disadvantages for each ecozone for pastoralists.

Main pasture ecozone	Advantages for livestock owners		Constraints for livestock owners	
	Small flocks/herds	Big flocks/herds	Small flocks/herds	Big flocks/herds
Betpak dala plain (open access land)	• Reasonable pasture in summer • Access to shallow wells with cool water, without high cost for pump fuel • Absence of biting flies • Can obtain de facto private control over wells		Prohibitive cost of movement with small flock/herd, no economy of scale	• Pasture not as good as further north • Difficult to obtain reliable shepherding labor • Expensive for transport fuel • Requires mobile home for shepherds
Chu riverine floodplain 5–20 km from villages (majority communal land, some private grazing blocks)	• Good spring and autumn grazing for all livestock species • Access to free water • Can gain private block with pasture and water		• Too far for villagers to access • Insect pests in spring and summer • Pasture not available in winter and poor quality in summer	• Insect pests in spring and summer • Pasture not available in winter and poor quality in summer
Chu river valley 3 km around villages (communal land)	• Good pasture for cattle and goats • Neighbourhood shepherding has no cash cost	• Cheaper cost than moving animals to distant pastures • Communal land does not involve rent or tenure rules • Access to free water	• Not good pasture for sheep • Risk of wolf attack • Insect pests in spring and summer • Cost of supplementary feed in winter • Chu river water is warm and polluted in summer	• Sheep need better pasture in winter and summer • Risk of wolf attack • Insect pests in spring and summer • Villagers and administration resent large herds consuming communal pastures • Difficult to retain shepherding labour
Moiynkum desert (privatised rented grazing blocks)	• Best pasture for late autumn, winter and early spring • Little cost for feed supplements • Access to water in wells • No need to share pastures with other owners' livestock • Healthier livestock as no contact with other flocks/herds		• Prohibitive cost for acquiring grazing block • Large owners not willing to manage entrusted livestock from small-scale owners • Pay cost per head animal to large owners for management	• Difficult getting reliable shepherds • Expensive for transport fuel • Expensive fuel needed for water pumps • Scarcity of usable wells & salty • Ticks in late spring • Very hot sand in summer, bad for livestock • Pasture vegetation exhausted if livestock stay all year at one site

regarding the way in which their personal circumstances circumscribe their choices. These discussions illustrate several important regularities in the way pastoralists decide where to keep and when to move their animals.

7.1. Matching forage resources

A critical measure of site suitability for livestock must be basic resources of forage across the main pasture ecozones. Given the choice, animals and their human managers are selective and may choose locations where vegetation has the highest energy or protein contents, even if the biomass in these areas is low compared to that of surrounding zones (Fryxell et al., 2004; Turner et al., 2005). There are studies on free-ranging wild herbivore distribution that underscore the importance of forage quality versus density, in addition to plant species composition, avoidance of predators and duration in patches (e.g., Courant and Fortin, 2012, on bison). In our case study, accessing the higher quality but briefly available spring flush of forage is also a factor underlying pastoralists' stated choices of site suitability, and has been likewise recorded in other pastoralist systems from Africa (Oba and Katira, 2006; Allsopp et al., 2007) to Mongolia (Fernandez-Gimenez, 2000). For example, nomadic pastoralists in Turkana, Kenya (McCabe and Ellis, 1987) are most densely aggregated on annual grasses during the wet season. In the Niger delta of Africa's Sahel, pastoralists.

> "traditionally moved into the Northern drylands in the wet season to exploit the transient pulse of plant growth [Breman and de Wit 1983]. . . .It would otherwise be relatively disadvantageous to remain in the delta during the wet season due to wet ground, poor forage quality, and tsetse when there is an abundant supply of high quality forage in the north" (Coughenour, 1991).

Our case study has indicated that pastoralists' decisions on the most suitable vegetation for grazing livestock are partly influenced by the seasonally-variable production of edible biomass particularly in relation to quality (in protein content). In the open-ended interviews, pastoralists expressed more interest in the forage quality of plants at particular seasons and sites, than in the total biomass or quantity of the available vegetation. Having centuries of culturally-transmitted knowledge, Kazakh pastoralist shepherds watch where their livestock graze, browse and prosper, and try to take them to the sites the animals prefer. Especially in the growing season when vegetation is plentiful, or when livestock populations are so low that forage is not a limiting constraint, the volume of edible biomass on offer may be less important than its quality—conditions which apply in this case study. If grazing animals can consume only a portion of what is available, they cannot increase their feed intake by going to places where there is even more forage that they cannot eat. They can instead seek higher quality forage that passes through their digestive system more quickly than low quality, which allows them to consume both more and better food (White 1983; Demment and van Soest, 1985).

7.2. Site suitability of other biophysical factors

Since the distribution of livestock does not match the forage resources, either in terms of quantity or quality, we have then considered the potential roles of other biophysical factors mentioned by the pastoralists. In the semi-arid climate, water is a critical resource but the availability and quality of water points is spatially uneven. Some protection from or avoidance of pests and predators is also a consideration affecting the desirability of sites in certain seasons. Given the large latitudinal extent of the pasture resources, there are climatic differences in temperature and precipitation across ecozones which create seasonal limitations or attractions. There are also topographical distinctions which alter the local conditions for raising livestock. These factors, when taken together, modify the degree to which livestock can be matched to the forage resources.

7.3. Is there ideal knowledge of the resources?

The IFD model prediction is founded on a premise that resource consumers have complete knowledge of the environment within which to select sites for food resources. Refinements of this prediction have shown that resource-seekers may be unaware of or unable to distribute according to available food resources (Shochat et al., 2002; Hancock and Milner-Gulland, 2006; Bai et al., 2009). However, the livestock managers in our case study are aware of the more ideal resource matching ecozones. It has been less than a human generation since the cessation of the diktats by the state-controlled livestock collective farms for the dates and pasture destinations of the seasonal livestock migrations (Mynbaev 1957; Alimaev and Behnke, 2008). These regulated movements arose out of Soviet scientists' detailed field assessments of the seasonal qualities of the biophysical resources in each ecozone—pasture, water, temperature, snow depth, etc., which led to precise calculations of appropriate stocking densities for each vegetation association, for each season. These field studies on the biophysical characteristics of the distinctive ecozones confirmed the rationale of the previous Kazakh nomadic migrations prior to the establishment of the state collective farms. We might now assume that the Soviet and pre-Soviet livestock owners were very knowledgable about the climate, forage and water resources, and their livestock distributions were probably well-matched to the natural resources, in terms of IFD.

Older pastoralists—who now have their own private livestock—recount the exact dates at which they were required to move the Soviet collective farm livestock from one ecozone to the next; some pastoralists still follow this migratory pattern and continue to move according to the same dates. Younger current livestock owners used to travel with their shepherding parents in the recent past with the state farm livestock, and they too recall the long-distance standardized seasonal migrations which were then required. So there does not seem to be an absence of knowledge about the ideal site suitability for resource matching. The knowledge about sites can be and is easily shared between community members—many are closely related and all socialize frequently. The proof of this is that nearly all the pastoralists interviewed are able to describe the qualities of different sites, even though they do not use them. More pertinently, the pastoralists give reasons why they choose to use or not to use certain sites. They know, but they do not go.

7.4. Is distribution free? Costs of access

If this is the case, then pastoralist decision-making on site selection for their livestock may conform to some precepts of ideal free distribution (IFD)—knowledge is present—but other preconditions of the model are not met. There are other mechanisms proposed by animal ecologists to account for observed undermatching between food resources and population distributions. In general terms, these are impediments to "free" movement by consumers to sites where resources are distributed. These include: travel costs (e.g., Belisle, 2005); topography, distance to water, predator risk (e.g., Roguet et al., 1998).

In the case study here of Kazakh pastoralists, some of these mechanisms also seem to be operating. Transport costs for livestock owners to access more distant but recognized better pastures are a stated limitation; avoidance of predators (and pests) is stated as a push factor out of certain sites or an accepted cost of remaining in some sites. Micro-topography, in particular aspect, is an acknowledged positive attribute of using the sand dunes of the desert pastures; human intervention in prior provision of deep wells is an attractive feature of some sites.

Pastoralists, like other resource managers, tend toward parsimony and seek the most output for the least input. The site must be accessible by human managers at less cost than an equivalent alternative. Furthermore, occupation of a site must be socially and legally acceptable without high financial outlay or social conflict. The present site selection for livestock occurs in what is nowadays a system of open or low-cost access to a variety of pasture lands and water points. There are few institutional constraints on accessing the different ecozones. In this sense of IFD, distribution is "free". Nevertheless, the livestock owners exhibit diverse strategies in making use of the different ecozones. We argue here that a principal explanation of these differences is the scale of individual private livestock wealth. The economic effect of flock size on pastoralists' decision-making on site selection was recorded a decade previously in the same case study area (Kerven et al., 2004, 2006, 2008). That research additionally found positive relationships between the owners' financial costs and livestock productivity returns to forage resource matching.

What is apparent from the present field research and previous literature is that "resources" and "site suitability", as applied in the ecological sciences, are filtered by economic costs and returns when humans are making decisions. Some livestock owners do not have the economic resources or the incentives to freely match the biophysical resources. Instead, owners in making choices evaluate holistically a site's suitability for livestock as bundles of environmental, institutional and economic factors. These interacting factors mean that there is not necessarily a good fit between the available natural resources and the resource-consuming population of livestock. Too many other factors intervene to constrain a "free" resource matching for most livestock owners.

The outcome from this case study contributes to analyses of resource matching by human decision-makers. We find that matching is ideal in that knowledge is present, but is not free in that costs are incurred in matching. An analysis of Mongolian pastoralists concluded that resource matching was both ideal and free: "The herders of each flock are assumed to make rational optimal short-term decisions by predicting the consequences of all possible movements of their flock. They are then assumed to take the action that offers the globally optimal economic outcome" (Okayasu et al., 2012 Okayasu et al., 2012 145). Another well-documented pastoral case, in Cameroon, finds that knowledge of resources is complete and an open access land use system means that pastoralists are free to move, though with some travel costs (Moritz et al., 2014a, 2014b). In an environment where the resources cannot be readily known, for example in the case of open sea fishing by artisanal fishers, the conclusion is reached that the distribution of resource consumers (fishers) is neither "ideal" nor "free", due to the many social and economic variables which affected human decision-making on site selection and resource matching (Abernethy et al., 2007).

Our case study explores the dimension of internal socio-economic differentiation among pastoralists, who are diverse human agents, and argues that resource matching cannot be achieved by all individual pastoralists' flocks. In our case, resource matching is ideal (knowledge is present and shared), but not free, due to disparity of costs for different types of pastoralists. This conclusion accords with several other studies of pastoralism in widely differing natural and social conditions (McCabe and Fratkin, 1994; Turner, 1999; Turner and Hiernaux, 2002; Baker and Hoffman, 2006). While these studies have not necessarily been framed as IFD propositions, they likewise find that the means or incentives are not present for all livestock owners to pursue an optimal resource matching strategy. Only those with the largest flocks have both the financial means and the motivation to seek out sites which are more suitable for their livestock each season. Owners of small versus large herds behave quite differently with regards to accessing near and distant pastures.

Our research has sought to depict, partly in a coarse-grained fashion through remote sensed images, secondary sources on botanical assessments, as well as small-sample questionnaire surveys, the natural resources at the landscape level used by the resource consumers—the livestock. At the same time, the research has delved into some of the causes and effects from the perspective of the livestock managers, through information collected by qualitative in-depth interviews and participant-observation. There have long been well-substantiated instances of the scientific benefits of multidisciplinary research on how pastoralists view and manage their environments. Our studies are another contribution to this multi-stranded analytical approach. We have applied ecological and socio-economic analysis to understanding pastoral site selection criteria between seasons and ecozones at a landscape scale.

8. Conclusions

The study has found that the distribution patterns of livestock on the landscape are being pinched and stretched according to both forage and non-forage attractions and repulsions. The effects of human decisions on livestock distribution mean that natural resource matching and site suitability are adjusted according to the economic and legal conditions within which humans operate.

There are environmental and economic consequences if livestock are not able to access the optimal available natural resources. This constrained resource matching may damage the range resources by concentration of livestock; losing the nutritive value of some pastures which are not accessed and thus not maximizing animal nutrition; economic inefficiencies as free pasture and water must be substituted by purchased inputs; reducing the value and income that owners can derive from their livestock. These consequences have previously been highlighted for this case study area (Kerven et al., 2006, 2008; Alimaev et al., 2008).

Ultimately, if resource matching is severely inhibited, there is a loss of productivity to the nation as a whole. In this case, one would ask what could be done to pull the livestock distribution out of its present shape on the land, so that animals could more readily access the best natural resources for their requirements, at least cost to their owners. The policy conclusions suggest actions which could allow for better matching between livestock populations and available resources. To cite a leading pasture scientist in Kazakhstan "We need to prove to the [Kazakhstan] government that the way pasture is used now [i.e., year-round grazing in one location] is not good. We don't have to prove this to the shepherds as they already know" (Alimaev pers. com 2012). Since the end of the Soviet state farms more than two decades ago, year-round grazing in the Moiynkum sandy desert has led to overgrazing, as shown in our previous field research in the same study area (Alimaev et al., 2008).

Matching available natural resources to livestock needs is not cost-free. Moving flocks and herds, families, shepherds and heavy vehicles between pastures hundreds of km apart on sand tracks every few months is expensive; life in the remote pastures is boring, lonely and can be dangerous. There is no telecommunication, electricity, schooling, health facility or social life. Yet we find that at least 40% of the livestock owners have chosen to move their livestock to remote seasonal pastures—they have done this without any external assistance or encouragement, but because they calculate that the returns are worthwhile. This is a practical result that Kazakh policy-makers and international agencies advising the Kazakh government need to consider very seriously.

Our research has indicated some of the policy and practical steps that could be taken to realign livestock to the optimal natural resources. In the past 20 years, Kazakhstan's huge pasture resources of 189.3 million ha, or 69.5 % of the overall surface area, have become underutilized—only an estimated 30% of the total pastures are currently grazed, in part due to the reduction in functioning water points (Ministry of Agriculture of the Republic of Kazakhstan, 2013). Although the livestock population has not yet rebounded to that at the end of the Soviet period, being now at about two thirds of the 1991 level (FAOStats, 2015) there appears to be a national undermatching between available pastures and resource consumers, compared to the Soviet period. The Kazakh government is currently designing policies on the regulations for pasture access and for support to modernize the livestock sector. Amongst many objectives, the 2020 Agricultural Development Program mentions that a "package of measures should be implemented to motivate distant-pasture livestock rearing" [seasonal movement between different pastures] (USDA United States Department of Agriculture, 2013), in recognition that reliance on Kazakhstan's natural pastures contributes to cost reduction in the livestock sector. However, no concrete details are provided on how this this goal is to be achieved. Instead, much emphasis is given in the policy documents to growing more livestock feed crops, especially for cattle and the profitable export beef market.

The government is providing credit and subsidies for agriculture, but aimed primarily to support big business and therefore going to larger farmers and livestock owners. These inputs include discounts on purchases of imported pedigree breeds, particularly cattle, support to rehabilitate wells in remote areas (covering 80% of the cost) and support for fodder production. But uptake is rather slow—wells are very expensive to repair because of the depth of water, and only the wealthy are able to cover even 20% of the costs.

Our research presented here, as well as our previously published papers with Kazakh colleagues, has highlighted the main impediments for livestock keepers to access all of the forage and water resources necessary for more optimal migratory practices. The deterioration of basic infrastructure—roads, bridges, wells, and less effective livestock services including veterinary and insect control, has resulted in many livestock owners being unable to match their livestock needs to the available resources.

The pastoralists are quite aware of a mismatch between available seasonal pastures and adequate animal water supply. As one of the largest livestock owners (No. 32) remarked, "the government should help the livestock owners in this area by repairing the bridge [across the Chu river], so that people can take their animals north to Betpak dala in summer as in the past *sovkhoz* times". There are many unused former wells around which, by default, forage plants have been able to regenerate for about twenty years since the collapse of the state livestock farms. These wells then became unusable for most newly-privatised pastoralists due to two factors: lack of security of tenure and secondly, high capital cost of private repairs. Simply put, few livestock owners are willing to invest in major repairs to deep wells which they cannot own, and when they only have rights to a one-year lease to the pasture land around the well. While the national government has declared in 2014 that some Moiynkum wells will be rehabilitated with state funds, local opinion is that only the wealthiest and best-connected livestock owners will benefit from this program.

Other constraints to optimal resource matching are the increase in populations of predators, insects and ticks. Ecologically and economically sustainable measures are needed to reduce loss and illness of livestock. Loss due to predators could be compensated, so as to preserve the remaining wolves, which are already hunted and shot if found. Improved and regular vaccinations would reduce risks of human and livestock diseases due to insects. Finally, there is a social issue, as the sons and especially the daughters of livestock owners often do not wish to stay in the remote rangelands and help raise the family's livestock. In Kazakhstan's wealthy economy, the attraction of tertiary education leading to better employment prospects in the cities and mining sector is draining away the youth from the pastoral regions. The difficulty of finding reliable shepherds is a major worry for livestock owners. Some type of state employment benefits may help attract shepherding labor to stay in the rangelands.

The forbears of the present-day Kazakh pastoralists formerly migrated many hundreds of kilometers annually from north to south along the ecological zones formed by the Moiynkum desert-Chu River-Betpak dala-Sary Arka transect (Alimaev and Behnke, 2008; Mateev and Polyakov, 1950; Mynbaev, 1957). Many of the more successful modern pastoralists in this region recount how their grandparents still used to go on these migrations within the Soviet state farm management system, then being supplied with water, new deep wells and some conveniences of the 20th century, but following the same grazing routes as their forefathers in the pre-Tsarist times. This paper has laid out some of the options and limitations which confront present-day livestock owners in this study area, in deciding where to graze and move their animals, given the basic biophysical conditions about which they are fully aware.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landusepol.2015.12.030.

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