Shrub Encroachment and Shrinking of Pastures in Inner and Western Tien-Shan, Kyrgyzstan

Evgenii Shibkov[1,*]

[1] University of Central Asia, Graduate School of Development, Mountain Society Research Institute, 125/1 Toktogul Street, Bishkek, 720001, Kyrgyz Republic, evgenii.shibkov@ucentalasia.org

* corresponding author

doi: 10.5281/zenodo.11584845

Abstract: The pastoral tradition in Kyrgyzstan, shaped by the country's landscape, faces significant challenges due to various types of pasture degradation. According to official data from the pasture department, approximately 70% of Kyrgyz pastures are degraded. One type of degradation is the overgrowth of pastures by shrubs, such as caragana, juniper, and wild rose. This encroachment poses a threat to the sustainability of pastoralism, to reduce the pasture areas that are impacting rural livelihoods. Although, some pastures are transforming due to shrub reduction processes, leading to opposite socioeconomic and environmental consequences. At the same time, shrubs benefit pasture ecosystems by aiding biodiversity and soil stabilization. This problem has attracted attention in both government and local community discussions. However, local administrations responsible for pasture management since 2009 cannot effectively address the issue. One contributing factor is the lack of attention from the scientific community, which tends to prioritize more popular topics while neglecting this important issue. Another factor is that the scarcity of spatial data on pasture conditions hinders research efforts. The proposed research aims to enhance understanding by addressing three key questions: firstly, reviewing existing literature to comprehend government and local community awareness in managing shrub encroachment; secondly, exploring broader consequences beyond pasture use, such as ecological and environmental impacts; and finally, integrating spatial and remote sensing data into research methodologies. Achieving these objectives will facilitate the development of effective policies and strategies for managing shrub encroachment and ensuring the long-term sustainability of pastoralism in Kyrgyzstan.

Keywords: remote sensing; pastures; shrub encroachment.

1 Introduction

Mountain pastures are characterized by a complex topography with highly heterogeneous vegetation types, and plant communities play an important role in sustaining rural livelihoods in Kyrgyzstan. Pastoralism has a long history with different management regimes. However, pastoralism in Kyrgyzstan faces pasture degradation problems due to inappropriate grazing management and ongoing climatic changes.

Mountain pastures are 9.147 million hectares and share 85% of the total agricultural land and 45.9% of the total territory of Kyrgyzstan. However, 70% of pastures are degraded (Pasture Department 2018). Over the past few decades, there has been a significant increase in areas covered by shrubs, leading to pasture degradation due to shrub encroachment. This has become a critical environmental issue in arid and semi-arid mountainous pastures. Shrub encroachment areas are expanded by Juniperus, Rosa, and Caragana shrub species (Figure 1). Expanding Caragana species creates more pasture use concerns, making those seasonal pastures unsuitable for grazing, threatening sustainable pastoralism, and affecting rural communities and the overall economic well-being of Kyrgyzstan.

Nevertheless, shrub encroachment may positively affect pasture ecosystems' multifunctionality and prevent slope soil erosions in mountain pastures.

On the other hand, the shrinkage of native pastures-shrubland-forest mosaics (further shrinkage) may lead to changes in primary vegetation cover and its spatiotemporal dynamics, as well as in environmental and socio-ecological systems. The understanding that strikes a balance between the positive environmental aspects of shrubs and the need to preserve productive grazing areas is essential for the long-term viability of pastoralism in Kyrgyzstan.

Pasture degradation issues in Kyrgyzstan have been widely reported and discussed (Dörre and Kasymov 2021, Tomaszewska and Henebry 2021). Few studies on shrub encroachment focused on the *Caragana* shrub species expansion in the Susamyr Valley of the Chu province from a pasture use perspective. Understanding shrub encroachment and shrinkage's environmental and socio-ecological aspects is critical for predicting vegetation communities that are essential in regulating pasture ecosystem functioning.

There are three main open questions concerning shrub encroachment and shrinkage in mountain pastures in Kyrgyzstan to fill a knowledge gap and show how the proposed research will address them. First, there is a need to understand and obtain information on the socioeconomic and socio-ecological impacts of shrub encroachment, shrinkage, reduced pasture areas, and perceptions of pasture users. Few studies have investigated the perceived impacts of shrub species expansion on pasture users and their livelihoods (Levine et al. 2019). Proposed research on those issues addresses the much-needed gap in understanding the impacts of shrub encroachment as perceived by pasture managers and users with different interests and priorities. Second, assessment and spatial data on shrub encroachment and shrinkage areas by various shrub species in seasonal pastures or vegetation types is crucial. The lack of effective measures and data for assessing and monitoring shrub encroachment at a large spatial scale limits research on the

modelling and simulation of shrub encroachment. Combining vast historical data on pastures with remote sensing data may provide vital data to the existing Kyrgyzstan's land resources database. Moreover, many studies worldwide utilize Geographic Information Systems (GIS) for this type of assessment (Anderson et al. 1996).

and Doboluu ayil aykmaks of Naryn districts of the Naryn region located in the central part of Kyrgyzstan (Inner Tien-Shan). The secondary study site is the pastures of the Chatkal region of the Jalal-Abad province, located in the western part of Kyrgyzstan (Western Tien-Shan) (Figure 2). Both study sites have high district status and hold equal

Figure 1. Shrub encroachment by Juniperus turkestanica (left), Caragana pleiophylla (center) and Rosa turkestanica (right) shrub species in Inner Tien-Shan mountain pastures.

Remote sensing techniques have certain limitations, relying primarily on medium-resolution satellite data (Landsat) and low-resolution (MODIS) (Ovakoglou et al. 2022). However, modern technologies, e.g., Unmanned Aerial Vehicles (UAVs), can overcome these limitations by harnessing cutting-edge data collection techniques for particular complex mountain terrains. Additionally, advanced machine learning algorithms will be employed to effectively classify and segment the remote sensing data, enabling accurate and efficient data interpretation.

Third, there is a lack of studies on the ecological characteristics of shrub species and the ecological implications of shrub encroachment and shrinkage on vegetation communities' structure and functioning, encroachment dynamics, spatial heterogeneity under grazing management, and environmental changes by vegetation types (ecological zones). Understanding the mechanism of shrub encroachment states and stages is crucial for managing and restoring semi-arid highland pastures.

The character of the study is interdisciplinary: to use tools and methods of GIS, remote sensing, and machine learning analyses, the identification, dynamics, mechanisms, and changes of shrub areas will be implemented. The social-economic, socio-ecological, and environmental cause-effect study - combines qualitative and quantitative data to analyse the interaction between the increase of shrubs on land use and their role in pasture management.

2 Materials and methods

2.1 Study Area

This research will be conducted on two study sites. The primary study site is the pastures of Naryn City, Jan-Bulak,

shrub encroachment concerns at different vegetation types. Each site possesses unique vegetation characteristics regarding shrub species diversity, ecological and environmental factors, and land use patterns. This study can comprehensively understand shrub encroachment and shrinkage by comparing diverse areas using standardized methodology and approaches.

2.2 Data Collection and Analysis

Data collection will involve several key parameters: pasture conditions and management, socioeconomic impacts of shrub encroachment. Following Ayil Aymaks (Local Government) selection from each study area, a baseline survey will be conducted in seasonal pastures at various distances from villages. Each pasture will be divided into three main groups depending on seasonal use. The chosen pastures will be randomly stratified based on the data collection results.

This study will apply primary qualitative and quantitative data collection methods and Rapid Rural Appraisal (RRA) tools (Gibbs 1985) at the different level. The theory of adaptive management (Holling 1980) will be used to investigate how farmers adapt to the issue of changing shrub areas. The theory of ecological coupling or resource conflict (Norton 2005) will be used to understand how ecological changes caused by shrub encroachment impact human activities. The results will be evaluated in the last stage by discussing them with local stakeholders, related government institutions, and non-governmental organizations.

Visual measurement of current shrub and pasture species coverage by vegetation types, historical data, GIS, remote sensing technologies, and modern computer science approaches will implement pasture conditions.

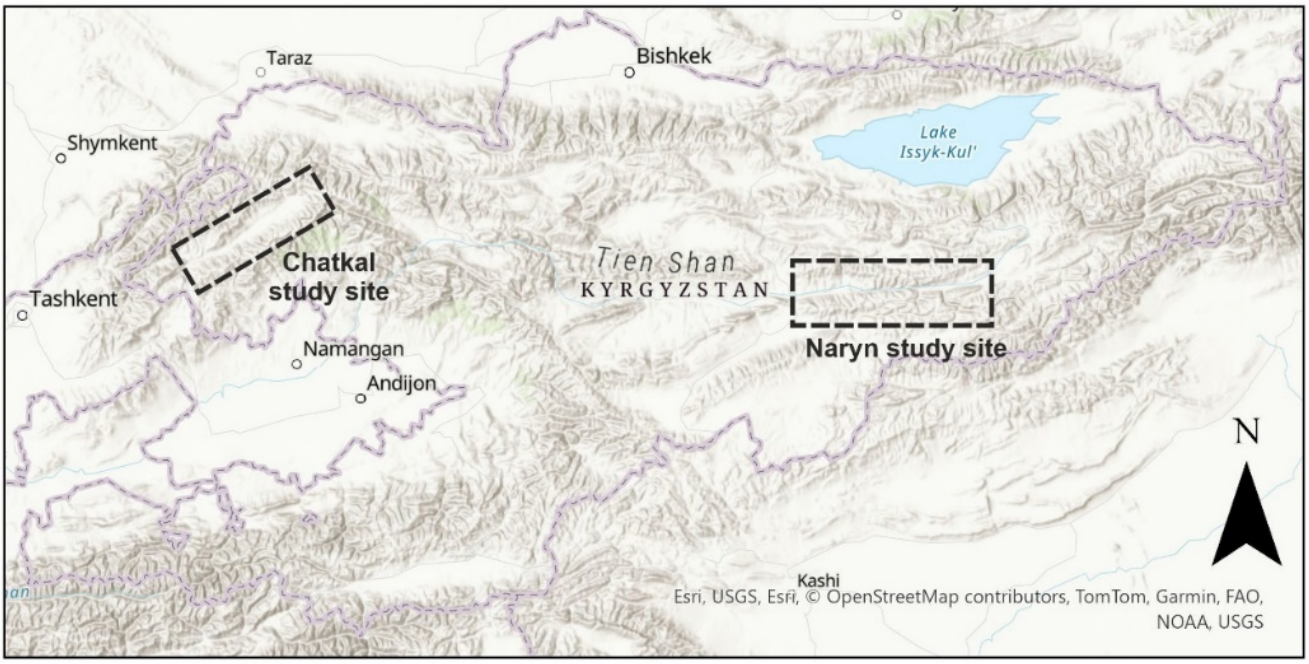

Figure 2. The map of study areas in Inner Tien-Shan and Western Tien-Shan mountain pastures.

Historical observations for the period from 1968 to 2020 will be carried out using available datasets such as Corona, Soviet Union aerial photographs, Landsat imagery, and Sentinel-2 for the same area. The aerial photographs will be obtained using a UAV. The locations of the photo flight will be randomly selected to achieve a representative sample of the shrub encroachment or degradation situation. All fieldwork sampling should cover 1 square kilometre of pastures (100 flights by 1 ha covering each flight). Sentinel-2 satellite images will also be used, with the corrections based on obtained UAV data for around 5000 square kilometres.

The Segment Anything Model (SAM) and U-Net neural networks will be used to acquire remote sensing data segmentation. Training U-Net requires annotations (Lovitt et al. 2022), which involve creating masks for each image that highlight areas occupied by shrubs equally as other objects. The SAM model will annotate historical and modern aerial photographs (Parulekar et al. 2024). The aerial photographs and their corresponding masks will then be converted to a compatible format for further training the U-Net neural network. Once trained, U-Net will be applicable for segmenting Sentinel-2 and historical satellite images.

The Quadrat and Line Point Intercept (LPI) methods will be used to collect ground-based measurements of shrub species (Root-Bernstein and Hoag 2022). A quadrat plot size of 25 m^2 will be used for shrubs to assess shrub species' ecological attributes and encroachment mechanism. Ground sampling will be performed using LPI techniques described by (Pellant et al. 2020). The collected data will serve as the basis for modelling ecological processes that determine the distribution of shrub species and their changes over time. We will use boosted regression trees (Elith and Leathwick 2017) to identify and quantify the potential factors influencing the likelihood of shrub encroachment and shrinkage. The influencing factors include climatic conditions (temperature and precipitation); terrain features (elevation, slope ratio, and aspect; percentages of natural or secondary shrubland and pastureland; and anthropogenic factors (distances to the nearest road, transitional pasture roads, and seasonal pasture shelters).

3 Expected results

This study is at the very beginning, so now we can talk about the first results where high resolution satellite images were compared of the same territories, but for a different period (Figure 3). The data obtained confirm that shrub area increasing leads to the degradation of pastures. Increasing shrubs density reduces the suitability of pastures for livestock grazing, negatively impacting the livelihoods of local people. Further research will provide important data for making pasture management decisions and understanding impacts on livelihoods.

Study findings can fulfil the shortage of spatial data and mapping material needed to assess and monitor shrub encroachment on a large regional and mountain systems scale by using advanced technologies such as UAVs and machine learning algorithms. This complex approach will contribute to a better understanding of shrub dynamics, facilitate the development of effective management strategies, and contribute to future research in this area. Third, an understanding of the ecological characteristics of shrub species and their influence on the structure and functioning of plant communities and biodiversity. Using a combination of different methods of environmental analysis, not only the predominant species of shrubs will be considered, but also spatiotemporal patterns, modelling the dynamics and mechanism of shrub encroachment and its further consequences and opportunities in sustainable pasture management.

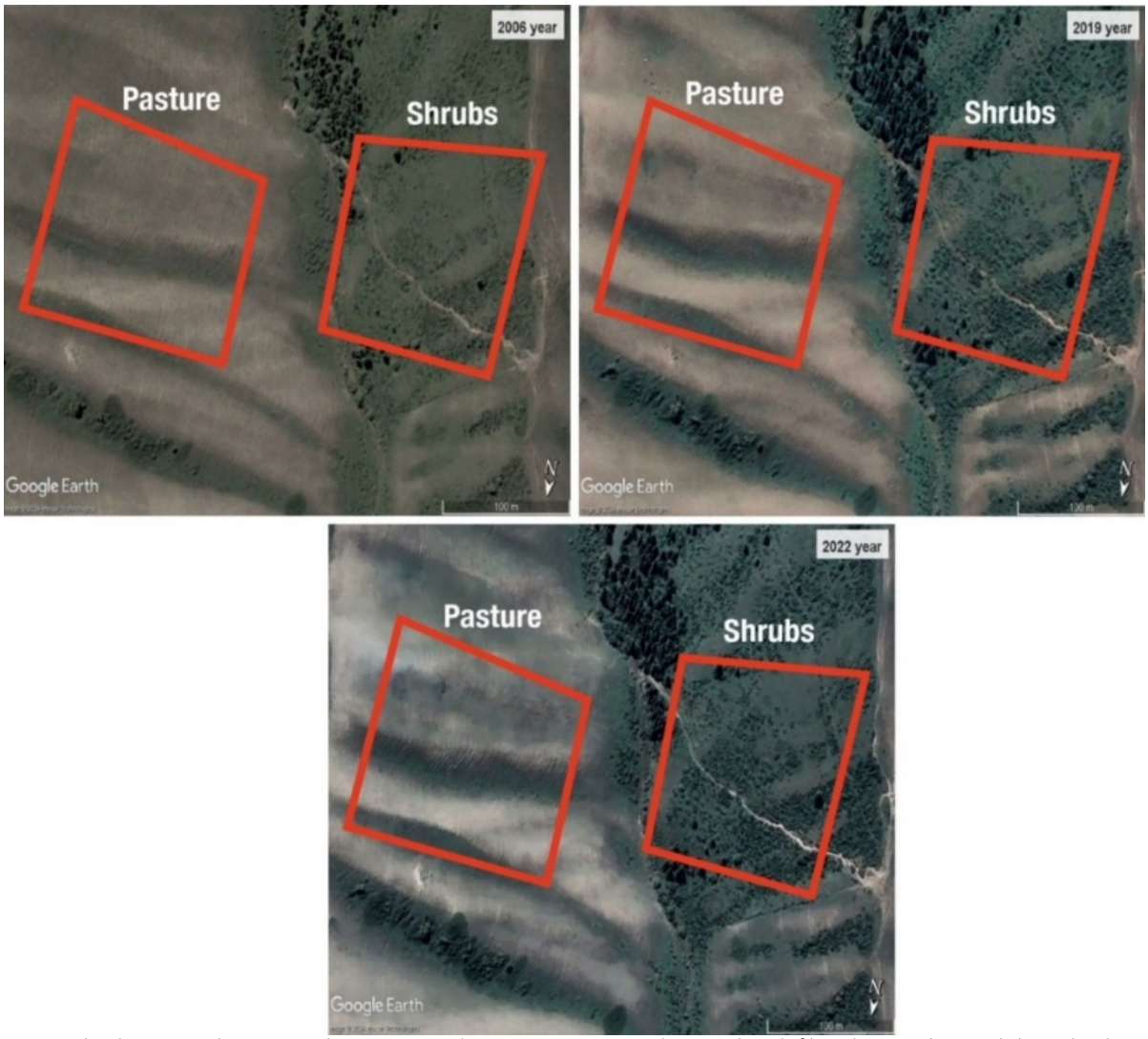

Figure 3. Shrub encroachment on the Naryn study site pastures in July 2006 (top left), July 2019 (top right), and July 2022 (bottom).

The study will analyse the interactions between human activities and ecological changes caused by shrub encroachment by applying theories such as adaptive management and ecological interactions. Furthermore, combined with the latest modern technical solutions, the research is intended to contribute to the diversity and versatility of scientific knowledge on this issue in Kyrgyzstan and the region.

4 Discussion

The expected results of this study should significantly enrich existing knowledge about the degradation of mountain pastures due to shrub growth. This knowledge is critical to understanding not only the socioeconomic impacts but also the socioecological effects caused by invasive shrub growth. Despite widespread discussions on the problem of shrub growth in pastures, many researchers only mention this phenomenon, leaving it badly studied (Andrade et al. 2015). The proposed research focuses on a multifaceted and complex analysis of this issue.

Research directly focused on shrubs is often limited to a superficial understanding based on previous research. A distinctive feature of this research is the use of ultra-high resolution aerial images (1–2 cm per pixel) collected from UAV. It is at variance with previous studies that used medium-resolution remote sensing data (MODIS, Landsat) (Bi et al. 2021). It will also apply advanced machine learning techniques, such as the combined use of neural networks, including SAM and U-Net, for high-precision segmentation of medium-resolution satellite imagery. The data collected during the field ecological survey will certainly provide a more comprehensive approach to understanding the problem of shrub growth.

Unlike other studies that have examined the problem of shrub degradation from the perspectives of land use and socioeconomic consequences, this study will address the potential positive environmental outcomes of this phenomenon, such as soil cover strengthening and increased biodiversity (Ridder et al. 2020). A separate aspect of the proposed research is the study of shrub drying in arid and semi-arid ecosystems, which can lead to changes in the primary vegetation cover and its spatiotemporal dynamics, equally in ecological and socioecological systems. Understanding the balance between the positive ecological aspects of shrub expansion and the need for conservation is essential for mountain pastures.

5 Conclusion

In conclusion, it is important to note that although the issue of pasture degradation to manage shrub growth is current and important, it has not received adequate attention among pasture observers in Kyrgyzstan. However, providing a comprehensive and detailed understanding using an integrated approach to the study of this phenomenon is important not only for understanding its general condition in society, but also for the socio-ecological situation. Using ultra-high-resolution aerial photography data and advanced machine learning techniques, the research objectives offer more detailed and mathematical analysis than the main studies, as well as historical dynamics of shrub growth. Considering the positive overall phenomenon under study brings additional versatility and complexity to this study.

The previous results of this study demonstrate that shrub encroachment directly affects the land use by the local community. However, as this research on the beginning stage, the future results are expected to significantly advance knowledge of the socio-ecological and socio-economic impacts of forest growth, providing valuable information for land management and conservation strategies. By addressing gaps in current research and providing a more holistic view, this research will contribute to the development of evidence-based policies and practices aimed at balancing environmental benefits with the need to consider rangeland management.

Acknowledgments: The author would like to thank the reviewers of the ICERS conference for their advice and comments to improve this paper, as well as Munavar Zumanova from Michigan State University for her help.

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