Unraveling the change of land-use regimes with satellite and ground surveys in the steppe belt of Russia from 1990 to 2018

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Abstract. One of the recent phenomena in land-change history in the steppe belt of Russia after 1990 is the formation of unclaimed or partially claimed agricultural lands, their periodic and fragmented use, suggesting the change of land-use regimes compared to intensive cropping in the Soviet period (pre 1991). Therefore, there is a strong need for the systematic field and remotely-sensed monitoring of shifts of land-use regimes, because they may impact various socio-ecological processes, such as the spread of wildfires, degradation and recovery of vegetation on spared agricultural lands. Here we present an elaboration on monitoring with satellite observations and field surveys of land-cover dynamic in the steppe belt of Orenburg Province and with more detailed focus on the districts (rayons) of Orenburg Province, which were once a part of Virgin Lands Campaign (1954-1963), when croplands expanded at the expense of agro-environmental frontiers. Our remote-sensing observations and ground surveys revealed widespread abandonment from 1990 to 2018. The calculation of Shannon’s Diversity Index confirmed the change in the typology of land-use regimes in Orenburg Province - transition from stable cultivation back to 1990 to new land regimes, such as stable cultivated areas with minor abandonment (typology #1) - e.g., Asekeevskij district; complete cropland contraction without recultivation (typology #2) - e.g., Akbulaksij district; strong fluctuation of cultivated and abandoned croplands from year to year (typology #3) - e.g., Pervomajskij district. Former Virgin Lands Campain areas were more exposed to typology #3. Shannon’s diversity index was useful to evaluate the changing land regimes and areas prone to socio-economic and environmental shocks. We hypothesize a new stage of land regimes may provide opportunities for biodiversity conservation, but also threats such as the spread of wildfires, particularly under the projection of an increase of aridity.

1. Introduction
The steppe belt of Eurasia underwent an unprecedented transformation during the 19\textsuperscript{th} and 20\textsuperscript{th} centuries from grassland-dominated biome to anthrome with a dominance of croplands and different degrees of population density, for instance, in Russia and Kazakhstan [1, 2]. Croplands in the early 20\textsuperscript{th} century and, more specifically during the Virgin Lands Campaign (1954-1963), expanded at the expense agro-environmental frontiers when more than 40 million hectares of new croplands were ploughed up just in 10 years [3–5]. Later on, the croplands stabilized by the 1980s. Previous studies also showed that the disintegration of the state-command economy and transformation to market-driven conditions after 1990 resulted in partial abandonment of cultivated croplands and the formation...
of secondary steppes [6, 7]. However, the process of cropland abandonment was not uniform and most likely, areas that were least suited for farming (e.g., with higher aridity and poorer soils) were more prone to abandonment [3, 8]. Therefore, we were interested in evaluating whether, due to large socio-political changes after 1990, land use shifted from one regime to another—e.g., from stable agricultural landscapes in steppe biome with a dominance of croplands, either to a) landscapes with minor cropland abandonment, b) landscapes with complete cropland abandonment and shifting to steppe-dominant landscapes, c) landscapes with medium abandonment, albeit with strong fluctuation of cultivated and abandoned croplands from year to year.

We also intentionally selected districts for more detailed surveys in Orenburg province, which were once a part of the Virgin Lands Campaign, and where current cultivation practices may represent different degrees of contraction of croplands and land-use intensity [4, 5, 9] (figure 1). The soils represent different types of Chernozems and Kastanozems, but also Solonetz soils.

Satellite observations became a common data set for monitoring agricultural land-use change: a) due to a wide swath of satellite footprints, b) repetitive nature of observations, c) spectral and spatial resolution suited for monitoring land-cover change. Optical multispectral 30-meter Landsat satellite images going as early as the 1980s until these days can be combined with 10 to 20-meter optical multispectral Sentinel-2 images (from 2015 and on) to document land-cover changes, including the steppe biome. However, satellite observations may not be sufficient and may not and should not completely substitute ground-based monitoring because a) many semi-automatic machine-learning approaches to produce land-cover change maps rely on good quality training and validation data sets, b) it is important to observe monitor steppe landscapes from geobotany, land use and other perspectives. At the same time, ground sample-based observations should be: a) representative to the study region, b) being unbiased in terms of sampling, c) should be cost and labor-efficient given the spread of the studied districts across Orenburg province (west-east, approximately 700 km).

Hence we addressed the following research questions:
1) What are the land-use changes observed with satellite observations (Landsat and Sentinel-2) from 1990 to 2018 across the districts of Orenburg province?
2) What are the implications of land-use changes to the shift of land-use regimes from 1990 to 2018?
3) What is the best approach in designing such ground-based monitoring for such a large region as Orenburg Province?

Our work is structured as follows. First, we introduce the remote-sensing and landscape analysis methods, then ground surveys. Further, we discuss the results on land-use change from 1990 to 2018 and reveal the shifts in land-use regimes. Then, we elaborate on the qualitative outlook on land transitions in former Virgin Lands Campaign’s districts based on ground surveys.

2. Materials and Methods
2.1. Land-cover change analysis with satellite imagery and Shannon’s diversity index
To reconstruct land-cover change and evaluate its dynamic, we used 30-meter Landsat satellite and 20-meter multispectral Sentinel-2 images, which were resampled to 30 meters to match with Landsat data. The cloud platform Google Earth Engine was used to preprocess satellite imagery for periods 1990, 2000, 2010, 2018 [4, 7]. We used atmospherically corrected satellite imagery to assemble cloud-free mosaics for three seasons—Spring, Summer, Fall for each period with calculated medians, which were assembled in the stacks and further classified. We classified them with a non-parametric random forest classifier, which was iteratively tuned regarding key parameters—number of trees, input features, the proportion of training data, etc. Our classification catalog consisted of cropland, grassland, forest and other classes for each period (1990, 2000, 2010, 2018) and then with a post-classification approach, we revealed stable cropland and grassland classes, as well as the transitions between the periods, e.g., from cropland to grassland (we called it abandonment), and recultivation (from formerly abandoned cropland reverted to grassland, back to cropland). Ground validation data were used for
accuracy assessment and a better understanding of the association of land cover and land use in the ground and associated reflectances from satellite imagery to prepare training data sets. Accuracy assessment was performed, such as construction of contingency tables, calculation of user’s, producer’s and overall accuracies, and well as we performed error-adjusted area estimates [10, 11].

![Figure 1](image-url)

**Figure 1.** Example of ground reference field-surveys in Orenburg Province of Russia. The outline of Virgin Lands Campaign’s districts [9] differs from the official designation, with expert inclusion of those districts, which also experienced massive cropland expansion from 1954 to 1963 [12].

We also quantified the diversity of cropland to grassland transitions and vice versa in different periods (e.g., cropland to grassland, grassland to cropland) for 1990-2000-2010-2018 with Shannon’s Diversity Index (SHDI) [13, 14]. A low value of this index suggested little to no diversity of such transitions, while multiple transitions would be reflected by the higher value of the index. In general, our assumption was - areas with a good agricultural endowment will stay permanently cultivated (low values of SHDI), while less suited areas for farming, e.g., in the former Virgin Lands Campaign area, will be prone to multiple transitions, with periodic abandonment and recultivation (higher values of SHDI).

2.2. **Ground reference evaluation of land-cover change**

Our ground reference followed the philosophy that a sample should maintain representativeness of the sampled area, but at the same time, balance out travel and labor costs, especially across such a large area as Orenburg Province. Hence, it required us to understand the nature of the study area, potential thematic classes and existing limitations [15]. Based on that, among existing sampling strategies, such as purely random, systematic, stratified random, and two-stage random sampling, we selected a two-stage random sampling approach. This approach assumes a two-stage clustered random sampling, when randomly meaningful areas are chosen and then random sampling is performed [7, 16, 17]. In this case, a field survey team may reach such an area and concentrate on surveying random sampling points instead of visiting randomly distributed points across a large region. Also, to facilitate efficient data collection, for each sampled area block, we digitized paved and unpaved roads and established a buffer of 400 meters where ground reference points were randomly sampled. We also evaluated the proportion of land-cover types in and out of 500-meter buffers is similar (figure 1). Next, before the actual sampling within the established buffers, we estimated the actual sampling size. We followed the
approaches suggested by the UN Food Agricultural Organization on monitoring forest cover, when the sample size is estimated based on potential distribution and proportion of classes, expected percentage of accuracy of maps, and expected errors, the error of level allowed and the desired level of confidence [18]. Further, based on existing land-cover products, we estimated the potential spatial autocorrelation with Moran’s I statistics for sampled 10*10 km blocks, which resulted in importance to maintain at least a 500-meter distance between the samples to reduce spatial autocorrelation. We also developed a field protocol, when we recorded for each sampled point a) broad land-cover classes (e.g., cropland, grassland), b) actual land use (e.g., type of crops and their stage, grazing, haycutting evidences or their absences), c) projective vegetation cover, d) vegetation composition, e) extra comments, f) five field photos 1-in the ground, azimuth 2-0°, 3-90°, 4-180°, 5-270° (figure 2). The field assessment has been conducted in different places for the last ten years, while more systematic repetitive observations were performed from 2018 to 2020. During the field campaign, we used NextGIS Mobile to allocate the ground-reference points.

Figure 2. Field survey photos in Belyaev district of Orenburg province. Abandoned cropland reverted to grassland.

3. Results and Discussion

3.1. Land-cover change analysis with satellite imagery and Shannon’s diversity index
Our study revealed widespread agricultural change when approximately 2.8 million hectares (31%) of cropland became abandoned from 1990 to 2018 [7]. We reached high classification overall accuracies, approximately 92-95% for 1990-2000-2010-2018 maps, and user’s and producer’s accuracies for the thematic classes around 90%. Abandonment primarily occurred from 1990 to 2000, and later both abandonment and recultivation went hand in hand [7]. Abandonment rates varied from 1990 to 2018 across the districts of Orenburg province, with the lowest abandonment rate in Gajskij district (12%) and the highest abandonment rate in Akbulakskij district (40%) (figure 3a). In general, we did not find that abandonment rates in former Virgin Lands Campaign’s districts were higher compared to other districts (Mann-Whitney-Wilcoxon test, non-normal distribution, alpha=0.05). However, the abandonment rates could probably be higher from 1990 to 2018 if recultivation would not occur, which took place from 2010 to 2018. Many districts experienced both abandonment and recultivation, while others stood stable with a minor abandonment. At the same time, Akbulakskij district (the south of Orenburg Province), experienced massive abandonment with little recultivation by 2018. The previous studies showed such high abandonment rates in neighboring Kazakhstan over the same periods [3, 6], suggesting that similar socio-political processes shaped agricultural land-change patterns. We should also note, the advantage of satellite remote sensing is in its ability to reveal both cropland expansion and abandonment over the same year or period, while official statistics show a net change (e.g., either cropland decline or no change, or increase).
Our results with a calculated Shannon’s diversity index (SHDI) showed the unique evolving land regimes in the post-Soviet period (figure 3b). The low values of SHDI indicated both districts with stable cultivated croplands (land regime typology #1)–the example of Asekeevskij district, and districts with massive abandonment and little recultivation (figure 3b, figure 4a), the example of Akbulakskij district (land regime typology #2) (figure 3b, figure 4b). At the same time, high SHDI values helped to allocate the districts with a fluctuation of cultivated and abandoned croplands with abandonment and recultivation from period to period (land regime typology #3) – example of Sol-Ileckij, Pervomajskij and Svetlinskij districts (figure 3b, figure 4c). The districts with high SHDI values partially coincided with districts with large patches of abandonment (secondary steppes) found in the previous study [4]. Such districts had lower population density compared to other districts, population decline from 1990 to 2018, abandonment of infrastructure, lower yields and a higher degree of aridity [4]. Most likely, the farmers in these districts experienced difficulty in farming and, after few years of unsuccessful years of farming, abandoned their plots. Further, the abandoned plots could be transferred to other farmers once investors are found and all legal paperwork is performed. But it may take several years, while the agricultural plot may stay idle with a slow reversion to steppes. Likewise, the areas with low SHDI primarily occurred in areas with scarce grasslands and small patches of restored grasslands due to cropland abandonment. The best-endowed croplands remained cultivated despite socio-economic and environmental shocks. However, low values of SHDI may also indicate the districts with massive cropland abandonment and little recultivation, thus low diversity of land transitions. Hence, a careful interpretation of low SHDI is required in the context of the diversity of cropland abandonment trajectories. Nevertheless, it is possible to conclude that high SHDI values may serve as a measure of areas, which are risky to farm, and can be prone to cropland contraction in times of socio-economic and environmental shocks. We also observed statistically higher SHDI values in former Virgin Lands.
Campaign’s districts compared to others (Mann-Whitney-Wilcoxon test, non-normal distribution, alpha=0.05). Hence, agricultural expansion at the expense of the agro-environmental frontiers resulted in a greater fluctuation of cultivated and abandoned lands, once socio-political conditions changed of 1990, therefore, showing the influence of the past land-use legacies on the current cultivated patterns.

![Figure 4](image-url)  
**Figure 4.** Developed typology of land regimes for 1990-2000-2010-2018. a) land regime typology #1 - districts with stable cultivated cropland and little abandonment, b) land regime typology #2 - districts with massive abandonment and little recultivation, c) land regime typology #3 - districts with a fluctuation of cultivated and abandoned croplands with abandonment and recultivation from period to period.

### 3.2. Ground reference evaluation of land-cover change

Our ground survey visits in the former Virgin Lands Campaign area in 2018-2020 supported remote-sensing observations from 1990 to 2018 of land-cover change. Additionally, we had non-systematic observations dating back as early as 2010. A two-stage clustered random sampling allowed us to reduce travel time and costs of data collection, but at the same time to maintain a degree of representativeness of a study area. Our developed sampling approach (figure 1) mimicked the Land Use/Cover Area frame Survey (LUCAS) initiative with ground surveys of land use and land cover, plus with the collection of additional information, such as soil properties. Since LUCAS sampling protocol only covers the EU, except for some private efforts outside the EU, such as Ukraine [19], our sampling approach can potentially expand the pan-European ground survey efforts that can be used for different purposes, such as detailed monitoring of the steppe belt of Russia.

Our field observations confirmed ongoing cropland abandonment. At the same time, the annual revisit allowed to reveal recultivation of some abandoned plots, for instance, in the Belyaevskij, Svetlinskij (figure 3) and Pervomajskij districts (figure 4c). We also noticed the formation of different geobotanical compositions on the partially recovered steppes due to cropland abandonment. For instance, the abandoned croplands represented various compositions of herbaceous communities, including agropyron commonly used for hayfields, lessing feather grass (*Stipa lessingiana*), winter cress (*Barbarea*)-Leymus compositions, and in early stages of abandonment-weeds. We also documented that wheat and sunflower production are two common types of crops, however, with more crop diversity in northern districts of Orenburg province. In the southern parts, the crops such as watermelons also occur. We also documented grassland use, primarily haycutting and grazing. Overall, field visits suggested low haycutting and grazing pressure, sometimes fragmented and
scattered over the year. At the same time, grazing intensity was high close to the settlements. Finally, we observed the traces of wildfires and associated compositions of vegetation in post-burning periods. Hence, our sampling approach unintentionally allowed the collection of validation data for wildfire monitoring efforts too. Hence, in combination with satellite monitoring, ground surveys provide valuable information on land-change transitions in the steppe belt of Eurasia.

4. Conclusion
Our study showed widespread cropland abandonment across Orenburg province from 1990 to 2018, including former Virgin Lands Campaign districts. Abandoned croplands can serve as a valuable source for the restoration of steppes, particularly where recultivation of abandoned croplands is not foreseen. Revealed typology of changed land regimes, particularly typology #3 - with strong fluctuation of cultivated and abandoned croplands from year to year suggest a careful evaluation of planned recultivation activities, particularly in areas risky for cropland cultivation but highly relevant for an alternative to cropland uses, and provision of ecosystem services and esthetic values of steppes. We also showed, agricultural expansion at the expense of the agro-environmental frontiers during the Virgin Lands Campaign resulted in a greater fluctuation of cultivated and abandoned lands once socio-political conditions changed in 1990, therefore, showing the influence of the past land-use legacies on the current cultivated patterns. Shannon’s diversity index was useful to evaluate the changing land regimes and areas prone to socio-economic and environmental shocks. We also underscored the valuable role of repetitive ground surveys and the importance of the plausible design of such surveys a) to be representative, b) cover a large area, c) balance out travel and labor costs.

Data availability
Produced land-cover change are freely available at https://erda.ku.dk/archives/c41fb139755c6eac1e57250110e1e2a2/published-archive.html Please cite this data set and work.

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