Preprint

Agricultural Land Abandonment

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Introduction

Agricultural land abandonment is increasingly a global land-cover change phenomenon that has strong implications for the environment (e.g., biodiversity, carbon sequestration, novel ecosystems, wildfires) and societal well-being (livelihood, agricultural landscapes). Agricultural land abandonment is often referred to as the cessation of farming and giving away land for natural succession, such as grasses, shrubs, and trees on former agricultural lands, but may also result in land degradation. Agricultural land abandonment can be a more complex land-change transition, including the cessation of agricultural activity in favor of land uses other than agricultural ones, such as forestry, construction of dwellings, game reserves, and tourism. Studies have shown that agricultural land abandonment often is driven by rational decision-making and profit maximization, including weighing up opportunity costs and alternative livelihood strategies. However, the conditions of institutions, which are supposed to govern land use, and the personal characteristics of those involved in agricultural activities, are playing a vital role in the decision of abandonment. It should also be noted that the decision on abandonment or maintenance of farming can be quite complex and driven by non-economic factors, such as personal predisposition to farming, education, ethnicity, religion, age, and availability of successors. The progress of studying land abandonment and existing research gaps are highlighted in the text.

Definition and Spatial Distribution of Agricultural Land Abandonment Globally

In the literature, abandoned agricultural lands are sometimes also called old fields, fallow or idle fields, or post-agrogenic lands. Agricultural land abandonment is often referred to as the process of cessation of farming activities, both with intentional and unintentional giving away of land for natural encroachment, for instance, natural afforestation due to dispersal of seeds from the neighboring forest patches. However, abandonment may also represent bare and degraded lands without much vegetation succession. Yet, other land-change trajectories may also occur on abandoned lands, such as intentional reforestation (e.g., tree plantations in European countries, the United States, and South Africa), creation of game and nature reserves (the European countries and Africa-Tanzania), and the sprawl of residential areas in rural-urban fringes (for example, Bucharest). Such multiple pathways of abandonment and reuse of abandoned lands are touched on by the opinion paper **Munroe, et al. 2013**. In sum, agricultural land abandonment is often not a terminal but rather a transitional process. At the same time, abandonment can be distinguished from fallowing as a crop rotation process, slash-and-burn agriculture, or shifting

cultivation in both forest- and grassland-dominated areas. Agricultural land abandonment was considered a common land-change process across the developed countries and transition economies, such as the European Union countries and the former Soviet Bloc countries, but the evidence suggests it is a common land-change process in other parts of the world, such as in China, Iran, Nepal, and South Korea. The studies **Alcantara, et al. 2013** and **Hatna and Bakker 2011** provided useful insights about widespread agricultural land abandonment in Europe, particularly across post-Soviet and post-socialist countries in Central and Eastern Europe. However, multiple studies suggest that agricultural land abandonment is a widespread land-change process globally, and the literature review **Li and Li 2017** as well as a study of **Yin, et al. 2020** confirmed so. In general, certain regions could be particularly prone to abandonment, such as the mountainous and the Mediterranean regions, for instance, in Europe, Africa and the Middle East.

Alcantara, C., T. Kuemmerle, M. Baumann, et al. 2013. Mapping the extent of abandoned farmland in Central and Eastern Europe using MODIS time series satellite data. *Environmental Research Letters* 8.3. DOI: 10.1088/1748-9326/8/3/035035
- A wall-to-wall study that mapped agricultural land abandonment across Europe with the aid of MODIS satellite imagery. The study also showed how different abandonment rates are from country to country.

Hatna, E., and M. M. Bakker. 2011. Abandonment and expansion of arable land in Europe. *Ecosystems* 14.5: 720–731. DOI: 10.1007/s10021-011-9441-y
- A study that documented the spatial distribution and determinants of agricultural land abandonment in Europe.

Li, S., and X. Li. 2017. Global understanding of farmland abandonment: A review and prospects. *Journal of Geographical Sciences* 27.9: 1123–1150. DOI: 10.1007/s11442-017-1426-0
- A good review of the global patterns and drivers of land abandonment.

Munroe, D. K., D. B. van Berkel, P. H. Verburg, and J. L. Olson. 2013. Alternative trajectories of land abandonment: Causes, consequences and research challenges. *Current Opinion in Environmental Sustainability* 5.5 (October): 471–476. DOI: 10.1016/j.cosust.2013.06.010
- A good opinion paper, which also includes a theoretical flowchart on alternative trajectories of land abandonment.

Yin, H., A. Brandão, J. Buchner, et al. 2020. Monitoring cropland abandonment with Landsat time series. *Remote Sensing of Environment* 246:111873. DOI: 10.1016/j.rse.2020.111873
- Documented evidence of widespread agricultural land abandonment globally. The study also showed the challenge of mapping abandonment among smallholder farmers.

Mapping Agricultural Land Abandonment

There has been great progress in mapping agricultural land abandonment recently. Earlier studies relied on official statistical records, such as agricultural statistics. For instance, **Ioffe, et**

al. 2004 used sown area statistics to study cropland abandonment in post-Soviet Russia. Long-term observations with the aid of topographic maps and ancillary geography and statistical data allowed **Matasov, et al. 2020** to reconstruct cropland dynamic and land abandonment in Russia since the late 18th century and link it to changing land-use regimes. The progress of aerial observation and remote-sensing technology often stemmed from the military reconnaissance, such as the US U-2 and Corona spy programs, and allowed reconstruction of land-cover change, including agricultural land abandonment. The US Geological Survey (USGS) Landsat program made another breakthrough in land-change studies, including studying agricultural land abandonment, because of the free availability of long-term satellite data records going back to the 1970s. One of the first studies on land abandonment with the aid of satellite imagery was probably **Peterson and Aunap 1998**, which reconstructed agricultural land abandonment in post-Soviet Estonia. Landsat MSS, later Landsat 4–5 TM, 7 ETM+, and nowadays Landsat 8 OLI were particularly useful because of spectral and spatial resolution that matched agricultural fields in many parts of the world. **Prishchepov, et al. 2012** showed the importance of the selection of multiseasonal images to capture well a greater diversity of the different states of agriculture and subtle transitions of agriculture to abandoned fields. Free availability of 250-meter/500-meter AQUA/TERRA MODIS data that repeatedly cover large swaths since 1999 allowed **Alcantara, et al. 2013** to map farmland abandonment across Eastern Europe. Later on, **Lesiv, et al. 2018**, developed a cropland abandonment map that covered major parts of the former Soviet Union. A recent change of the paradigm regarding free access to the USGS Landsat archives, implementation of cloud computing, and advancement of machine-learning methods boosted a more sophisticated analysis of land abandonment. For instance, **Yin, et al. 2018** assessed multiple trajectories of abandonment and recultivation with dense Landsat satellite time-series data. **Kolecka 2018** used satellite imagery to assess the degree of forest succession as a proxy for agricultural land abandonment. **Dara, et al. 2020** studied with dense Landsat time-series data the timing and the patterns of abandonment of managed grasslands in drylands. Currently, the free accessibility of synthetic aperture radar data such as Sentinel-1 and optical Sentinel-2 MSI via the European Space Agency's Copernicus program, complemented by the commercial Planet program with enormous access of fine-scale microsatellite data, boosted research on multisource image fusion and opened opportunities to have a more detailed look at the incomplete (e.g., fields with decreased land-use intensity), hidden, and complete abandonment as well as at various land abandonment transitions in cloud-prevalent areas, e.g., the tropics. For instance, with multisource image fusion of optical and synthetic aperture radar data, **Huang, et al. 2019** studied land abandonment induced by armed conflict in Myanmar. We live in exciting times when a great amount of freely available multisource imagery, improved computational facilities, and algorithms allow "deep" image analysis. Such technological progress opens opportunities for better understanding the patterns and stages of land abandonment locally, regionally, and globally. It should be noted that other techniques, such as soil profiles and botanical surveys, can serve as a proxy for the reconstruction of the timing of land abandonment and land uses in the past and may complement the conventional interpretation of satellite and aerial imagery.

Alcantara, C., T. Kuemmerle, M. Baumann, et al. 2013. "Mapping the extent of abandoned farmland in Central and Eastern Europe using MODIS time series satellite data." *Environmental Research Letters* 8.3.DOI: 10.1088/1748-9326/8/3/035035

- From case studies to the regional scale. The very first study that mapped farmland abandonment at the regional level.

Dara, A., M. Baumann, M. Freitag, et al. 2020. Annual Landsat time series reveal post-Soviet changes in grazing pressure. *Remote Sensing of Environment* 239 (March): 111667.
  DOI: 10.1016/j.rse.2020.111667Save Citation »Export Citation »E-mail Citation »
- Application of Landsat dense time-series to map subtle changes related to the abandonment of managed grasslands in drylands.

Huang, X., B. Ziniti, and N. Torbick. 2019. Assessing conflict driven food security in Rakhine, Myanmar with multisource imagery. *Land* 8.6 (14 June): 95. DOI: 10.3390/land8060095Save Citation »Export Citation »E-mail Citation »
- This study exemplifies the beneficial use of multisource imagery to map subtle changes in cloud-prevalent tropical areas.

Ioffe, G., T. Nefedova, and I. Zaslavsky. 2004. "From spatial continuity to fragmentation: The case of Russian farming." *Annals of the Association of American Geographers* 94.4: 913–943.
- The Russian/American geographers, unravelled the drastic implications of the collapse of the Soviet Union on farming in Russia. They used sown statistics as proxy of cropland abandonment. The paper provides the evidences on fragmentation of Russian farming, the potential drivers of cropland abandonment. Authors complement the analysis, in essay style, with useful insights on rural life in Russia. This study is truly the classics!

Kolecka, N. 2018. Height of successional vegetation indicates moment of agricultural land abandonment. *Remote Sensing* 10.10: 1568. DOI: 10.3390/rs10101568
- This study underscores how different stages of succession on agricultural fields can be mapped with the aid of satellite imagery.

Lesiv, Myroslava, Dmitry Schepaschenko, Elena Moltchanova, et al. 2018. "Spatial distribution of arable and abandoned land across former Soviet Union countries." *Scientific Data* 5:180056. DOI: 10.1038/sdata.2018.56
- A study, which developed a freely available product on cropland abandonment across a large portion of the Soviet Union. This work incorporated the previous efforts on detailed mapping of cropland abandonment with satellite imagery, as well as the modeling efforts.

Matasov, V., A. V. Prishchepov, M. R. Jepsen, and D. Müller. 2020. Spatial determinants and underlying drivers of land-use transitions in European Russia from 1770 to 2010. *Journal of Land Use Science* 1–16. DOI: 10.1080/1747423X.2019.1709224
- A study that reconstructed long-term transformation of agricultural land use, including agricultural land abandonment, with the aid of historical maps, statistical records, and satellite imagery.

Peterson, U., and R. Aunap. 1998. Changes in agricultural land use in Estonia in the 1990s detected with multitemporal Landsat MSS imagery. *Landscape and Urban Planning* 41.3–4 (6 July): 193–201.

- Probably one of the first studies on land abandonment with the aid of satellite imagery. Study showed widespread agricultural land abandonment right after the breakup of the Soviet Union.

Prishchepov, A. V., V. C. Radeloff, M. Dubinin, and C. Alcantara. 2012. The effect of Landsat ETM/ETM+ image acquisition dates on the detection of agricultural land abandonment in Eastern Europe. *Remote Sensing of Environment* 126:195–209. DOI: 10.1016/j.rse.2012.08.017
- The importance of seasonal image-dates versus a selection of classification methods to study cropland and grassland land abandonment.

Yin, H., A. V. Prishchepov, T. Kuemmerle, B. Bleyhl, J. Buchner, and V. C. Radeloff. 2018. Mapping agricultural land abandonment from spatial and temporal segmentation of Landsat time series. *Remote Sensing of Environment* 210:12–24. DOI: 10.1016/j.rse.2018.02.050
- Freeing Landsat archives boosted processing of dense Landsat time-series, mapping timing and complex trajectories of land abandonment and recultivation.

Spatial Determinants and Underlying Causes of Agricultural Land Abandonment

Policy and institutions, which govern land use, economy and market conditions, technological transformations or their absences, demography, predisposing site conditions, trigger events such as wars and droughts, and sociocultural factors of the farmer, they all may determine the rates and patterns of agricultural land abandonment. In general, agricultural land abandonment is driven by rational behavior when an agent of land use (e.g., farmer) discontinues farming activities when costs of production outweigh the returns from agricultural production. For instance, **Gellrich, et al. 2007** and **Prishchepov, et al. 2013** in parallel to **Ioffe, et al. 2004**, showed that abandoned lands were often found in areas with low yields and far away from the settlements. There is a consensus that agricultural lands are commonly observed on more deficient soils, distant from the markets, settlements, and roads, with part-time employment in agriculture and rural population decline. However, there might be deviations from the classic Ricardian land-rent theory due to varying underlying causes of abandonment from place to place. For instance, abandonment patterns can be observed nearby settlements due to land speculation, better employment opportunities outside the agricultural sector, and other underlying causes. It should also be noted that abandonment is not necessarily be driven explicitly by rational economic behaviour, but also by other personal non-economic factors, such as education, predisposition to farming, life course, personal beliefs, and family structure. To establish the relationship between the patterns, rates, and potential determinants of abandonment, qualitative and quantitative methods or their combinations, such as interviews, qualitative narratives, and statistical analyses, are often employed. For instance, **Grinfelde and Mathijs 2004** employed the structural equation-modeling framework to understand the complexity of the drivers of agricultural abandonment at the farm level in Latvia. **Ioffe, et al. 2004** (listed under **Mapping Agricultural Land Abandonment**) used a top-down approach and also aimed to develop a simplified causal chain to understand the drivers of land abandonment by bringing the example of Russia. **Meyfroidt, et al. 2016** used the panel regressions to establish a simplified causal inference about the drivers of abandonment in Russia, Ukraine, and Kazakhstan. It should be

noted that the drivers of abandonment may vary from place to place, but also among the different actors. Therefore, a multi-level analysis, such as at the country, province, district, and farm levels, may provide more nuances to the drivers of abandonment. Recently, interest in understanding the role of land-use legacies on patterns of agricultural land abandonment has evolved. For instance, using various approaches, **Munteanu, et al. 2017** (across the Carpathians in Europe) and **Shackleton, et al. 2019** (in South Africa) showed pieces of evidence about the impact of past land-use regimes on contemporary land abandonment patterns. Last but not least, it should also be noted here, the recent change of the paradigm about free satellite imagery accessibility and improved image processing capabilities has allowed the performance of more rigorous analysis, such as on timing and persistence of abandonment and linkages to potential drivers. For instance, **Yin, et al. 2019** employed Landsat time-series to map abandonment patterns in the Chechen Republic, Russia, and link abandonment patterns with the Russian-Chechen War hotspots in the Caucasus. Yet, the understanding of the driving mechanisms of land abandonment is in its infancy, and it is hoped that more efforts will be placed to study them in the future. One recent work in this direction, **He, et al. 2020**, studied behavioral mechanisms behind land abandonment, revealing the role of aging and part-time farming on the decision of land abandonment in mountainous areas in China.

Gellrich, M., P. Baur, B. Koch, and N. E. Zimmermann. 2007. Agricultural land abandonment and natural forest re-growth in the Swiss mountains: A spatially explicit economic analysis. *Agriculture Ecosystems & Environment* 118.1–4 (January): 93–108.
- Exemplary study on the application of spatially explicit modeling approaches to understand the spatial determinants of agricultural land abandonment in Switzerland.

Grinfelde, I., and E. Mathijs. 2004. Agricultural land abandonment in Latvia: An econometric analysis of farmers' choice. 1–24.
- Employment of the structural equation modeling framework to understand the drivers of agricultural abandonment among Latvian farmers.

He, Y., H. Xie, and C. Peng. 2020. Analyzing the behavioural mechanism of farmland abandonment in the hilly mountainous areas in China from the perspective of farming household diversity. *Land Use Policy* 99:104826. DOI: 10.1016/j.landusepol.2020.104826
- One of the successful attempts from a behavioral economics prism to understand the decision behind agricultural land abandonment among farmers in mountainous areas in China.

Meyfroidt, P., F. Schierhorn, A. V. Prishchepov, D. Müller, and T. Kuemmerle. 2016. Drivers, constraints and trade-offs associated with recultivating abandoned cropland in Russia, Ukraine and Kazakhstan. *Global Environmental Change* 37:1–15. DOI: 10.1016/j.gloenvcha.2016.01.003
- Studying the drivers of agricultural land abandonment and recultivation across Russia, Ukraine, and Kazakhstan with panel regressions.

Munteanu, C., T. Kuemmerle, M. Boltiziar, et al. 2017. Nineteenth-century land-use legacies affect contemporary land abandonment in the Carpathians. *Regional Environmental Change* 17.8 (December): 2209–2222. DOI: 10.1007/s10113-016-1097-x

- The study uses several time steps to map agricultural dynamics and model potential implications of the past land uses (e.g., Habsburg period) on abandonment patterns in socialist and post-socialist time across the Carpathian region.

Prishchepov, A. V., D. Müller, M. Dubinin, M. Baumann, and V. C. Radeloff. 2013. Determinants of agricultural land abandonment in post-Soviet European Russia. *Land Use Policy* 30.1: 873–884. DOI: 10.1016/j.landusepol.2012.06.011
- The study revealed that agricultural land abandonment patterns in European Russia reflected quasi–von Thünen rings when cultivated lands remained close to the markets and settlements and in areas with low yields.

Shackleton, C. M., P. J. Mograbi, S. Drimie, et al. 2019. Deactivation of field cultivation in communal areas of South Africa: Patterns, drivers and socio-economic and ecological consequences. *Land Use Policy* 82:686–699. DOI: 10.1016/j.landusepol.2019.01.009
- Importance of land-use legacies and other driving factors to understand the deactivation of farming activities and land abandonment among smallholders in South Africa.

Yin, H., V. Butsic, J. Buchner, et al. 2019. Agricultural abandonment and re-cultivation during and after the Chechen Wars in the Northern Caucasus. *Global Environmental Change* 55:149–159. DOI: 10.1016/j.gloenvcha.2019.01.005
- Application of Landsat time-series to monitor agricultural land abandonment and empirically link with the Chechen War hotspots.

Implications of Land Abandonment for the Environment and Societal Well-Being

   Various stages of agricultural land abandonment may also have different implications for the environment. For instance, in temperate regions, cropland abandonment may progress from the establishment of the pioneer vegetation, including weeds, then encroachment of shrubs and trees, and consequently to the canopy closure and establishment of forest. It may take more than one hundred years to reach the climax in forest and twenty to fifty years in grassland-dominated biomes. Agricultural land abandonment may result in the defragmentation of forest and grassland areas, including the creation of ecological corridors and rewilding. Two books are of particular interest, where book chapters touch on the topic of agricultural land abandonment and rewilding, namely **Pereira and Navarro 2015** and **Pettorelli, et al. 2019**. The article **Xie, et al. 2020** goes in unison with these two books and reflects on the opportunities of abandoned agricultural lands as a source for the environmental conservation alternative to farming. **Kamp, et al. 2011** showed through field studies how avian species increased on abandoned lands in steppes in Kazakhstan and how opportunities for conservation can be lost with ongoing recultivation. Another study, **Suárez-Seoane, et al. 2002**, showed non-uniform impacts on various species along the successional gradient in the Mediterranean region. **Vuichard, et al. 2009**; **Schierhorn, et al. 2013**; **Kurganova, et al. 2015**, with various modeling approaches and inputs, showed that abandoned lands could serve as an important global terrestrial source for a carbon sink. However, abandonment may also result in the establishment of novel ecosystems, including the encroachment of invasive species. For instance, across Eastern Europe, the encroachment of

Sosnowsky's hogweed (*Heracleum sosnowskyi*) has resulted in a poisonous threat to people. Similarly, as highlighted by **Oelofse, et al. 2016**, black wattle (*Acacia mearnsii*) has encroached on formerly cultivated lands and rangelands in Eastern Cape, South Africa, and represents a great environmental and economic threat. However, in some cases, black wattle provided the source for the improvement of livelihoods to local households (e.g., fencing, use as a green fertilizer, firewood). Abandoned lands can be an ideal source for the spread of wildfires, for instance, due to the accumulation of flammable dry matter such as old grass, and this is a common phenomenon in the Mediterranean region and in the Eurasian steppes. Agricultural land abandonment can be a result of changing livelihood strategies but also may impact livelihoods. For instance, "retiring" from farming in favor of other opportunities and overall transformation—"de-agrarianization"—can go hand in hand with land abandonment. Agricultural land abandonment can be linked with abandonment of rural communities. The different signs of abandonment of rural communities were studied by **Holcomb, et al. 2020** in the United States. Abandonment can be associated with a selection of alternatives to agricultural activities, such as the establishment of protected areas or game reserves, with examples being in Tanzania (**Brockington 1999**). However, the immediate outcome of such establishments can be dubious, producing both winners and losers. Abandonment may also have a spillover effect. If one farmer abandons farmland, neighboring farms may follow the same pathway. In light of the ongoing rapid global urbanization and depopulation of rural areas in many parts of the world, the role of abandoned lands imposes crucial societal and ethical challenges. Such challenges include trade-offs between alternative land uses and giving away land for nature, the role of international trade and governance, changing diets, land-sparing and land-sharing dilemmas, and the preservation of potentially available agricultural lands for future generations. A special issue in the *Land* MDPI journal **Prishchepov, et al. 2020** entitled *Agricultural Land Abandonment: Patterns, Drivers and Consequences* provided a dozen open-access research papers on this topic. The relevant studies **MacDonald, et al. 2000** and **Benayas, et al. 2007** provide comprehensive reviews of multiple implications of agricultural land abandonment on the environment and societal well-being. Nevertheless, the evident research gaps of implications of land abandonment on various ecological and societal processes open a niche for advancing studies on land abandonment.

Benayas, J. M. R., A. Martins, J. M. Nicolau, and J. J. Schulz. 2007. Abandonment of agricultural land: An overview of drivers and consequences. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* 2.057: 14.
- A comprehensive revision of implications of land abandonment on the environment with insights on the determinants of land abandonment.

Brockington, Daniel. 1999. "Conservation, displacement and livelihoods. The consequences of the eviction for pastoralists moved from the Mkomazi Game Reserve, Tanzania." *Nomadic Peoples* 3.2: 74–96. DOI: 10.3167/082279499782409370
- Exemplary study that unravels the complex implications of the decisions of discontinuation of pastoral activity in favor of the establishment of a game reserve.

Holcomb, J. P., P. Frederic, and S. D. Brunn. 2020. A visual typology of abandonment in rural America: From end-of-life to treading water, recycling, renaissance, and revival. *Land* 9.3: 94. DOI: 10.3390/land9030094

- A primary example of how abandonment of rural communities can be studied from the perspective of human geography.

Kamp, J., R. Urazaliev, P. F. Donald, and N. Hölzel. 2011. Post-Soviet agricultural change predicts future declines after recent recovery in Eurasian steppe bird populations. *Biological Conservation* 144.11: 2607–2614. DOI: 10.1016/j.biocon.2011.07.010
- This study shows how abandonment provides windows of opportunities for an increase of avian biodiversity, by bringing an example of restored grasslands because of cropland abandonment in Kazakh steppes.

Kurganova, I., V. Lopes de Gerenyu, and Y. Kuzyakov. 2015. Large-scale carbon sequestration in post-agrogenic ecosystems in Russia and Kazakhstan. *CATENA* 133:461–466. DOI: 10.1016/j.catena.2015.06.002
- A study that confirmed the findings about the importance of abandoned lands to sequester CO_2 in boreal, temperate, and steppe zones of Eurasia.

MacDonald, D., J. R. Crabtree, G. Wiesinger, et al. 2000. Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response. *Journal of Environmental Management* 59.1: 47–69.
- An overview of implications of agricultural land abandonment in mountainous areas of Europe.

Oelofse, M., T. Birch-Thomsen, J. Magid, et al. 2016. The impact of black wattle encroachment of indigenous grasslands on soil carbon, Eastern Cape, South Africa. *Biological Invasions* 18.2 (February): 445–456. DOI: 10.1007/s10530-015-1017-x
- An example of the impact of black wattle invasive species that encroached on abandoned agricultural fields on ecological processes in South Africa.

Pereira, H. M., and L. M. Navarro, eds. 2015. *Rewilding European landscapes*. Cham, Switzerland: Springer Open. DOI: 10.1007/978-3-319-12039-3
- A book on various aspects of rewilding including the role of abandoned lands and ecosystem services.

Pettorelli, N., S. M. Durant, and J. T. du Toit, eds. 2019. *Rewilding*. 1st ed. Cambridge, UK: Cambridge Univ. Press. DOI: 10.1017/9781108560962
- Another book on various aspects of rewilding including the role of abandoned lands.

Prishchepov, A., F. Löw, and F. Schierhorn, eds. 2020. *Special issue: Agricultural land abandonment: Patterns, drivers and consequences*. *Land* MDPI. https://www.mdpi.com/journal/land/special_issues/land_abandonment
- A collection of research papers on various aspects of agricultural land abandonment, including the implications to livelihoods.

Schierhorn, F., D. Müller, T. Beringer, A. V. Prishchepov, T. Kuemmerle, and A. Balmann. 2013. Post-Soviet cropland abandonment and carbon sequestration in European Russia, Ukraine, and Belarus. *Global Biogeochemical Cycles* 27.4: 1175–1185. DOI: 10.1002/2013GB004654

- A study which implemented process-based terrestrial ecosystem modeling and showed that abandoned lands across Belarus, Ukraine, and Russia turned into major terrestrial carbon sink after the collapse of the Soviet Union.

Suárez-Seoane, S., P. E. Osborne, and J. Baudry. 2002. Responses of birds of different biogeographic origins and habitat requirements to agricultural land abandonment in northern Spain. *Biological Conservation* 105.3: 333–344. DOI: 10.1016/S0006-3207(01)00213-0
- This study presents a non-uniform impact on avian biodiversity depending on the successional stage of abandonment fields as well as the period of the year in the Mediterranean region.

Vuichard, N., P. Ciais, L. Belelli, P. Smith, and R. Valentini. 2009. "Carbon sequestration due to the abandonment of agriculture in the former USSR since 1990." *Global Biochemical Cycles* 22.GB4018:8.
- Probably the first systematic study that modeled the impacts of post-Soviet cropland abandonment on CO_2 sequestration on abandoned fields.

Xie, Z., E. T. Game, R. J. Hobbs, D. J. Pannell, S. R. Phinn, and E. McDonald-Madden. 2020. Conservation opportunities on uncontested lands. *Nature Sustainability* 3.1: 9–15. DOI: 10.1038/s41893-019-0433-9
- A paper which revisits global abandonment patterns and presents opportunities for biodiversity conservation.