Rocha Najila Souza da (Orcid ID: 0000-0003-0988-778X)

Remote sensing of grasslands in South American Pampas (scientometrics analysis)

Najila Souza da Rocha[1], Bijeesh Kozhikkodan Veettil[2,3,*], Raymond D Ward[4,5,6],
Juliana Costi[7], Silvia Beatriz Alves Rolim[1]

[1] Centro Estadual de Pesquisas em Sensoriamento Remoto e Meteorologia,
Universidade Federal do Rio Grande do Sul (UFRGS),
Porto Alegre, Rio Grande do Sul, Brazil

[2] Laboratory of Ecology and Environmental Management, Science and Technology Advanced Institute, Van Lang University, Ho Chi Minh City, Vietnam

[3] Faculty of Applied Technology, School of Technology, Van Lang University, Ho Chi Minh City, Vietnam

[4] Centre for Aquatic Environments,
University of Brighton, Moulsecoomb, Brighton, BN2 4GJ, United Kingdom

[5] Institute of Agriculture and Environmental Sciences,
Estonian University of Life Sciences, Kreutzwaldi 5, EE-51014, Tartu, Estonia

[6] Colégio de Estudos Avançados,
Federal University of Ceará – Fortaleza,
Ceará, 60020-181, Brazil

[7] Laboratoire Environnements et Paléoenvironnements Océaniques et Continentaux (EPOC) — UMR CNRS 5805,
Université de Bordeaux, Pessac, France

*Corresponding author: bkozhikkodanveettil@vlu.edu.vn

Abstract

Remotely sensed data contains a range of information (spectral, spatial, radiometric, and temporal) useful in mapping and monitoring grassland extent, minimizing the cost of field data collection and laboratory analysis, thereby improving management and conservation of these ecosystems. The South American Pampa Biome is one of the highly productive ecosystems in the world consisting of an evergreen grassland environment in the southern areas of the continent (Brazil, Uruguay and Argentina). In this review paper, a scientometrics analysis of the applications of grassland remote sensing in South American Pampa Biome was performed with Web of Science Collection data using the relationship between authors/co-authors, institutions, countries and keywords. Despite the large number of published works on the application of remote sensing in grassland ecosystems, comparatively few have been conducted in the South American Pampa biome. Of 166 published articles on remote sensing of grassland systems, the first one published on the Pampas was in 1995, while research in this topic has been going on since 1985 in the rest of the world. Recently, some Journals have demonstrated interest in remote sensing of the Pampa region: a) *IEEE Journal of Selected Topics in Applied Earth*, b) *ISPRS Journal of Photogrammetry and Remote Sensing* and c) *Science of The Total Environment*. A number of remote sensing methods applied elsewhere have yet to be applied in the South American Pampas, including LiDAR applications. A wide range of grassland parameters that can be estimated using remote sensing includes ecosystem health, alien species invasion, and biomass.

Keywords: Biome, ecosystems; LiDAR; vegetation mapping

1 Introduction

Almost 25% of the earth's terrestrial area is covered by grasslands, and these store 20% of global pedologic carbon (Liu et al. 2019). Permanent grasslands (as opposed to semi-natural grasslands) are one of the most productive ecosystems on the earth (Lemaire et al. 2011). Grasslands are widely distributed throughout the world along tropical, subtropical and temperate regions; Llanos of South America are examples of tropical/subtropical grasslands whereas Prairies of North America and Pampas of South America are examples of temperate grasslands (Coupland 1979). Grassland vegetation plays a major role in the world's food security as it is an essential resource for diary and meat production (Scurlock and Hall 1998). One of the fundamental actions needed for the stability of grasslands is the promotion of sustainable economic activities. Among them, cattle ranching with the management of native grasslands that maintains the ecosystem conditions of the region and economic development is essential. It is important to emphasize that native grassland vegetation differs profoundly from cultivated pastures, usually formed by exotic species that result from the elimination of the original vegetation (Overbeck et al. 2007).

Anthropogenic activities that modify water-soil-plant interactions (such as land use changes) combined with extreme climate phenomena have resulted in the ecological deterioration of grassland ecosystems (Zhang et al. 2016; Liu et al. 2019). Climate change driven variations in the seasonality and intensity of rainfall influence grassland ecosystems and associated species interactions, and these in turn are likely to influence their ability to mitigate climate change (Suttle et al. 2007). Livestock activities in many developing countries are highly dependent on grassland ecosystems and, therefore, negative impacts from climate change can affect livestock-dependent economies in such regions (Thornton et al. 2009). In many regions of the world, a reduction in grassland areas due to agricultural intensification and climate-driven changes have also been observed since the last few decades (Dusseux et al. 2015), which includes changes in regional and global carbon balance, grassland productivity, food production, and habitat (Liu et al. 2019). This underlines the importance of proper and continuous monitoring of grassland ecosystems in such areas.

1.1 The South American Pampa Biome

The South American Pampa Biome (**Figure 1**) is a permanent grassland ecosystem distributed in Uruguay (51,000 km^2), Argentina (550,000 to 600,000 km^2) and Southern Brazil (176,496 km^2). The Pampas in Argentina include the provinces of Buenos Aires, La Pampa, Santa Fe, Entre Rios and Cordoba. The whole of Uruguay is considered as a part of the Pampas. In Brazil, southern regions of the State of Rio Grande do Sul are also included. The whole area is located within the Southern Temperate Zone, comprising a natural and highly species diverse grassland ecosystem with both direct and indirect interrelationships between humans and biodiversity (Roesch et al. 2009). The grassland plant community in the South American Pampas is mainly composed of *Stipa* spp., *Briza* spp., *Bromus* spp., and *Poa* spp. (Cabrera 1971). It has been reported that 356 alien plant species have been identified in Pampa grasslands (natural as well as semi-natural) and it is a challenge to tackle these biological invasions at a regional scale (Fonseca et al. 2013). *Eragrostis plana* Nees is one of the most successful invasive species in Pampa Biome, introduced in the 1950s from South Africa and currently present in nearly 10% of the total area of the Pampas (Gonzalez 2017). Key factors influencing grassland ecosystems in the South American Pampa biome are climate change, overgrazing, afforestation, alien plant species and expansion of croplands.

Since the 16th century, the main economic activity in the South American Pampas has been livestock production, mainly cattle and sheep, due to the presence of evergreen grasslands (Carvalho and Batello 2009; Modernel et al. 2016). Between 2000 and 2010 soy cultivation increased by 210%, and approximately 43 million cattle graze pastures in the grasslands (natural and planted) (Modernel et al. 2016). The Pampas is one of the largest temperate regions in the southern hemisphere dedicated to cereal and oil crops (Rimski-Korsakov et al. 2012). Due to its extremely sandy texture, soil in this region is fragile and is prone to erosion (by water and wind). Furthermore, climate change and anthropogenic factors may lead to the loss of biodiversity and socioeconomic opportunities (Roesch et al. 2009). Even though this region has tremendous agricultural potential, there is a need for aggressive action and changes in crop production to save Pampas soil from degradation (Wingeyer et al. 2015). Modernel et al. (2016) studied the beef production farms in Pampas and Campos across Rio de la Plata. Analyzing 280 farms, the authors estimated that, on average, meat production (but not income) tended to decline with reduction in native grassland area in the region. However, they also highlight the multi-functionality of the agro-ecosystems and raise questions on the dominant focus on greenhouse gas emissions as the sole indicator of sustainability.

During the last few decades, satellite and ground-based remote sensing and Global Positioning System (GPS) have been used as key tools for high-precision grassland management (Ali et al. 2016). Various biophysical parameters, such as ecosystem health, of grasslands have been retrieved using remotely sensed data in recent years (Xu and Guo 2015). In present study, a range of grassland parameters that can be estimated using remote sensing in the Pampas are discussed in detail. A number of remote sensing methods applied to grassland environments in the world are yet to be applied in South American Pampas, including LiDAR applications.

2 Data and Methods

Literature Search Strategy

In the present study, we used the Web of Science Core Collection database assigned by Clarivate Analytics to identify the articles published in the World regarding the Pampa biome and Remote Sensing (RSPampa). Since Grassland remote sensing is an interdisciplinary subject (Li et al. 2021), its domain is not limited merely to remote sensing but falls within other domains, such as ecology and environment. The search formula of the method selected according to the RSPampa research subjects were: (‘Pampa biome’ or ‘pampa’) AND (‘Remote Sensing’ or ‘Normalized Difference Vegetation Index (NDVI)’ or (‘Thermal Infra-red’ or ‘Landsat’ or ‘Sentinel’ or ‘MODIS’ or ‘big data’ or ‘Google Earth Engine’). The database was refined to the period from 1995 to 2021 (update on July, 22), the document type was set as articles written in English (as majority of the international ISI journals are published in English). It is worth noting that satellite-based maps of Pampean grasslands may have been covered in general LULC studies conducted in southern South America or the South American continent or global vegetation phenology in general (e.g. Justice et al. 1985; Houghton et al. 1991; Stone et al. 1994) and can be skipped out of the Scientometrics analysis as these studies do not match the keywords used in the analysis.

Scientometrics Analysis Method

We analyzed our data in VOSviewer and Microsoft Excel for data mining, analysis, processing, and visualization of the literature data. VOSviewer is free software used to illustrate the relationship between authors/co-authors, institutions, countries and keywords, which can reveal the research topic of the literature and also reflect the researcher hotspot in the field (Li et al. 2021). Scientometrics Analysis Methods, which are used in many fields of study for extensive and detailed evaluations at different levels, integrate computer engineering, big data applications and statistics (Li et al. 2021). In addition, scientometrics are suitable for providing detailed visual features in the form of a knowledge map and analysis of citations or cited references (Chen 2013). The scientometrics analysis is considered as the finest method to understand the trends in research as well as to discover new key research areas (Delbari et al. 2015). This feature is helpful for understanding the spatiotemporal evolution of research characteristics and judging the scientific research progress in a systematic and comprehensive manner (Li et al. 2021). It is worth noting that, in general, the understanding of a research topic become deeper with increase in the number of references obtained (Chen 2017).

Once we obtained information from the RSPampa field, we indicated the most popular papers regarding the South American Pampa Biome and discussed in comparison with other grassland ecosystems status around the World. Finally, we suggest future topics for RSPampa research and some strategies to improve scientific knowledge in the field.

3 Results and discussion

A total number of 166 documents, which were published between 1995–2021, were obtained using the related keywords on Web of Science Collection, the earliest (1995) document of RSPampa was cited 79 times and used NDVI method and NOAA-AVHRR data for the classification of Argentinean Pampas (Kerdiles and Grondona 1995). There is a notable lack of publications between 1995 to 2000, when the second paper was published. However, RSPampa only became an important subject of study in 2016 with 19 published papers which further augmented in 2020 with 31 published papers (**Figure 2**). These results demonstrate the slow development of RSPampa research studies, while in the rest of the world research related to grasslands ecosystems commenced in 1985 and has grown exponentially since the 1990s (Li et al. 2021). The first published research in the field was from Argentina, and around 2015 we found a few articles published from Brazil. **Figure 3** shows a low interest in Pampa Biome research from the international scientific community. In 2015, Pylro et al. (2015) reported a lack of researches in microbiomes including Pampa biome; the authors also indicated that these studies needed some leads to improve the knowledge.

According to Li et al. (2021), remote sensing of grassland ecosystems has evolved from nine fields (remote sensing, environmental science, ecology, imaging science and photographic technology, multidisciplinary geosciences, physical geography, forestry and biodiversity conservation, agronomy, and meteorology and atmospheric sciences), concentrated mainly in remote sensing, environmental science, ecology and imaging science photography. When RSPampa research is analyzed, we noted the same field categories in the top 5 subject distribution (**Figure 4**). However, while in the rest of world, forestry, meteorology and atmospheric sciences have appeared as an important issue, RSPampa is not among these disciplines in the top 10 main research fields.

Influential Journals

The RSPampa subject has appeared in 106 journals since 1995, but in 76 (71%) of them this subject appears only once. Most of the publications on this topic are concentrated in only 15 (14%) journals, which are also the most cited by the scientific community (**Appendix 1**). The top 15 Journals for RSPampa articles have published 56 (33% of the total number of documents) papers. As shown in **Table 1**, the top three journals with the largest number of publications are *International Journal of Remote Sensing* (8), *Remote Sensing* (8) and *Agriculture Ecosystems & Environment* (6). The first two journals are also considered to be the leading Journals in the publication of grassland remote sensing (Li et al. 2021). However, recently (since 2015), 3 other Journals have shown interest in the same topic: *IEEE Journal of Selected Topics in Applied Earth Observation and Geoinformation* (5), *ISPRS Journal of Photogrammetry and Remote Sensing* (3) and *Science of the Total Environment* (3). However, *IEEE Journal of Selected Topics in Applied Earth Observation and Geoinformation* and *Science of the Total Environment* do not appear as top 20 when we are looking at grassland remote sensing (Li et al. 2021).

Future of grassland remote sensing with reference to the Pampa Biome

Even though a large number of remotely sensed data and methods have been used all over the world for grassland research, it is deduced from the available literature that only a few have been applied in the South American Pampa Biome (**Appendix 1**). The main objectives of research in the Pampas region have been changing in recent years. In the 2000s, scientists were interested in investigating agriculture, land use and fragmentation, and in recent years the main research interests have focussed on urbanization, change detection, circular economy and climate variability (**Figure 5**). In addition, Argentinean Pampas were the focus of a large number of studies in the past, whereas there is an increase in the number of studies in the Brazilian Pampas in recent years.

A large number of grassland parameters have been derived from remote sensing applications in the Pampas region. The non-exhaustive list of grassland parameters includes grassland coverage/area, growth and plant diversity/species richness, biomass and primary productivity, grassland use intensity and soil degradation patterns, age and population structure of invasive shrubs, biochemical, structural and functional trains of grasslands, heat and energy fluxes, and evapotranspiration. Evapotranspiration measurements have been shown to be effective when combining land surface temperature (LST) measurements from optical sensors and soil moisture measurements from microwave sensors (Castelli et al. 2018) or optical data such as AVIRIS and MODIS (Liu et al. 2012). For an accurate satellite-derived land heat flux measurement, a combination of infrared and microwave data is suggested by some researchers (e.g. Jimenez et al. 2017).

The South American Pampas are composed of areas with different geomorphological conditions (mountains, coasts, and plains). This requires multi-source remote sensing data and specific methods can be used for effective mapping and monitoring of grasslands in the region. Most the studies undertaken in recent years have used MODIS, Landsat and NOAA-AVHRR data. The potential of LiDAR data to monitor the Pampa biome grasslands still remains unexplored, even though such data provide high spatial resolution and carry information about the vegetation that exceeds their optical properties (Zhang et al. 2021). LiDAR data can also provide information on grazing intensities (Zhang et al. 2021) and differentiate between native and deliberately planted grasslands (Fisher et al. 2018) which are relevant in the case of Pampa Biome. One of the main drawbacks of airborne LiDAR is the data acquisition cost. The use of UAV platforms can substantially reduce the cost of LiDAR data acquisition.

The need for a "multi" approach

A combination of multiple data types is suggested by many researchers for accurate mapping of grassland ecosystems (Propastin and Kappas 2009; Esch et al. 2014; Pitkänen and Käyhkö 2017; Villoslada et al. 2018), which could clearly be applied in the Pampa Biome. Optical data (e.g. aerial photographs, Landsat imagery) combined with LiDAR data with various point densities (the point density of LiDAR data is the amount of measurements per area at which the earth surface is sampled) can be a suitable option. For example, a combination of low-density LiDAR data and optical remote sensing data can be used for reducing the classification errors while detecting grassland overgrowth, particularly in heterogeneous (e.g. where encroachment of woody plants into grasslands occurs or pastured and non-pastured grasslands) environments (Pitkänen and Käyhkö 2017). The use of high-density LiDAR instead of low-density one is believed to further enhance the classification accuracy (Pitkänen and Käyhkö 2017), although medium density LiDAR has been shown to work well in grasslands (Ward et al. 2013).

For spatially detailed and up-to-date information on grassland distribution and land use intensity in large areas, Esch et al. (2014) suggested using a combination of multi-seasonal (i.e. images are acquired in many seasons or throughout the year) high and medium resolution satellite imagery (e.g. LISS3 and AWiFS having a spatial resolution of 24 m and 56 m, respectively). The integration of optical satellite data (e.g. Landsat series) with field measurements can also improve the accuracy of mapping LAI within grasslands (Propastin and Kappas 2009). Lehnert et al. (2015)

obtained the best accuracy for mapping grasslands by applying a multi-scale, multi-sensor and multi-method approach, where spaceborne optical data with varying spatial resolution were used (WorldView-2m, Landsat-30m, MODIS-500m) and applied support vector machines (SVM) methods in particular. Integrated optical and radar data can be applied to differentiate natural grassland from invasive species effectively (Hong et al. 2014). Biomass estimation using multisource remote sensing data has been used effectively in the Pampa Biome. For example, Filho (2018) used a combination of multispectral (Sentinel-2) and hyperspectral (field spectrometer) data for successful biomass estimation in the Brazilian Pampa Biome.

4 Conclusions and future perspectives

Scientometrics analysis methods are powerful tools in recognizing the current research trends and to find new research areas which would help researchers understand the spatiotemporal evolution of research characteristics, judging the scientific research progress in a systematic and comprehensive manner. The results of scientometrics analysis indicated that the RSPampa subject has appeared in 106 journals since 1995. However, in 71% of them the subject about Pampas appears only once. The top 15 Journals for RSPampa articles have published 56 research/review articles which is 33% of the total number of documents analyzed. The top three journals with the largest number of publications are *International Journal of Remote Sensing*, *Remote Sensing,* and *Agriculture Ecosystems & Environment*. Since 2015, three other Journals (*IEEE Journal of Selected Topics in Applied Earth Observation and Geoinformation*, *ISPRS Journal of Photogrammetry and Remote Sensing*, and *Science of the Total Environment*) have shown interest in the same topic.

Pampa grasslands in South America are facing a number of problems, such as invasive species, forest planting with exotic species, expansion of agriculture (e.g. soybean and rice), climate change, and grazing. It is important to have a time-series analysis of grassland cover change in the region in order to conserve the indigenous ecosystem. Remote sensing, with its vast variety of data, including terrestrial photography/videography and field spectrometer, airborne and spaceborne multispectral/hyperspectral data, LiDAR and Radar, and different types of data taken from UAV platform, have been used by researchers for grassland studies around the world and the vast majority of these would be appropriate to apply in Pampas grassland research.

For detailed monitoring of grasslands in the South American Pampas, a multi-source approach is necessary, particularly due to the varying geomorphology of the region and a single type of data may not be effective in such cases. Pampean grassland parameters that can be estimated using remotely sensed data include: grassland cover/area, growth rates, plant diversity/species richness, biomass and primary productivity, grassland use intensity, soil degradation patterns, age and population structure of invasive shrubs, biochemical, structural and functional traits, and heat and energy fluxes. Future studies may provide more conclusions regarding the influence of different native grassland managements. It is suggested that multi-source and multi-type remote sensing data should be used for detailed study of different grassland parameters in the Pampas. Recent development in UAV technologies would be helpful in mapping and monitoring grassland ecosystems in this region in cost-effective and spatially accurate ways, particularly where used in conjunction with datasets having a greater spatial coverage. LiDAR data has yet to be used for South American Pampas grassland research, even though its use in other grassland regions has been well-proven.

Conflict of interest

Authors declare no conflicting interests.

References

Ali I, Cawkwell F, Dwyer E, Barrert B, Green S (2016) Satellite remote sensing of grasslands: from observation to management. Journal of Plant Ecology, 9, 649-671. DOI: 10.1093/jpe/rtw005

Cabrera AL (1971) Fitogeografía de la República Argentina. Boletín de la Sociedad Argentina de Botánica 14.

Carvalho PCF, Batello C (2009) Access to land, livestock production and ecosystem conservation in the Brazilian Campos biome: the natural grasslands dilemma. Livestock Science, 120, 158-162. DOI: 10.1016/j.livsci.2008.04.012

Castelli M, Anderson MC, Yang Y, Wohlfahrt G, Bertoldi G, Niedrist G, Hammerle A, Zhao P, Zebisch M, Notarnicola C (2018) Two-source energy balance modeling of evapotranspiration in Alpine grasslands. Remote Sensing of Environment, 209, 327-342. DOI: 10.1016/j.rse.2018.02.062

Chen C (2013) Hindsight, insight, and foresight: A multi-level structural variation approach to the study of a scientific field. Technol. Anal. Strateg. Manag., 25, 619–640. DOI: 10.1080/09537325.2013.801949

Chen C (2017) Science mapping: A systematic review of the literature. J. Data Inf. Sci., 2, 1–40. DOI: 10.1515/jdis-2017-0006

Coupland RT (1979) Grassland ecosystems of the world: Analysis of grasslands and their uses. Cambridge University Press, pp. 432.

Dusseux P, Hubert-Moy L, Corpetti T, Vertes F (2015) Evaluation of SPOT imagery for the estimation of grassland biomass. Int. J Appl. E Obs. Geoinf., 38, 72-77. DOI: 10.1016/j.jag.2014.12.003

Esch T, Metz A, Marconcini M, Keil M (2014) Combined use of multi-seasonal high and medium resolution satellite imagery for parcel-related mapping of cropland and grassland. Int. J Appl. E Obs. Geoinf. 28, 230-237. DOI: 10.1016/j.jag.2013.12.007

Filho MG (2018) Estimativas de variáveis biofísicas de vegetação campestre sob manejo pastoril por meio de sensoriamento remoto. Master's Thesis, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil.

Fisher RJ, Sawa B, Prieto B (2018) A novel technique using LiDAR to identify native-dominated and tame-dominated grasslands in Canada. Remote Sensing of Environment, 218, 201-206. DOI: 10.1016/j.rse.2018.10.003

Fonseca CR, Guadagin DL, Masciadri S, Germain P, Zalba SM (2013) Invasive alien plants in the Pampas grasslands: a tri-national cooperation challenge. Biological Invasions, 15, 1751-1763. DOI: 10.1007/s10530-013-0406-2

Gonzalez JDM (2017) Análise da susceptibilidade à invasão do capim-annoni-2 sobre áreas do Bioma Pampa do município de Aceguá – RS. Master's Thesis, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil.

Hong G, Zhang A, Zhou F, Brisco B (2014) Integration of optical and synthetic aperture radar (SAR) images to differentiate grassland and alfalfa in Prairie area. International Journal of Applied Earth Observation and Geoinformation, 28, 12-19. DOI: 10.1016/j.jag.2013.10.003

Houghton RA, Lefkowitz DS, Skole DL (1991) Changes in the landscape of Latin America between 1850 and 1985 I. Progressive loss of forests. Forest Ecology and Management, 38, 143-172. DOI: 10.1016/0378-1127(91)90140-Q

Jimenez C, Michel D, Hirschi M, Ermida S, Prigent C (2017) Applying multiple land surface temperature products to derive heat fluxes over a grassland site. Remote Sensing Applications: Society and Environment, 6, 15-24. DOI: 10.1016/j.rsase.2017.01.002

Justice CO, Townshend RG, Holben BN, Tucker CJ (1985) Analysis of the phenology of global vegetation using meteorological satellite data. International Journal of Remote Sensing, 6, 1271-1318. DOI: 10.1080/01431168508948281

Kerdiles H, Grondona O (1995) NOAA-AVHRR NDVI decomposition and subpixel classification using linear mixing in the Argentinean Pampa. International Journal of Remote Sensing, 16, 1303–1325. DOI: 10.1080/01431169508954478

Lehnert LW, Meyer H, Wang Y, Miehe G, Thies B, Reudenbach C, Bendix J (2015) Retrieval of grassland plant coverage on the Tibetan Plateau based on a multi-scale, multi-sensor and multi-method approach. Remote Sensing of Environment, 164, 197-207. DOI: 10.1016/j.rse.2015.04.020

Lemaire G, Hodgson J, Chabbi A (2011) Grassland productivity and ecosystem services. CABI, pp. 296.

Li T, Cui L, Xu Z, Hu R, Joshi PK, Song X, Tang L, Xia A, Wang Y, Guo D, Zhu J, Hao Y, Song L, Cui X (2021) Quantitative Analysis of the Research Trends and Areas in Grassland Remote Sensing: A Scientometrics Analysis of Web of Science from 1980 to 2020. Remote Sensing, 13, 1279. DOI: 10.3390/rs13071279

Liu S, Roberts DA, Chadwick OA, Still CJ (2012) Spectral responses to plant available soil moisture in a Californian grassland. International Journal of Applied Earth Observation and Geoinformation, 19, 31-44. DOI: 10.1016/j.jag.2012.04.008

Liu Y, Zhang Z, Tong L, Khalifa M, Wang Q, Gang C, Wang Z, Li J, Sun Z (2019) Assessing the effects of climate variation and human activities on grassland degradation and restoration across the globe. Ecological Indicators, 106, 105504. DOI: 10.1016/j.ecolind.2019.105504

Modernel P, Rossing WAH, Corbeels M, Dogliotti S, Picasso V, Tittonell P (2016) Land use change and ecosystem service provision in Pampas and Campos grasslands of southern South America. Environmental Research Letters, 11, 113002. DOI: 10.1088/1748-9326/11/11/113002

Overbeck GE, Muller SC, Fidelis A, Pfadenhauer J, Pillar VD, Blanco CC, Boldrini II, Both R, Fornech ED (2007) Brazil’s neglected biome: The South Brazilian Campos. Perspectives in Plant Ecology, Evolution and Systematics, 9, 101-116. DOI: 10.1016/j.ppees.2007.07.005

Pitkänen TP, Käyhkö N (2017) Reducing classification error of grassland overgrowth by combing low-density lidar acquisitions and optical remote sensing data. ISPRS Journal of Photogrammetry and Remote Sensing, 130, 150-161. DOI: 10.1016/j.isprsjprs.2017.05.016

Propastin PA, Kappas M (2009) Integration of Landsat ETM+ Data with Field Measurements for Mapping Leaf Area Index in the Grasslands of Central Kazakhstan. GIScience and Remote Sensing, 46, 212-231. DOI: 10.2747/1548-1603.46.2.212

Pylro VS, Morais DK, Rosesch LFW (2015) Microbiology: Microbiome studies need local leaders. Nature, 528, 39-39. DOI: 10.1038/528039e

Rimski-Korsakov H, Alvarez CR, Lavado RS (2015) Cover crops in the agricultural systems of the Argentine Pampas. Journal of Soil and Water Conservation, 70, 112A-118A. DOI: 10.2489/jswc.70.6

Roesch LFW, Vieira FCB, Pereira VA, Schunemann AL, Teixeira IF, Senna AJT, Stefenon VM (2009) The Brazilian Pampa: A fragile biome. Diversity, 1, 182-198. DOI: 10.3390/d1020182

Scurlock JMO, Hall DO (1998) The global carbon sink: a grassland perspective. Global Change Biology, 4, 229–233. DOI: 10.1046/j.1365-2486.1998.00151.x

Stone TA, Schlesinger P, Houghton RA, Woodwell GM (1994) A Map of the Vegetation of South America Based on Satellite imagery. Photogrammetric Engineering & Remote Sensing, 60, 541-551.

Suttle KB, Thomsen MA, Power ME (2007) Species interactions and reverse grassland responses to changing climate. Science, 315, 640. DOI: 10.1126/science.1136401

Thornton PK, Steeg J, Notenbaert A, Herrero M (2009) The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know and what we need to know. Agricultural Systems, 101, 113-127. DOI: 10.1016/j.agsy.2009.05.002

Villoslada M, Vinogradovs I, Ruskule A, Veidemane K, Nikodemus O, Kasparinskis R, Sepp K, Gulbinas J (2018) A multitiered approach for grassland ecosystem services mapping and assessment: The Viva Grass tool. One Ecosystem, 3, e2580. DOI: 10.3897/oneeco.3.e25380

Ward R, Burnside N, Joyce C, Sepp K (2013). The use of medium point density LiDAR elevation data to determine plant community types in Baltic coastal wetlands. Ecological Indicators, 33, 96-104. DOI: 10.1016/j.ecolind.2012.08.016

Wingeyer AB, Amado TJC, Bidegain MP, Studdert GA, Varela CHP, Garcia FO, Karlen DL (2015) Soil Quality Impacts of Current South American Agricultural Practices. Sustainability, 7, 2213-2242. DOI: 10.3390/su7022213

Xu D, Guo X (2015) Some Insights on Grassland Health Assessment Based on Remote Sensing. Sensors, 15, 3070-3089. DOI: 10.3390/s150203070

Zhang X, Bao Y, Wang D, Xin X, Ding L, Xu D, Hou L, Shen J (2021) Using UAV LiDAR to Extract Vegetation Parameters of Inner Mongolian Grassland. Remote Sensing, 13, 656. DOI: 10.3390/rs13040656

Zhang Y, Zhang C, Wang Z, Chen Y, Gang C, An R, Li J (2016) Vegetation dynamics and its driving forces from climate change and human activities in the Three-River Source Region, China from 1982 to 2012. Science of the Total Environment, 563–564, 210-220. DOI: 10.1016/j.scitotenv.2016.03.223

List of Tables and Figures

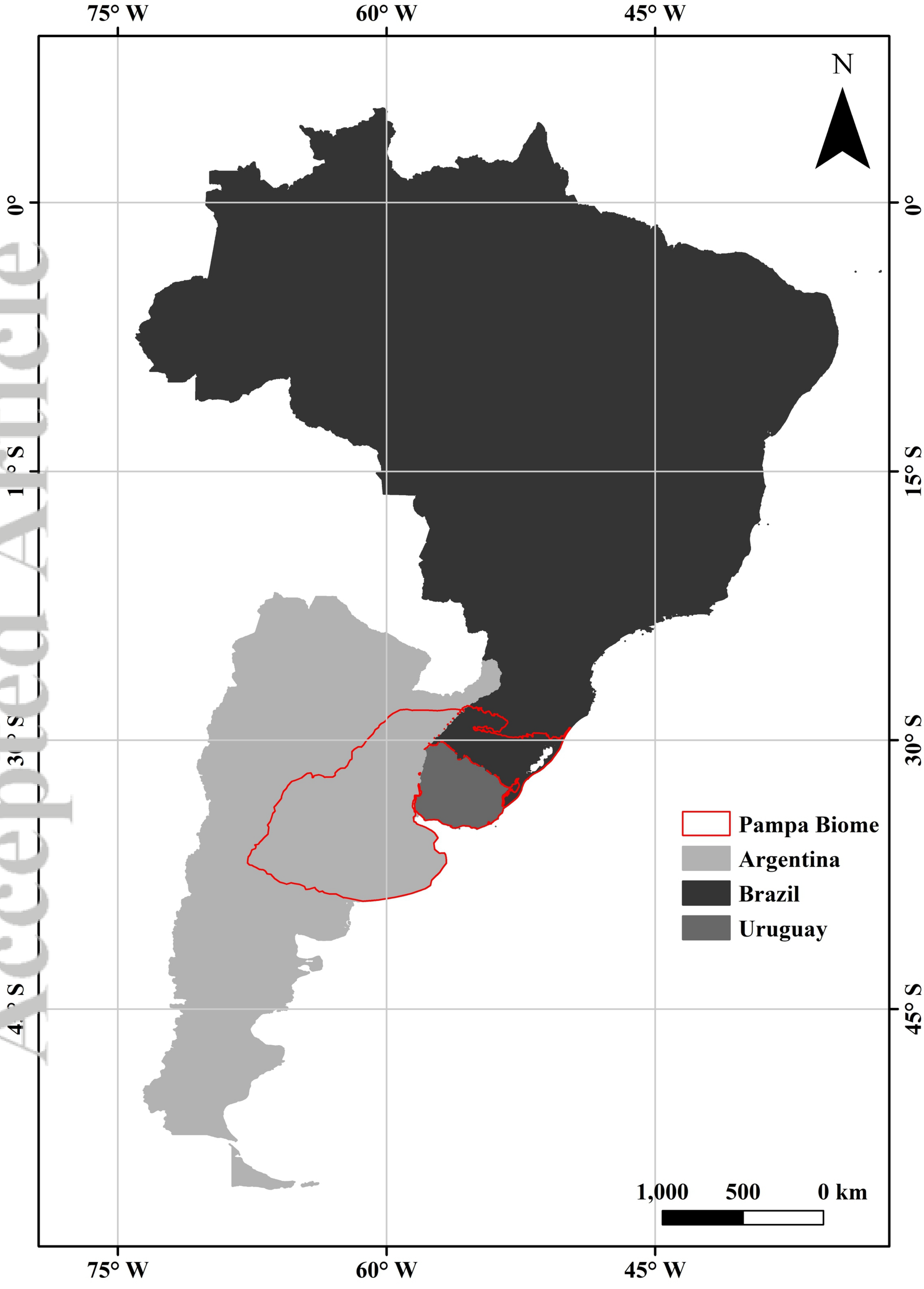
Figure 5: Network of keywords based on the co-occurrence method on RSPampa research from 1995-2021.

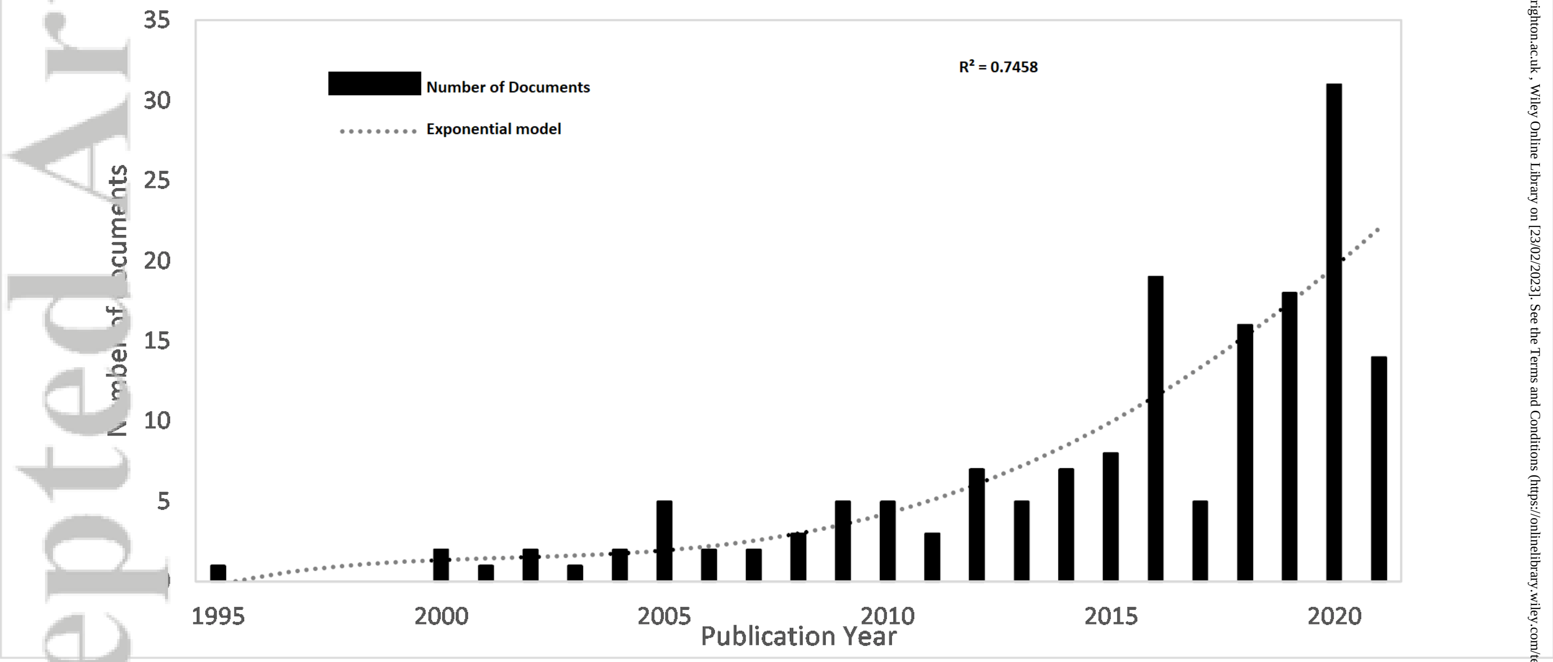
Appendix 1: Summary of studies using remote sensing data for grassland research in the South American Pampa Biome (2000-2020)

Table 1: Top 15 journals ranked by the number of documents in Remote Sensing Pampa research from 1995 to 2021.

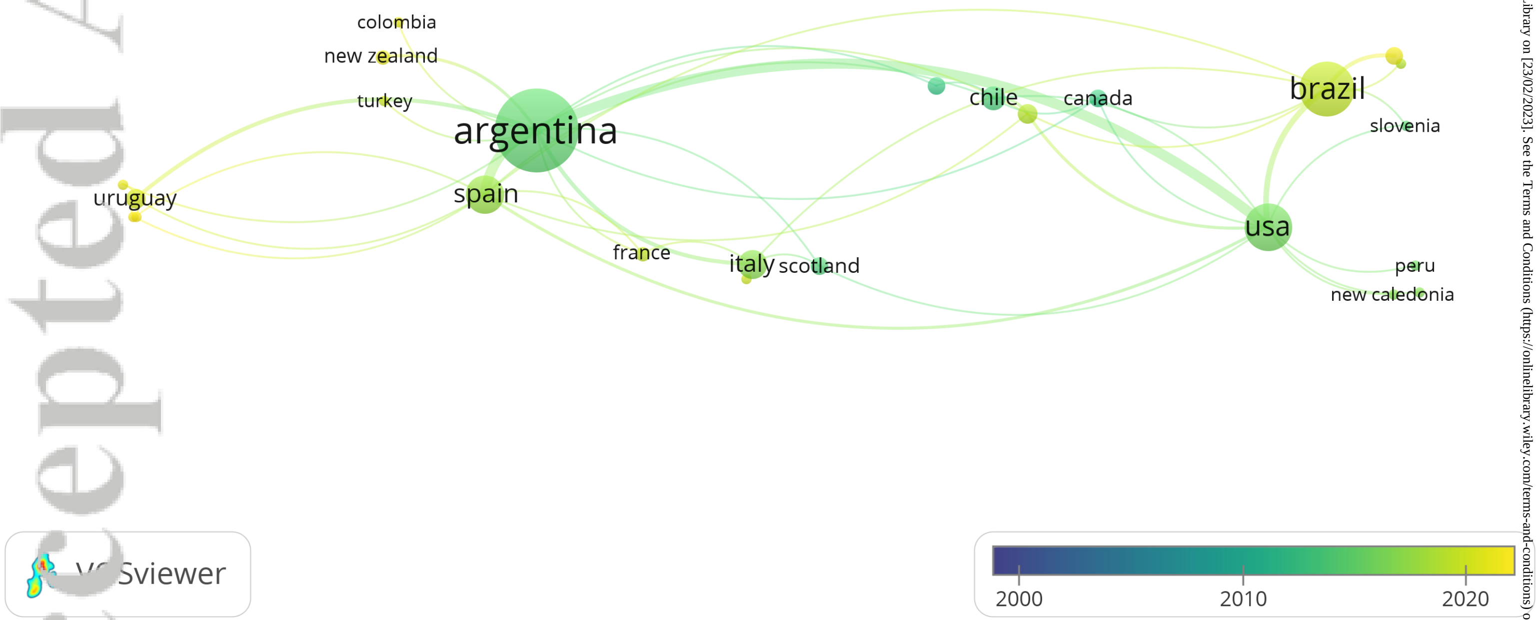
Journal	**ND**	**TLCS**	**AC**	**Year**	**IF**
International Journal of Remote Sensing	8	307	38.38	1995	3.266
Remote Sensing	8	138	17.25	2012	5.353
Agriculture Ecosystems & Environment	6	377	62.83	2006	6.064
IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing	5	43	8.6	2015	3.784
Ecosystems	4	235	58.75	2001	4.776
Applied Vegetation Science	4	99	24.75	2000	3.252
International Journal of Applied Earth Observation and Geoinformation	3	142	47.33	2014	5.933
Agricultural Systems	3	57	19	2007	5.622
Geomorphology	3	50	16.67	2011	4.623
ISPRS Journal of Photogrammetry and Remote Sensing	3	41	13.67	2018	9.948
Rangeland Ecology & Management	3	41	13.67	2005	2.019
Remote Sensing of Environment	3	39	13	2014	11.057
Science of the Total Environment	3	39	13	2018	7.842

Abbreviations: ND, the number of documents; TLCS, the total local citation score; AC, average citation; Year, published year started; IF, impact factor in the last 5 years.

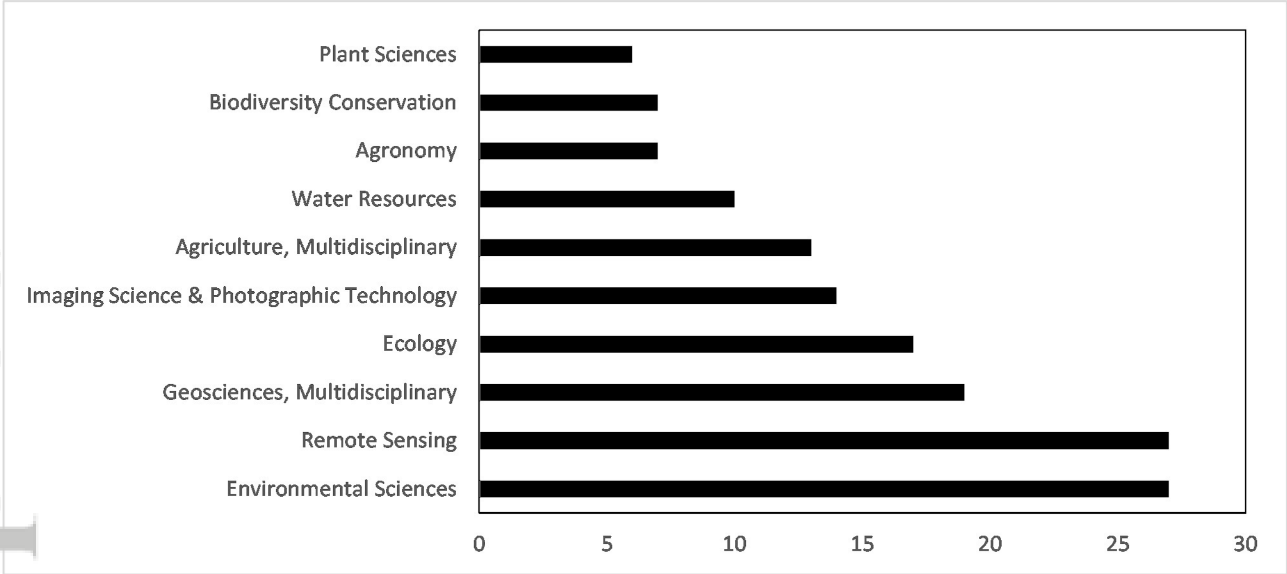

75° W
60° W
45° W
N
0°
15° S
30° S
45° S
Pampa Biome
Argentina
Brazil
Uruguay
1,000
500
0 km



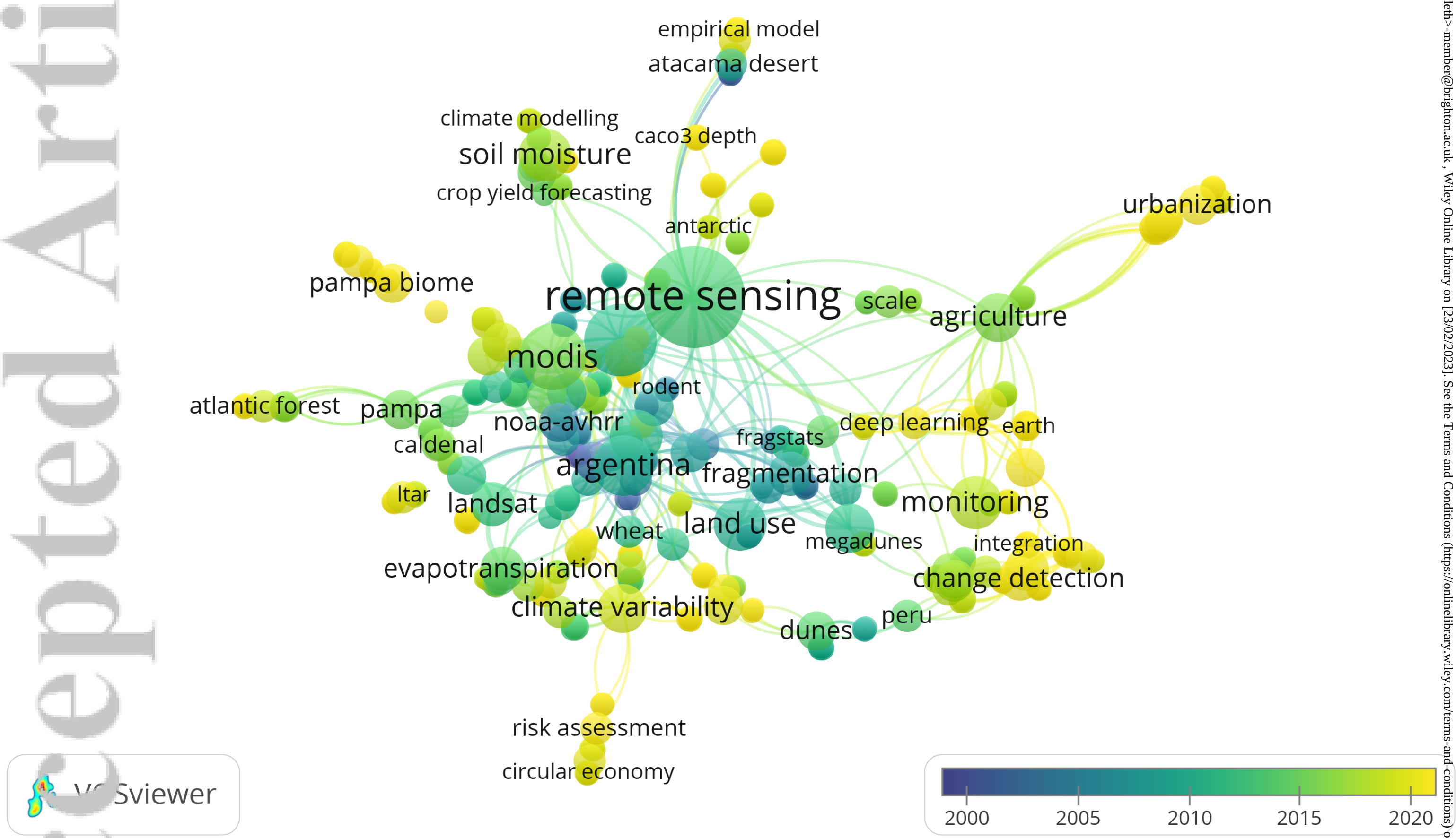
LDR_4658_Figure 2.png



LDR_4658_Figure 3.tif



LDR_4658_Figure 4.jpg



LDR_4658_Figure 5.tif