Remote Sensing of Grassland Production and Management – A Review

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Supplementary Material

Table S1. Copyright information of images of various grasslands downloaded from flickr (www.flickr.com).

| Image | Name                     | Photographer          |
|-------|--------------------------|-----------------------|
| A)    | Sandhills Region, Nebraska | Ken Lund             |
| B)    | Oberbayern (Lindegg)     | Renate Dodell         |
| C)    | Qinghai                  | sm c                  |
| D)    | Uruguay                  | Maureen Barlin Magalie L’Abbe |
| E)    | KwaZulu Natal            | Maureen Barlin        |
| F)    | Southern New Zealand     | hildaandjohn          |
| Author and Date     | Title                                                                                                                                                                                                 | Journal                                                                                   |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| Abuzar et al. 2017 | Farm Level Assessment of Irrigation Performance for Dairy Pastures in the Goulburn-Murray District of Australia by Combining Satellite-Based Measures with Weather and Water Delivery Information. | ISPRS International Journal of Geo-Information                                               |
| Ali et al. 2014    | Application of statistical and machine learning models for grassland yield estimation based on a hypertemporal satellite remote sensing time series.                                                        | IEEE Geoscience and Remote Sensing Symposium                                                |
| Ali et al. 2017a   | Modeling managed grassland biomass estimation by using multitemporal remote sensing data - A machine learning approach.                                                                                | IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing           |
| Ali et al. 2017b   | Application of repeat-pass TerraSAR-X staring spotlight interferometric coherence to monitor pasture biophysical parameters: limitations and sensitivity analysis.                                       | IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing           |
| An et al. 2013     | Estimating above-ground net primary productivity of the tallgrass prairie ecosystem of the Central Great Plains using AVHRR NDVI.                                                                   | International Journal of Remote Sensing                                                   |
| Anaya et al. 2009  | Aboveground biomass assessment in Colombia: A remote sensing approach.                                                                                                                                | Forest Ecology and Management                                                              |
| Anderson et al. 1993 | Evaluating Landsat Thematic Mapper derived vegetation indices for estimating above-ground biomass on semiarid rangelands.                                                                           | Remote Sensing of Environment                                                              |
| Andrimont et al. 2018 | Targeted grassland monitoring at parcel level using Sentinels, street-level images and field observations.                                                                                           | Remote Sensing                                                                             |
| Asam et al. 2015   | Estimation of grassland use intensities based on high spatial resolution LAI time series.                                                                                                             | International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences |
| Baeza et al. 2010  | Spatial variability of above-ground net primary production in Uruguayan grasslands: a remote sensing approach.                                                                                          | Applied Vegetation Science                                                                 |
| Baghi et al. 2019  | Do soil-adjusted or standard vegetation indices better predict aboveground biomass of semi-arid saline rangelands in North-East Iran?                                                               | International Journal of Remote Sensing                                                   |
| Barrachina et al. 2015 | Estimating above-ground biomass on mountain meadows and pastures through remote sensing.                                                                                                           | International Journal of Applied Earth Observation and Geoinformation                     |
| Barrett et al. 2014 | Assessment of multi-temporal, multi-sensor radar and ancillary spatial data for grasslands monitoring in Ireland using machine learning approaches.                                                  | Remote Sensing of Environment                                                              |
| Author(s)               | Title                                                                 | Journal                                      |
|------------------------|----------------------------------------------------------------------|----------------------------------------------|
| Bastin et al. 2012     | Separating grazing and rainfall effects at regional scale using remote sensing imagery: A dynamic reference-cover method. | Remote Sensing of Environment                |
| Bekkema and Elevald 2018 | Mapping grassland management intensity using Sentinel-2 satellite data. | GI Forum 2018                                |
| Bella et al. 2004      | Remote sensing capabilities to estimate pasture production in France. | International Journal of Remote Sensing     |
| Benie et al. 2005      | Remote sensing-based spatio-temporal modeling to predict biomass in Sahelian grazing ecosystem. | Ecological Modelling                         |
| Bjerke et al. 2015     | Impacts of snow season on ground-ice accumulation, soil frost and primary productivity in a grassland of sub-Arctic Norway. | Environmental Research Letters               |
| Blanco et al. 2009     | Remote sensing of spatial and temporal vegetation patterns in two grazing systems. | Rangeland Ecology & Management               |
| Boschetti et al. 2007  | Assessment of pasture production in the Italian Alps using spectrometric and remote sensing information. | Agriculture, Ecosystems & Environment        |
| Brinkmann et al. 2011  | Quantification of aboveground rangeland productivity and anthropogenic degradation on the Arabian Peninsula using Landsat imagery and field inventory data. | Remote Sensing of Environment                |
| Buono et al. 2010      | Spatial and temporal variation of primary production of Patagonian wet meadows. | Journal of Arid Environments                 |
| Chen et al. 2011       | Herbaceous biomass estimation from SPOT 5 imagery in semiarid rangelands of Idaho. | GIScience & Remote Sensing                  |
| Chen et al. 2014       | The impact of climate change and anthropogenic activities on alpine grassland over the Qinghai-Tibet Plateau. | Agricultural and Forest Meteorology          |
| Chi et al. 2018        | Assessing the effects of grazing on variations of vegetation NPP in the Xilingol Grassland, China, using a grazing pressure index. | Ecological Indicators                       |
| Chladil and Nunez 1995 | Assessing grassland moisture and biomass in Tasmania - the application of remote sensing and empirical models for a cloudy environment. | International Journal of Wildland Fire      |
| Courault et al. 2010   | Combined use of FORMOSAT-2 images with a crop model for biomass and water monitoring of permanent grassland in Mediterranean region. | Hydrology and Earth System Sciences         |
| Crabbe et al. 2019     | A preliminary investigation of the potential of Sentinel-1 radar to estimate pasture biomass in a grazed pasture landscape. | Remote Sensing                              |
| Cui et al. 2012        | Classification management for grassland using MODIS data: a case study in the Gannan region, China. | International Journal of Remote Sensing     |
| Diouf et al. 2015      | Fodder biomass monitoring in sahelian rangelands using phenological metrics from FAPAR time series. | Remote Sensing                              |
| Author(s) and Year | Title and Description | Journal/Conference Publication |
|--------------------|-----------------------|--------------------------------|
| Donald et al. 2010 | Using MODIS imagery, climate and soil data to estimate pasture growth rates on farms in the south-west of Western Australia. | Animal Production Science |
| Donald et al. 2013 | Satellite derived evidence of whole farmlet and paddock responses to management and climate. | Animal Production Science |
| Dube and Pickup 2001 | Effects of rainfall variability and communal and semi-commercial grazing on land cover in southern African rangelands. | Climate Research |
| Dusseux et al. 2011 | Identification of grazed and mown grasslands using a time series of high-spatial-resolution remote sensing images. | International Workshop on the Analysis of MultiTemporal Remote Sensing Images |
| Dusseux et al. 2012 | Contribution of radar images for grassland management identification. | SPIERS - Remote Sensing for Agriculture, Ecosystems, and Hydrology XIV |
| Dusseux et al. 2013 | Temporal kernels for the identification of grassland management using time series of high spatial resolution satellite images. | IEEE International Geoscience and Remote Sensing Symposium - IGARSS |
| Dusseux et al. 2014a | Combined use of multi-temporal optical and radar satellite images for grassland monitoring. | Remote Sensing |
| Dusseux et al. 2014b | Identification of grassland management practices from leaf area index time series. | Journal of Applied Remote Sensing |
| Dusseux et al. 2014c | Agricultural practices in grasslands detected by spatial remote sensing. | Environmental Monitoring and Assessment |
| Dusseux et al. 2015 | Evaluation of SPOT imagery for the estimation of grassland biomass. | International Journal of Applied Earth Observation and Geoinformation |
| Edirisinghe et al. 2011 | Quantitative mapping of pasture biomass using satellite imagery. | International Journal of Remote Sensing |
| Edirisinghe et al. 2012 | Spatio-temporal modelling of biomass of intensively grazed perennial dairy pastures using multispectral remote sensing. | International Journal of Applied Earth Observation and Geoinformation |
| Eisfelder et al. 2017 | Above-ground biomass estimation based on NPP time series - A novel approach for biomass estimation in semi-arid Kazakhstan. | Ecological Indicators |
| Estel et al. 2018 | Combining satellite data and agricultural statistics to map grassland management intensity in Europe. | Environmental Research Letters |
| Fan et al. 2010 | Assessment of effects of climate change and grazing activity on grassland yield in the Three Rivers Headwaters Region of Qinghai-Tibet Plateau, China. | Environmental Monitoring and Assessment |
| Feng and Zhao 2011 | Grazing intensity monitoring in Northern China steppe: Integrating CENTURY model and MODIS data. | Ecological Indicators |
| Author(s)            | Title                                                                                                            | Journal/Conference                                    |
|---------------------|------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|
| Feng et al. 2017    | Identifying the relative contributions of climate and grazing to both direction and magnitude of alpine grassland productivity dynamics from 1993 to 2011 on the Northern Tibetan Plateau. | Remote Sensing                                        |
| Fern et al. 2018    | Suitability of NDVI and OSAVI as estimators of green biomass and coverage in a semi-arid rangeland.                | Ecological Indicators                                  |
| Franke et al. 2012  | Assessment of grassland use intensity by remote sensing to support conservation schemes.                           | Journal for Nature Conservation                         |
| Franklin et al. 2010| Consequences of buffelgrass pasture development for primary productivity, perennial plant richness, and vegetation structure in the drylands of Sonora, Mexico. | Conservation Biology                                   |
| Friedl et al. 1994  | Estimating grassland biomass and leaf area index using ground and satellite data.                                 | International Journal of Remote Sensing               |
| Froliking et al. 2005| Interannual variability in North American grassland biomass/productivity detected by SeaWinds scatterometer backscatter. | Geophysical Research Letters                           |
| Fu et al. 2014      | An improved indicator of simulated grassland production based on MODIS NDVI and GPP data: A case study in the Sichuan province, China. | Ecological Indicators                                  |
| Gaffney et al. 2018 | Using APAR to predict aboveground plant productivity in semi-arid rangelands: spatial and temporal relationships differ. | Remote Sensing                                        |
| Gao et al. 2013a    | Using MODIS time series data to estimate aboveground biomass and its spatio-temporal variation in Inner Mongolia’s grassland between 2001 and 2011. | International Journal of Remote Sensing               |
| Gao et al. 2013b    | Effects of topography and human activity on the net primary productivity (NPP) of alpine grassland in northern Tibet from 1981 to 2004. | International Journal of Remote Sensing               |
| Gao et al. 2016a    | Changes in global grassland productivity during 1982 to 2011 attributable to climatic factors.                   | Remote Sensing                                        |
| Gao et al. 2016b    | Climatic change controls productivity variation in global grasslands.                                           | Scientific Reports                                     |
| Gao et al. 2017     | Aboveground net primary productivity of vegetation along a climate-related gradient in a Eurasian temperate grassland: spatiotemporal patterns and their relationships with climate factors. | Environmental Earth Sciences                           |
| Garioud et al. 2019 | Challenges in grassland mowing event detection with multimodal sentinel images.                                  | International Workshop on the Analysis of MultiTemporal Remote Sensing Images |
| Gomez-Gimenez et al. 2017 | Determination of grassland use intensity based on multi-temporal remote sensing data and ecological indicators. | Remote Sensing of Environment                          |
| Grant et al. 2012   | Quantifying biomass production on rangeland in southern Alberta using SPOT imagery.                               | Canadian Journal of Remote Sensing                    |
| Grant et al. 2015a | Satellite-based assessment of grassland yields. | The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences |
|--------------------|-------------------------------------------------|----------------------------------------------------------------------------------|
| Grant et al. 2015b | The use of radar images for detecting when grass is harvested and thereby improve grassland yield estimates. | Grassland Science in Europe |
| Griffiths et al. 2020 | Towards national-scale characterization of grassland use intensity from integrated Sentinel-2 and Landsat time series. | Remote Sensing of Environment |
| Gu et al. 2013 | Mapping grassland productivity with 250-m eMODIS NDVI and SSURGO database over the Greater Platte River Basin, USA. | Ecological Indicators |
| Gu and Wylie 2015 | Developing a 30-m grassland productivity estimation map for central Nebraska using 250-m MODIS and 30-m Landsat-8 observations. | Remote Sensing of Environment |
| Guerini et al. 2020 | Estimating natural grassland biomass by vegetation indices using Sentinel 2 remote sensing data. | International Journal of Remote Sensing |
| Guido et al. 2014 | Spatial and temporal variability in aboveground net primary production of Uruguayan grasslands | Rangeland Ecology & Management |
| Guo et al. 2000 | Biophysical and spectral characteristics of cool- and warm-season grasslands under three land management practices in Eastern Kansas. | Natural Resources Research |
| Guo et al. 2003 | Grasslands discriminant analysis using Landsat TM single and multitemporal data. | Photogrammetric Engineering & Remote Sensing |
| Guo et al. 2004 | Measuring spatial and vertical heterogeneity of grasslands using remote sensing techniques. | Journal of Environmental Informatics |
| Guo et al. 2012 | Spatial variations in aboveground net primary productivity along a climate gradient in Eurasian temperate grassland: effects of mean annual precipitation and its seasonal distribution. | Global Change Biology |
| Guo et al. 2019 | Remote sensing monitoring of green-up dates in the Xilingol grasslands of northern China and their correlations with meteorological factors. | International Journal of Remote Sensing |
| Hajj et al. 2014 | Irrigated grassland monitoring using a time series of TerraSAR-X and COSMO-SkyMed X-band SAR data. | Remote Sensing |
| Halabuk et al. 2015 | Towards detection of cutting in hay meadows by using of NDVI and EVI Time Series. | Remote Sensing |
| Hall et al. 2010 | Inventorying management status and plant species richness in semi-natural grasslands using high spatial resolution imagery. | Applied Vegetation Science |
| Authors                        | Title                                                                 | Journal                                                                 |
|-------------------------------|----------------------------------------------------------------------|------------------------------------------------------------------------|
| He et al. 2014                | Large-scale estimation and uncertainty analysis of gross primary production in Tibetan alpine grasslands. | Remote Sensing of Environment                                           |
| Hill et al. 2004              | Estimation of pasture growth rate in the south west of Western Australia from AVHRR NDVI and climate data. | International Journal of Remote Sensing                                  |
| Ikeda et al. 1999             | Estimation of aboveground grassland phytomass with a growth model using Landsat TM and climate data.     | Journal of Geophysical Research - Biogeoosciences                        |
| Irisarri et al. 2012          | Patterns and controls of above-ground net primary production in meadows of Patagonia: A remote sensing approach. | Journal of Vegetation Science                                            |
| Jackson and Prince 2016       | Degradation of net primary production in a semiarid rangeland.        | Remote Sensing of Environment                                           |
| Jansen et al. 2018            | The development of near real-time biomass and cover estimates for adaptive rangeland management using Landsat 7 and Landsat 8 surface reflectance products. | Remote Sensing                                                          |
| Jia et al. 2015               | Primary productivity and precipitation-use efficiency in temperate grassland in the Loess Plateau of China. | PLoS ONE                                                               |
| Jia et al. 2016               | Estimation and uncertainty analyses of grassland biomass in Northern China: comparison of multiple remote sensing data sources and modeling approaches. | Ecological Indicators                                                   |
| Jia et al. 2018               | Uncertainty in simulating regional gross primary productivity from satellite-based models over northern China grassland. | Ecological Indicators                                                   |
| Jiang et al. 2015             | The spatial pattern of grassland aboveground biomass on Xizang Plateau and its climatic controls. | Journal of Plant Ecology                                               |
| Jialong et al. 1998           | Estimating grassland yields using remote sensing and GIS technologies in China. | New Zealand Journal of Agricultural Research                            |
| Jin et al. 2014               | Remote sensing-based biomass estimation and its spatio-temporal variations in temperate grassland, Northern China. | Remote Sensing                                                          |
| Jin et al. 2019               | Grassland production in response to changes in biological metrics over the Tibetan Plateau. | Science of the Total Environment                                        |
| Jobbagy et al. 2002           | Patterns and controls of primary production in the patagonian steppe: a remote sensing approach. | Ecology                                                                |
| John et al. 2018              | Grassland canopy cover and aboveground biomass in Mongolia and Inner Mongolia: Spatiotemporal estimates and controlling factors. | Remote Sensing of Environment                                           |
| Justice and Hiernaux 1986     | Monitoring the grasslands of the Sahel using NOAA AVHRR data: Niger 1983. | International Journal of Remote Sensing                                |
| Author(s)            | Year    | Title                                                                                     | Journal                                                                 |
|---------------------|---------|-------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|
| Kath et al.         | 2019    | Remotely sensed agricultural grassland productivity responses to land use and hydro-climatic drivers under extreme drought and rainfall. | Agricultural and Forest Meteorology                                      |
| Kawamura et al.     | 2005a   | Quantifying grazing intensities using geographic information systems and satellite remote sensing in the Xilingol steppe region, Inner Mongolia, China. | Agriculture, Ecosystems & Environment                                      |
| Kawamura et al.     | 2005b   | Comparing MODIS vegetation indices with AVHRR NDVI for monitoring the forage quantity and quality in Inner Mongolia grassland, China. | Grassland Science                                                        |
| Kogan et al.        | 2004    | Derivation of pasture biomass in Mongolia from AVHRR-based vegetation health indices.     | International Journal of Remote Sensing                                  |
| Kolecka et al.      | 2018    | Regional scale mapping of grassland mowing frequency with Sentinel-2 time series.         | Remote Sensing                                                           |
| Kurtz et al.        | 2010    | Ground and satellite based assessment of rangeland management in sub-tropical Argentina. | Applied Geography                                                        |
| Leimgruber et al.   | 2001    | Spatial patterns in relative primary productivity and gazelle migration in the Eastern Steppes of Mongolia. | Biological Conservation                                                  |
| Li et al.           | 1998    | Estimating grassland yields using remote sensing and GIS technologies in China.          | New Zealand Journal of Agricultural Research                              |
| Li et al.           | 2005    | Establishing grassland yield models using projection pursuit regression method.           | New Zealand Journal of Agricultural Research                              |
| Li et al.           | 2013a   | Monitoring and modeling spatial and temporal patterns of grassland dynamics using time-series MODIS NDVI with climate and stocking data. | Remote Sensing of Environment                                             |
| Li et al.           | 2013b   | Estimating grassland aboveground biomass using multitemporal MODIS data in the West Songnen Plain, China. | Journal of Applied Remote Sensing                                         |
| Li et al.           | 2013c   | A method for estimating the gross primary production of alpine meadows using MODIS and climate data in China. | International Journal of Remote Sensing                                  |
| Li et al.           | 2015    | Influence of meadow changes on net primary productivity: a case study in a typical steppe area of XilinGol of Inner Mongolia in China. | Geosciences Journal                                                      |
| Li et al.           | 2016a   | Mapping grazing intensity using remote sensing in the Xilingol steppe region, Inner Mongolia, China. | Remote Sensing Letters                                                   |
| Li et al.           | 2016b   | Modeling grassland aboveground biomass using a pure vegetation index.                    | Ecological Indicators                                                    |
| Li et al.           | 2018    | Renewed estimates of grassland aboveground biomass showing drought impacts.              | Journal of Geophysical Research - Biogeosciences                          |
| Li et al.           | 2019a   | Spatial and temporal variations in grassland production from 2006 to 2015 in Mongolia along the China-Mongolia railway. | Sustainability                                                           |
| Authors         | Title                                                                 | Journal                                      |
|-----------------|----------------------------------------------------------------------|----------------------------------------------|
| Li et al. 2019b | Spatial variation of human influences on grassland biomass on the Qinghai-Tibetan plateau. | Science of The Total Environment             |
| Li et al. 2019c | Temporal variability of precipitation and biomass of alpine grasslands on the Northern Tibetan Plateau. | Remote Sensing                               |
| Liang et al. 2009 | Remotely sensed dynamics monitoring of grassland aboveground biomass and carrying capacity during 2001-2008 in Gannan pastoral area. | Acta Prataculturae Sinica                    |
| Liang et al. 2016 | Multi-factor modeling of above-ground biomass in alpine grassland: a case study in the Three-River Headwaters Region, China. | Remote Sensing of Environment                |
| Liu et al. 2004 | Assessment of grassland degradation near Lake Qinghai, West China, using Landsat TM and in situ reflectance spectra data. | International Journal of Remote Sensing     |
| Liu et al. 2015 | Modeling aboveground biomass of an alpine desert grassland with SPOT-VGT NDVI. | GScience & Remote Sensing                    |
| Liu et al. 2017 | Spatiotemporal dynamics of grassland aboveground biomass on the Qinghai-Tibetan Plateau based on validated MODIS NDVI. | Scientific Reports                           |
| Liu et al. 2019 | Estimating rangeland forage production using remote sensing data from a small Unmanned Aerial System (sUAS) and PlanetScope satellite. | Remote Sensing                               |
| Lopes et al. 2017 | Object-based classification of grasslands from high resolution satellite image time series using gaussian mean map kernels. | Remote Sensing                               |
| Luo et al. 2014 | Responses of grass production to precipitation in a mid-latitude typical steppe watershed. | Transactions of the ASABE                   |
| Ma et al. 2019  | Quantifying grazing intensity using remote sensing in alpine meadows on Qinghai-Tibetan Plateau. | Sustainability                               |
| Magiera et al. 2017 | Modelling biomass of mountainous grasslands by including a species composition map. | Ecological Indicators                        |
| Malss et al. 2018 | The use of radar satellite images for the detection of cutting frequency of grassland. | Grassland Science in Europe                 |
| Mao et al. 2014 | Spatiotemporal dynamics of grassland aboveground net primary productivity and its association with climatic pattern and changes in Northern China. | Ecological Indicators                        |
| Marsett et al. 2006 | Remote Sensing for grassland management in the arid southwest. | Rangeland Ecology & Management               |
| Maselli et al. 2013 | Simulation of grassland productivity by the combination of ground and satellite data. | Agriculture, Ecosystems & Environment        |
| Medina et al. 2009 | Use of satellite images to assess forage production in the rangelands of Zacatecas. | Tecnica Pecuria en Mexico                   |
| Meng et al. 2017 | Evaluation of remote sensing inversion error for the above-ground biomass of alpine meadow grassland based on multi-source satellite data. | Remote Sensing                               |
| Authors                  | Title                                                                 | Journal                                      |
|-------------------------|----------------------------------------------------------------------|----------------------------------------------|
| Moreau et al. 2003      | Assessing the biomass dynamics of Andean bofedal and totora high-protein wetland grasses from NOAA/AVHRR. | Remote Sensing of Environment                |
| Munyati and Makgale 2009| Multitemporal Landsat TM imagery analysis for mapping and quantifying degraded rangeland in the Bahurutshe communal grazing lands, South Africa. | International Journal of Remote Sensing     |
| Na et al. 2018          | Effects of different grazing systems on aboveground biomass and plant species dominance in typical Chinese and Mongolian steppes. | Sustainability                               |
| Numata et al. 2007      | Characterization of pasture biophysical properties and the impact of grazing intensity using remotely sensed data. | Remote Sensing of Environment                |
| Otgonbayar et al. 2019  | Mapping pasture biomass in Mongolia using Partial Least Squares, Random Forest regression and Landsat 8 imagery. | International Journal of Remote Sensing     |
| Palmer et al. 2010      | Biomass production and water use efficiency of grassland in KwaZulu-Natal, South Africa. | African Journal of Range and Forage Science |
| Paruelo et al. 1997     | ANPP estimates from NDVI for the central grassland region of the United States. | Ecology                                      |
| Paruelo et al. 2000     | Estimation of primary production of subhumid rangelands from remote sensing data. | Applied Vegetation Science                  |
| Paudel and Anderson 2010| Assessing rangeland degradation using multi temporal satellite images and grazing pressure surface model in Upper Mustang, Trans Himalaya, Nepal. | Remote Sensing of Environment                |
| Piao et al. 2007        | Changes in biomass carbon stocks in China's grasslands between 1982 and 1999. | Global Biogeochemical Cycles                |
| Pineiro et al. 2006     | Seasonal variation in aboveground production and radiation-use efficiency of temperate rangelands estimated through remote sensing. | Ecosystems                                   |
| Porter et al. 2014      | Estimating biomass on CRP pastureland: A comparison of remote sensing techniques. | Biomass & Bioenergy                          |
| Potter 2014             | Monitoring the production of Central California coastal rangelands using satellite remote sensing. | Journal of Coastal Conservation              |
| Price et al. 2002a      | Optimal Landsat TM band combinations and vegetation indices for discrimination of six grassland types in eastern Kansas. | International Journal of Remote Sensing     |
| Price et al. 2002b      | Comparison of Landsat TM and ERS-2 SAR data for discriminating among grassland types and treatments in eastern Kansas. | Computers and Electronics in Agriculture     |
| Prince 1991             | Satellite remote sensing of primary production: comparison of results for Sahelian grasslands 1981-1988. | International Journal of Remote Sensing     |
| Propastin et al. 2011   | Modified light use efficiency model for assessment of carbon sequestration in grasslands of Kazakhstan: combining ground biomass data and remote-sensing. | International Journal of Remote Sensing     |
| Lastname   | Year     | Title                                                                 | Journal                                    |
|------------|----------|----------------------------------------------------------------------|--------------------------------------------|
| Punalekar  | 2018     | Application of Sentinel-2A data for pasture biomass monitoring using   | Remote Sensing of Environment              |
|            |          | a physically based radiative transfer model.                         |                                            |
| Qamer      | 2016     | An assessment of productivity patterns of grass-dominated rangelands  | Sustainability                            |
|            |          | in the Hindu Kush Karakoram region, Pakistan.                        |                                            |
| Quan       | 2017     | A radiative transfer model-based method for the estimation of grassland | International Journal of Applied Earth    |
|            |          | aboveground biomass.                                                 | Observation and Geoinformation             |
| Raab       | 2020     | Target-oriented habitat and wildlife management: estimating forage    | Remote Sensing in Ecology and Conservation  |
|            |          | quantity and quality of semi-natural grasslands with Sentinel-1 and   |                                            |
|            |          | Sentinel-2 data.                                                     |                                            |
| Ramoelo    | 2015     | Monitoring grass nutrients and biomass as indicators of rangeland     | International Journal of Applied Earth     |
|            |          | quality and quantity using random forest modelling and WorldView-2   | Observation and Geoinformation             |
|            |          | data.                                                                |                                            |
| Reeves     | 2001     | Mapping weekly rangeland vegetation productivity using MODIS         | Journal of Range Management                |
|            |          | algorithms.                                                          |                                            |
| Reeves     | 2006     | Applying improved estimates of MODIS productivity to characterize    | Rangeland Ecology & Management             |
| and Baggett| 2014     | A remote sensing protocol for identifying rangelands with degraded   | Ecological Indicators                      |
|            |          | productive capacity.                                                 |                                            |
| Reinfelds  | 2011     | Monitoring and Assessment of Surface Water Abstractions for Pasture  | Water Resources Management                 |
|            |          | Irrigation from Landsat Imagery: Bega-Bemboka River, NSW, Australia. |                                            |
| Ren        | 2015     | Are soil-adjusted vegetation indices better than soil-unadjusted      | Grass and Forage Science                   |
| and Feng   |          | vegetation indices for above-ground green biomass estimation in      |                                            |
|            |          | arid and semi-arid grasslands?                                        |                                            |
| Ricotta    | 2003     | The role of C3 and C4 grasses to interannual variability in remotely  | International Journal of Remote Sensing    |
|            |          | sensed ecosystem performance over the US Great Plains.               |                                            |
| Robinson   | 2014     | Mapping the global distribution of livestock.                         | PLoS ONE                                  |
|            | 2019     | Rangeland productivity partitioned to sub-pixel plant functional      | Remote Sensing                            |
|            |          | types.                                                               |                                            |
| Roeder     | 2008     | Trend analysis of Landsat-TM and -ETM+ imagery to monitor grazing    | Remote Sensing of Environment              |
|            |          | impact in a rangeland ecosystem in Northern Greece.                  |                                            |
| Rossi      | 2018     | Optical responses on multiple spatial scales for assessing vegetation  | IEEE International Geoscience and Remote    |
|            |          | dynamics- a case study for alpine grasslands.                        | Sensing Symposium                         |
| Rossi      | 2019     | A comparison of the signal from diverse optical sensors for          | Remote Sensing                            |
|            |          | monitoring alpine grassland dynamics.                                 |                                            |
| Rossini    | 2012     | Remote sensing-based estimation of gross primary production in a     | Biogeosciences                            |
|            |          | subalpine grassland.                                                 |                                            |
| Roumiguie et al. 2017 | Insuring forage through satellites: testing alternative indices against grassland production estimates for France. | International Journal of Remote Sensing |
|---------------------|--------------------------------------------------------------------------------------------------|-------------------------------------------|
| Rufin et al. 2015   | Land use intensity trajectories on Amazonian pastures derived from Landsat time series. | International Journal of Applied Earth Observation and Geoinformation |
| Sankey et al. 2009  | Geospatial assessment of grazing regime shifts and sociopolitical changes in a Mongolian rangeland. | Rangeland Ecology & Management |
| Schucknecht et al. 2017 | Phenology-based biomass estimation to support rangeland management in semi-arid environments. | Remote Sensing |
| Schuster et al. 2015 | Towards detecting swath events in TerraSAR-X time series to establish NATURA 2000 grassland habitat swath management as monitoring parameter. | Remote Sensing |
| Schuster et al. 2015 | Grassland habitat mapping by intra-annual time series analysis - comparison of RapidEye and TerraSAR-X satellite data. | International Journal of Applied Earth Observation and Geoinformation |
| Seaquist et al. 2003 | A remote sensing-based primary production model for grassland biomes. | Ecological Modelling |
| Si et al. 2012      | Mapping spatio-temporal variation of grassland quantity and quality using MERIS data and the PROSAIL model. | Remote Sensing of Environment |
| Sibanda et al. 2016 | Comparing the spectral settings of the new generation broad and narrow band sensors in estimating biomass of native grasses grown under different management practices. | GIScience & Remote Sensing |
| Sibanda et al. 2017 | Testing the capabilities of the new WorldView-3 space-borne sensor’s red-edge spectral band in discriminating and mapping complex grassland management treatments. | International Journal of Remote Sensing |
| Siegmund et al. 2016 | Satellite-based monitoring of grassland: assessment of harvest dates and frequency using SAR. | Remote Sensing for Agriculture, Ecosystems, and Hydrology XVIII |
| Siegmund et al. 2019 | Grassland monitoring based on Sentinel-1. | Remote Sensing for Agriculture, Ecosystems, and Hydrology XVIII |
| Silverman et al. 2019 | Low-tech riparian and wet meadow restoration increases vegetation productivity and resilience across semiarid rangelands. | Restoration Ecology |
| Skinner et al. 2011 | Impact of sward properties on the predictability of forage quality and yield in grassland using remote sensing. | Agronomy Journal |
| Smit et al. 2008    | Spatial distribution of grassland productivity and land use in Europe. | Agricultural Systems |
| Smith et al. 2011   | Near real-time Feed On Offer (FOO) from MODIS for early season grazing management of Mediterranean annual pastures. | International Journal of Remote Sensing |
| Name et al. (Year) | Title | Details |
|-------------------|-------|---------|
| Stendardi et al. 2019 | Exploiting time series of Sentinel-1 and Sentinel-2 imagery to detect meadow phenology in mountain regions. | Remote Sensing |
| Stumpf et al. 2020 | Spatial monitoring of grassland management using multi-temporal satellite imagery. | Ecological Indicators |
| Sun et al. 2013 | Evaluation of net primary productivity and its spatial and temporal patterns in southern China’s grasslands. | Rangeland Journal |
| Sun et al. 2017 | Grassland degradation and restoration monitoring and driving forces analysis based on long time-series remote sensing data in Xilin Gol League. | Acta Ecologica Sinica |
| Tamm et al. 2016 | Relating Sentinel-1 interferometric coherence to mowing events on grasslands. | Remote Sensing |
| Tan et al. 2010 | Application of the ORCHIDEE global vegetation model to evaluate biomass and soil carbon stocks of Qinghai-Tibetan grasslands. | Global Biogeochemical Cycles |
| Tang et al. 2014 | Simulating spatiotemporal dynamics of Sichuan grassland net primary productivity using the CASA model and in situ observations. | Scientific World Journal |
| Taravat et al. 2019 | Automatic grassland cutting status detection in the context of spatiotemporal Sentinel-1 imagery analysis and artificial neural networks. | Remote Sensing |
| Tieszen et al. 1997 | NDVI, C-3 and C-4 production, and distributions in great plains grassland land cover classes. | Ecological Applications |
| Tiscornia et al. 2019 | Can we monitor height of native grasslands in Uruguay with earth observation? | Remote Sensing |
| Todd et al. 1998 | Monitoring the impact of grazing on rangeland conservation easements using MODIS vegetation indices. | Rangeland Ecology & Management |
| Vescovo and Gianelle 2008 | Using the MIR bands in vegetation indices for the estimation of grassland biophysical parameters from satellite remote sensing in the Alps region of Trentino (Italy). | Advances in Space Research |
| Voormansik et al. 2013 | Towards a detection of grassland cutting practices with dual polarimetric TerraSAR-X data. | International Journal of Remote Sensing |
| Authors                  | Title                                                                 | Journal                                      |
|-------------------------|----------------------------------------------------------------------|----------------------------------------------|
| Voormansik et al. 2015  | Observations of cutting practices in agricultural grasslands using polarimetric SAR. | IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing |
| Wang et al. 2008        | Relations between NDVI, grassland production, and crop yield in the Central Great Plains. | Geocarto International                       |
| Wang et al. 2010        | Modeling gross primary production of maize cropland and degraded grassland in northeastern China. | Agricultural and Forest Meteorology          |
| Wang et al. 2016        | Simulation of the grazing effects on grassland aboveground net primary production using DNDC model combined with time-series remote sensing data - a case study in Zoige Plateau, China. | Remote Sensing                               |
| Wang et al. 2017        | Prediction of aboveground grassland biomass on the Loess Plateau, China, using a random forest algorithm. | Scientific Reports                           |
| Wang et al. 2019a       | Assessing the impacts of drought on grassland net primary production at the global scale. | Scientific Reports                           |
| Wang et al. 2019b       | Multi-satellite analyses of spatiotemporal variability in photosynthetic activity over the Tibetan Plateau. | Journal of Geophysical Research - Biogeosciences |
| Wang et al. 2019c       | Modelling above-ground biomass based on vegetation indexes: a modified approach for biomass estimation in semi-arid grasslands. | International Journal of Remote Sensing     |
| Wang et al. 2019d       | Estimating leaf area index and aboveground biomass of grazing pastures using Sentinel-1, Sentinel-2 and Landsat images. | ISPRS Journal of Photogrammetry and Remote Sensing |
| Wang et al. 2020        | Detecting intra- and inter-annual variability in gross primary productivity of a North American grassland using MODIS MAIAC data. | Agricultural and Forest Meteorology          |
| Wehlage et al. 2016     | Interannual variability in dry mixed-grass prairie yield: a comparison of MODIS, SPOT, and field measurements. | Remote Sensing                               |
| Wei et al. 2019         | Driving mechanism of gross primary production changes and implications for grassland management on the Tibetan Plateau. | Journal of Resources and Ecology             |
| Wu et al. 2008          | Modeling gross primary production of a temperate grassland ecosystem in Inner Mongolia, China, using MODIS imagery and climate data. | Science in China Series D - Earth Sciences  |
| Wu 2012                 | Use of a vegetation index model to estimate gross primary production in open grassland. | Journal of Applied Remote Sensing            |
| Wu et al. 2014          | Climate changes during the past 31 years and their contribution to the changes in the productivity of rangeland vegetation in the Inner Mongolian typical steppe. | Rangeland Journal                            |
| Wylie et al. 1991       | Satellite and ground-based pasture production assessment in Niger: 1986 – 1988. | International Journal of Remote Sensing     |
| Year       | Title                                                                                   | Journal                               |
|------------|-----------------------------------------------------------------------------------------|---------------------------------------|
| 2002       | Satellite mapping of surface biophysical parameters at the biome scale over the North American grasslands: a case study. | Remote Sensing of Environment         |
| 2016       | Grassland and cropland net ecosystem production of the U.S. Great Plains: regression tree model development and comparative analysis. | Remote Sensing                        |
| 2014       | Spatio-temporal patterns and climate variables controlling of biomass carbon stock of global grassland ecosystems from 1982 to 2006. | Remote Sensing                        |
| 2009       | A comparison of two models with Landsat data for estimating above ground grassland biomass in Inner Mongolia, China. | Ecological Modelling                  |
| 2014       | Spatio-temporal patterns and climate variables controlling of biomass carbon stock of global grassland ecosystems from 1982 to 2006. | Remote Sensing                        |
| 2009       | A comparison of two models with Landsat data for estimating above ground grassland biomass in Inner Mongolia, China. | Ecological Modelling                  |
| 2010       | Simulating net primary production of grasslands in northeastern Asia using MODIS data from 2000 to 2005. | Journal of Geographical Sciences      |
| 2019       | Monitoring the impact of climate change and human activities on grassland vegetation dynamics in the northeastern Qinghai-Tibet Plateau of China during 2000-2015. | Journal of Arid Land                  |
| 2007       | Remote sensing monitoring upon the grass production in China. | Acta Ecologica Sinica                |
| 2008       | MODIS-based remote sensing monitoring of grass production in China. | International Journal of Remote Sensing |
| 2013       | MODIS-based remote-sensing monitoring of the spatiotemporal patterns of China’s grassland vegetation growth. | International Journal of Remote Sensing |
| 2016       | Alpine grasslands response to climatic factors and anthropogenic activities on the Tibetan Plateau from 2000 to 2012. | Ecological Engineering                |
| 2018       | Quantifying the influences of grazing, climate and their interactions on grasslands using Landsat TM images. | Grassland Science                     |
| 2019       | Quantitative monitoring of grazing intensity in the temperate meadow steppe based on remote sensing data. | International Journal of Remote Sensing |
| 1998       | An analysis of relationships among climate forcing and time-integrated NDVI of grasslands over the U.S. Northern and Central Great Plains. | Remote Sensing of Environment         |
| 2009       | Aboveground biomass in Tibetan grasslands. | Journal of Arid Environments         |
| 2012       | Assessing light to moderate grazing effects on grassland production using satellite imagery. | International Journal of Remote Sensing |
| 2015       | Remote sensing monitoring of grassland vegetation growth in the Beijing-Tianjin sandstorm source project area from 2000 to 2010. | Ecological Indicators                 |
| 2017       | Satellite-based estimation of net primary productivity for southern China’s grasslands from 1982 to 2012. | Climate Research                     |
| Authors          | Title                                                                 | Journal                                                                 |
|------------------|----------------------------------------------------------------------|-------------------------------------------------------------------------|
| Yang et al. 2018 | Modeling grassland above-ground biomass based on artificial neural network and remote sensing in the Three-River Headwaters Region. | Remote Sensing of Environment                                            |
| Yin et al. 2014  | The impacts of climate change and human activities on grassland productivity in Qinghai Province, China. | Frontiers of Earth Science                                               |
| Yin et al. 2018  | Seamless upscaling of the field-measured grassland aboveground biomass based on gaussian process regression and gap-filled Landsat 8 OLI reflectance. | ISPRS International Journal of Geo-Information                          |
| You et al. 2019  | Improved modeling of gross primary productivity of alpine grasslands on the Tibetan Plateau using the Biome-BGC model. | Remote Sensing                                                          |
| Yu et al. 2010   | Using remote sensing and GIS technologies to estimate grass yield and livestock carrying capacity of alpine grasslands in Golog Prefecture, China. | Pedosphere                                                              |
| Yu et al. 2018   | Quantifying grazing patterns using a new growth function based on MODIS Leaf Area Index. | Remote Sensing of Environment                                            |
| Yu et al. 2019   | Using Landsat OLI and random forest to assess grassland degradation with aboveground net primary production and electrical conductivity data. | ISPRS International Journal of Geo-Information                          |
| Zalite et al. 2014 | Towards detecting mowing of agricultural grasslands from multi-temporal COSMO-SkyMed data. | IEEE Geoscience and Remote Sensing Symposium                             |
| Zalite et al. 2015 | Monitoring of agricultural grasslands with time series of X-band repeat-pass interferometric SAR. | IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing |
| Zeng et al. 2019 | Estimating grassland aboveground biomass on the Tibetan Plateau using a random forest algorithm. | Ecological Indicators                                                   |
| Zhang et al. 2014a | Net ecosystem productivity of temperate grasslands in northern China: an upscaling study. | Agricultural and Forest Meteorology                                      |
| Zhang et al. 2014b | Spatial and temporal variability in the net primary production of alpine grassland on the Tibetan Plateau since 1982. | Journal of Geographical Sciences                                         |
| Zhang et al. 2016 | Application of synthetic NDVI time series blended from Landsat and MODIS data for grassland biomass estimation. | Remote Sensing                                                          |
| Zhang et al. 2017 | Empirical and model-based estimates of spatial and temporal variations in net primary productivity in semi-arid grasslands of northern China. | PLoS ONE                                                                |
| Zhang et al. 2018 | Spatial and temporal variability of grassland yield and its response to climate change and anthropogenic activities on the Tibetan Plateau from 1988 to 2013. | Ecological Indicators                                                   |
| Zhao et al. 2014  | Remote sensing estimates of grassland aboveground biomass based on MODIS net primary productivity (NPP): a case study in the Xilingol grassland of northern China. | Remote Sensing                                                          |
| Authors | Title                                                                 | Journal                                           |
|--------|----------------------------------------------------------------------|---------------------------------------------------|
| Zhao et al. 2019 | Modelling and analysis of net primary productivity and its response mechanism to climate factors in temperate grassland, northern China. | International Journal of Remote Sensing          |
| Zheng et al. 2019 | Seasonally and spatially varied controls of climatic factors on net primary productivity in alpine grasslands on the Tibetan Plateau. | Global Ecology and Conservation                    |
| Zheng et al. 2020 | Seasonally and spatially varied controls of climatic factors on net primary productivity in alpine grasslands on the Tibetan Plateau. | Global Ecology and Conservation                    |
| Zhou et al. 2014a | Effects of ecological restoration-induced land-use change and improved management on grassland net primary productivity in the Shiyanghe River Basin, north-west China. | Grass and Forage Science                          |
| Zhou et al. 2014b | A comparison of satellite-derived vegetation indices for approximating gross primary productivity of grasslands. | Rangeland Ecology & Management                     |
| Zhou et al. 2017a | Grassland degradation remote sensing monitoring and driving factors quantitative assessment in China from 1982 to 2010. | Ecological Indicators                             |
| Zhou et al. 2017b | Examining the short-term impacts of diverse management practices on plant phenology and carbon fluxes of Old World bluestems pasture. | Agricultural and Forest Meteorology                |
| Zhu et al. 2019  | Assessing the spatiotemporal dynamic of NPP in desert steppe and its response to climate change from 2003 to 2017: a case study in Siziwang banner. | Remote Sensing for Agriculture, Ecosystems, and Hydrology XXI |