Importance of grassland monitoring in European perspective of climate change – FINEGRASS project

Katarzyna Dabrowska-Zielinska
Institute of Geodesy and Cartography, 27 Modzelewskiego St., 02-679, Warsaw, Poland
Tel.: +48 22 3291974, Fax: +48 22 3291950, E-mail: katarzyna.dabrowska-zielinska@igik.edu.pl

Piotr Golinski
Poznan University of Life Sciences, Department of Grassland and Natural Landscape Sciences, 11 Dojazd St., 60-632 Poznan, Poland
Tel.: +48 61 8487414, Fax: +48 61 8487612, E-mail: pgolinsk@up.poznan.pl

Marit Jørgensen
Norwegian Institute of Bioeconomy Research - NIBIO, Holt, Tromsø, P.O. Box 115, NO-1431 Ås Norway
Tel.: +47 928 67101, E-mail: marit.jorgensen@nibio.no

Jorgen Mølmann
Norwegian Institute of Bioeconomy Research - NIBIO, Holt, Tromsø, P.O. Box 115, NO-1431 Ås Norway
Tel.: +47 928 67101, E-mail: jorgen.molmann@nibio.no

Gregory Taff
Norwegian Institute of Bioeconomy Research - NIBIO, Holt, Tromsø, P.O. Box 115, NO-1431 Ås Norway
Tel.: +47 928 67101, E-mail: gregory.taff@nibio.no

Stanisław Twardy
Institute of Technology and Life Sciences, Malopolska Research Centre, 21B Ulanow St., 31-450 Krakow, Poland
Tel.: +48 12 4128459, E-mail: itepkrak@itep.edu.pl

Maria Budzynska
Institute of Geodesy and Cartography, 27 Modzelewskiego St., 02-679, Warsaw, Poland
Tel.: +48 22 3291974, Fax: +48 22 3291992, E-mail: maria.budzynska@igik.edu.pl

Marek Czerwinski
Poznan University of Life Sciences, Department of Grassland and Natural Landscape Sciences, 11 Dojazd St., 60-632 Poznan, Poland
Tel.: +48 618487513, E-mail: marek.czerwinski@up.poznan.pl

Marek Kopacz
Institute of Technology and Life Sciences, Malopolska Research Centre, 21B Ulanow St., 31-450 Krakow, Poland
Tel.: 12 4128459 E-mail: m.kopacz@itep.edu.pl

Robert Kurnicki
Institute of Technology and Life Sciences, Malopolska Research Centre, 21B Ulanow St., 31-450 Krakow, Poland
Tel.: 12 4128459, E-mail: itepkrak@itep.edu.pl

Wanda Kowalik
Institute of Geodesy and Cartography, 27 Modzelewskiego St., 02-679, Warsaw, Poland
Tel.: +48 22 3291974, Fax: +48 22 3291978, E-mail: wanda.kowalik@igik.edu.pl

Monika Tomaszewska
Institute of Geodesy and Cartography, 27 Modzelewskiego St., 02-679, Warsaw, Poland
Tel.: +48 22 3291974, Fax: +48 22 3291978, E-mail: monika.tomaszewska@igik.edu.pl

Alicja Malinska
Institute of Geodesy and Cartography, 27 Modzelewskiego St., 02-679, Warsaw, Poland
Tel.: +48 22 3291974, Fax: +48 22 3291977, E-mail: alicja.malinska @igik.edu.pl

Barbara Golinska
Poznan University of Life Sciences, Department of Grassland and Natural Landscape Sciences, 11 Dojazd St., 60-632 Poznan, Poland
Tel.: +48 61 8487586, E-mail: bgolinsk@up.poznan.pl

Martyna Gatkowska
Institute of Geodesy and Cartography, 27 Modzelewskiego St., 02-679, Warsaw, Poland
Tel.: +48 22 3291974, Fax: +48 22 3291975, E-mail: martyna.gatkowska@igik.edu.pl

K. Dabrowska-Zielinska, P. Golinski, M. Jørgensen,
J. Mølmann, G. Taff, S. Twardy, M. Budzynska,
M. Czerwinski, M. Kopacz, R. Kurnicki, W. Kowalik,
M. Tomaszewska, A. Malinska, B. Golinska, M. Gatkowska

Abstract: The objective of the study was an assessment of the effect of climatic changes on grassland growth, its water conditions and biomass. Forecasting the grassland biomass and indicating the influence of climate on grasslands growth could be an important tool in grassland management on the national, regional and field grassland scales. Remote sensing gives the possibility to estimate the grassland growth conditions what have been achieved applying NOAA.AVHRR and Terra.MODIS. Identification of grasslands throughout the country have been done using Corine Land Cover (CLC) database. Vegetation index (NDVI) and surface temperature (Ts) have been calculated from satellite data. Meteorological data for Poland have been collected: i) for years 1997–2015, ii) for the period 1985–2014 to find the trends of climatic changes. There have been found: significant trends in air temperature (Ta) in NUTS1 in Poland; significant trend of increasing grassland surface temperature (Ts) in Poland based on satellite data; comparable results between Ts – Ts_mean and Ta – Ta_mean for the years 1997–2015; significant positive relationship between the (April-September) standardized precipitation evapotranspiration index (SPEI) and grass yields in Poland. In Norway, a trend towards earlier growth start in spring and increasing temperature sum in the growing season for the last ten years have been found, however, with large variation between years. Also, trends towards warmer springs and autumns since 1991 in Northern Norway has been observed. Climate changes may affect positively and negatively the grassland productivity. Proposed new and efficient methods based on satellite observations, can be used to monitor the productivity of grasslands to understand trends and anomalies that are likely to continue into the future, can help in planning for agricultural practices, can be an efficient tool in decision support system of grassland management and offsetting financial risks on large scales.

Keywords: grassland, biomass, NDVI, Ts, Ta, precipitation, SPEI, climate change

1. Introduction

Grasslands are one of the most important components of the environment and a significant part of European terrestrial ecosystems. They serve many important functions and ecosystem services. Among them are: providing cheap natural fodder for livestock, production of oxygen, mitigation of soil erosion, hampering mineralisation of peat-forming processes, flood control in the valleys, water retention particularly in organic soils, absorption of excess nutrients and preventing environmental pollution. Grasslands serve as habitat for many plants and animals species, for recreation, but also are important for European open landscapes, they are the source of biodiversity and space of human activity. Low intensity agricultural habitats are one of the most valuable sources of biodiversity in Europe (Bignal and Mc Cracken, 1996). Abandoned grasslands are in the undesirable processes of degradation and conversion into forest ecosystem, which again may decrease albedo and thus enhance global warming. However, grasslands ecosystems are un-

der threat and big pressure and their stability is in danger (Soer, 2015). European grasslands area has been reduced during the last years as a result of intensification of animal production, decrease in cattle and other ruminants population, use of concentrates and soybean in the feed rations, abandonment of use, and the effect of EU-policy (Huyghe et al., 2014). Grasslands lost their importance turning into energy crops as bioenergy. Permanent and temporary grasslands cover 33% and 6%, respectively, of the total agriculture areas in Europe and the area vary between countries. Grasslands productivity is affected by several factors as soil characteristics, climate: amount of rainfall and temperature, latitude, altitude and management. Grasslands contain a substantial amount of the world's soil organic carbon. Integrating data on grassland areas (FAOSTAT, 2009) and grassland soil carbon stocks (Sombroek et al., 1993) results in a global estimate of about 343 billion tonnes of C – nearly 50 percent more than is stored in forests worldwide (FAO, 2007). Just as in the case of forest biomass carbon stocks, grassland soil carbon stocks are susceptible

to loss upon conversion to other land uses (Paustian et al., 1997) or following activities that lead to grassland degradation (e.g. overgrazing). Current rates of carbon loss from grassland systems are not well quantified. During the high temperatures in 2003 and 2006, the carbon sequestration decreased substantially in grasslands in Central and Southern Europe, due to reductions in photosynthetic uptake resulting from drought stress (O'Mara, 2012).

Climate change influences grassland productivity throughout Europe (Sousanna et al., 2014). The extremes of the weather in winter, often lack of snow cover together with low temperatures as well as often occurrence of the increased air temperatures early in spring, cause shifts in phenology and disturbance in water balance of the grasslands areas, which influence the sward dry matter yield. Also lack of precipitation and increase of temperature later in spring and summer cause diminishing of moisture causing changing water conditions in some of the areas.

Monitoring of grassland to assess changes in the condition over time has been the subject of a lot of research at different scales. Initially the techniques focused on field-based measurements, but with the increase in availability of remote sensing products and tools, there is an expectation that remote sensing would provide rapid and definite answers to the challenges of detecting and monitoring grassland conditions and associated changes in productivity.

Analyzing the changes in grasslands in the area and productivity influenced by climate change is very important. Monitoring of grassland in global, biogeographical, country, regional and local scales should focus on grasslands types, areas, distribution, productivity and nutrient balances. In the collection of data focusing on grassland resources, monitoring of plant communities is included. The collected information is needed for objectives concerning different domains, both statistical, administrative, scientific and other. For example, monitoring of grassland in European Union is necessary for targeting, monitoring and evaluation of Common Agricultural Policy (Souchere et al., 2003), environmental issues like agri-environmental schemes, climate mitigation targets, High Nature Value Farmland, Habitats Directive and Nitrates Directive. Properly managed grasslands should give hay yields in the range of 60–100 and green forage yields

equal to 400 dt per ha. However, in Poland there is no intensive agricultural system of cultivation, what resulted in low agricultural productivity, and therefore the mean yield of grasslands is much lower than in the majority of the EU countries.

The development of methods for grassland monitoring and examination of the impact of climatic changes on biomass growth is considered as an important tool in grassland management on the national, regional and the field grassland scale. There is the necessity of the study of changes in grasslands due to climate as these changes influence changes in hydrological conditions what causes the changes in biomass and carbon uptake. Remote sensing methods are considered very beneficial for grassland monitoring and management because there is not enough information about their condition in existing publications. The Polish Central Statistical Office, for example, publishes only the yields of grassland without any deliberation about the meteorological conditions during their growth. The lack of reliable information about the grassland growth conditions and the influence of meteorological variables on their status, has led to the development of the Polish-Norwegian project where the prime objective, is the assessment of the influence of climatic changes on grassland growth, its water conditions and biomass, and subsequently yield with the application of the remote sensing techniques.

2. Study Area

Study area in Poland consists of five test sites (Fig. 1) located in Biebrza Valley (East Poland), in Wielkopolska region (three sites in West Poland) and in Jaworki (South Poland in Karpatian Mountains). Table 1 presents geographic coordinates of the test sites.

2.1. Norwegian Site

In Norway suitable grassland study sites with sufficient size for Landsat 8 and MODIS satellites spatial resolution have been identified. Study area in Norway is located in Troms County (North Norway) and consists of: two fields in the Vesterålen region (68°42´N), four fields in the Harstad region (68°45´N), and three fields in the Tromsø region

K. Dabrowska-Zielinska, P. Golinski, M. Jørgensen,
J. Mølmann, G. Taff, S. Twardy, M. Budzynska,
M. Czerwinski, M. Kopacz, R. Kurnicki, W. Kowalik,
M. Tomaszewska, A. Malinska, B. Golinska, M. Gatkowska
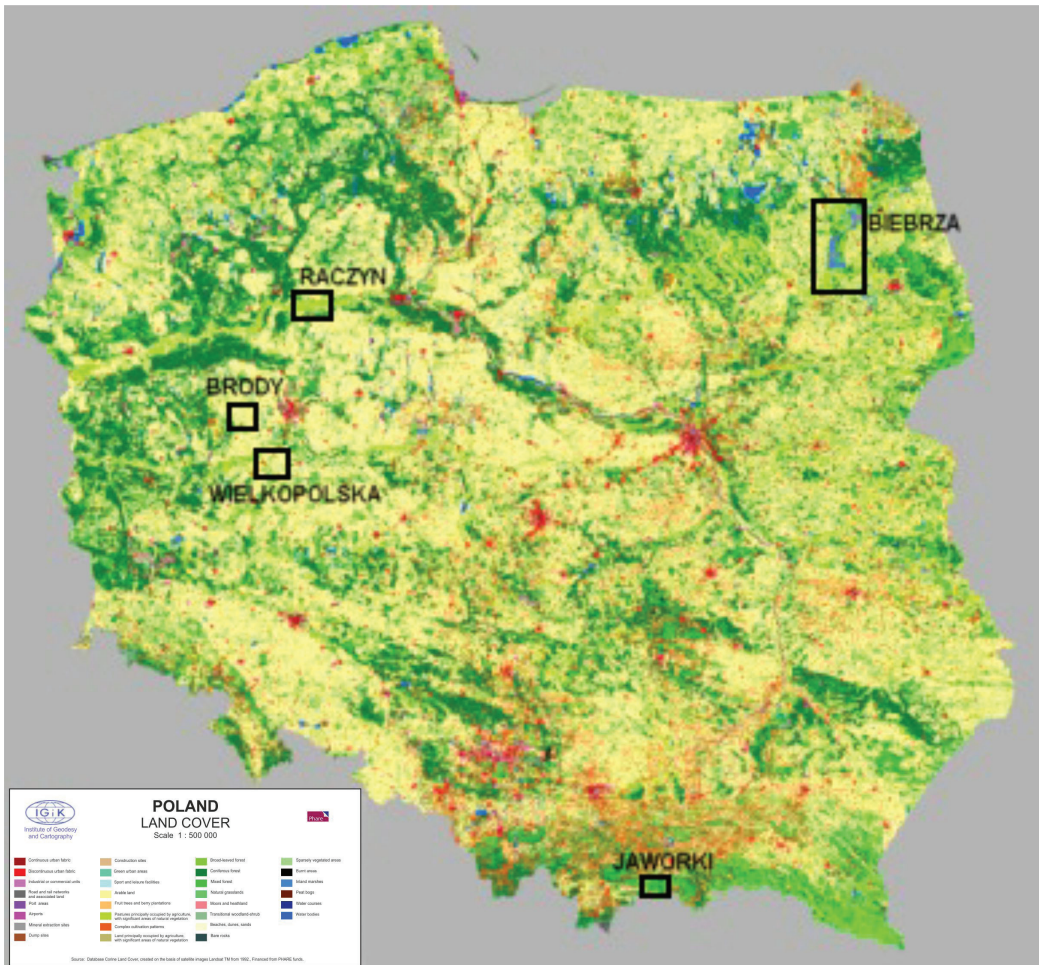
Geoinformation Issues
Vol. 8, No 1 (8), 55–71/2016

Fig. 1. Investigation sites location

(69°40´N). Figure 2 presents localisation of Troms County (left, yellow area) and localisation of the test sites regions in this county (right, red circles).

3. Data

3.1 In situ measurements

In-situ measurements in Poland have been carried out at the following test sites: Biebrza, Raczyn, Brody, Wielkopolska, Jaworki. In-situ measurements have been performed from May to September 2014–2016 simultaneously to satellite overpasses. Collected in-situ data have been used for deriving the correlation between collected data and satellite

derived indices. Elaborated models have been applied for obtaining grasslands parameters from satellite data. In-situ measurements involved simultaneously measured significant soil-vegetation parameters for all test sites such as:

– volumetric soil moisture in the layer of 0–15 cm using TDR method (TRIME-FM, IMKO Micromodultechnik GmbH), [%vol.];
– LAI using LAI-2000 Plant Canopy Analyzer (LiCor Inc.), $[m^2 m^{-2}]$ vegetation height, [m];
– biomass wet and dry $[g\ m^{-2}]$ and vegetation water content (water mass per mass of vegetation wet matter in percent) – in the laboratory from samples harvested inside the chamber from 0.4×0.4 m following the carbon flux measurement.
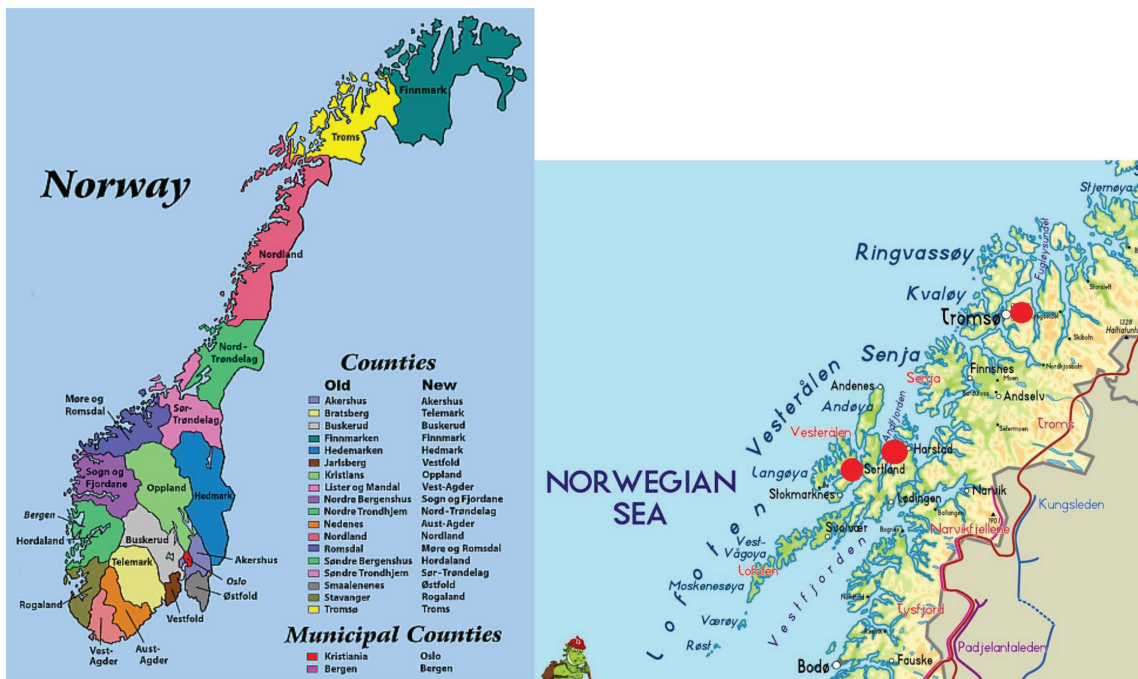
Fig. 2. Localisation of the test sites in Norway

At least three samples of the listed above parameters were collected for each measurement site. These three measurement samples included variation in vegetation structure (if any, e.g. density, height).

The grassland vegetation habitat type (species), as well as development stages (BBCH scale), have been described during each of the field campaigns. Also, the pictures have been taken to notice field

Table 1. Geographic coordinates of the test sites in Poland

Test site name Grassland type No of sites	Geographic coordinates			
	Latitude N		Longitude E	
	UL	LR	UL	LR
Brody Lowland non-valley 3 sites: Brody 1, Brody 2, Zgierzynka	52°28'	52°26'	16°15'	16°17'
Raczyn Lowland valley 3 sites: Raczyn 1, Raczyn 2, Raczyn 3	53°04'	53°02'	17°04'	17°07'
Wielkopolska Lowland non-valley 2 sites	52°05'	52°03'	16°40'	16°44'
Biebrza Lowland valley and lowland non-valley 16 sites	53°48'	53°05'	22°20'	23°02'
Jaworki Mountainous 5 sites in N slope and ten in S slope	49°26'	49°22'	20°32'	20°36'

K. Dabrowska-Zielinska, P. Golinski, M. Jørgensen,
J. Mølmann, G. Taff, S. Twardy, M. Budzynska,
M. Czerwinski, M. Kopacz, R. Kurnicki, W. Kowalik,
M. Tomaszewska, A. Malinska, B. Golinska, M. Gatkowska

situation (e.g. harvested, prisms of hay, swaths, grazed, places of dried vegetation, etc.) and vegetation growth conditions. The pictures have been helpful in statistical analyses of satellite data. The geographic position of measurement points has been fixed using previous GPS data. The correlation that have been established between soil – vegetation measurements, as soil moisture, biomass, LAI and carbon balance have later been applied for the grasslands areas presented at satellite images.

Annual yield data were collected for Poland from ca. 50 ha of grassland situated on mineral soils, utilized mainly for grazing, and of ca. 150 ha of grassland located on organic soils used for cutting as raw material for conserved fodder (hay, silage). For specific sites the effect of climate conditions over a 50-year period on yield of grasslands was analysed. Yield was compared with long-term averages of mean monthly and annual temperatures, monthly precipitation sum, and standardized precipitation evapotranspiration index (SPEI), which incorporates both these climatic elements and characterizes drought severity. The SPEI uses a difference between precipitation, expressed as the standardized precipitation index (SPI) and potential evapotranspiration (PET). The PET was calculated by temperature-based method. Temperature, precipitation and SPEI trends were determined by computing the Pearson correlation coefficient between the subsequent years and the corresponding SPEI values.

Meteorological data for Poland were taken from i) Meteorological stations (since 1985), ii) ECMWF database (since 1997). The meteorological data have been applied to elaborate the trends in meteorological parameters.

Norwegian site

All field measurements in Norway were done in diagonal transects established using: two fields in the Vesterålen region, four fields in the Harstad region, and three fields in the Tromsø region. The dates were selected as close to satellite pass-overs as possible. At the same time as yields the grass height was measured with a disc meter in 34 points along the diagonal transect as well as across the whole field, in a GPS located grid at every 15 m. The botanical composition of these fields was recorded

using the dry weight rank method. In addition, LAI was measured in the transects using an LAI-2200C meter, and soil humidity was measured with a tensiometer.

Meteorological data were used from the Holt research station in Northern Norway to assess temperature trends in spring, summer, and autumn since 1991.

3.2 Satellite data

The CORINE (Co-ORdination of INformation on the Environment-CLC) database has been used as the geographical information system to provide information on grasslands areas. Regular EO observations gave satellites such as Terra and Aqua MODIS, NOAA.AVHRR, and Landsat 8. The data were available with different space and time resolution. For Polish test sites MODIS 8-day products were downloaded from the US Geological Survey website. NOAA.AVHRR data were available from the IGiK station.

Data from low spatial resolution satellites as Terra and Aqua MODIS, NOAA.AVHRR give information with the one day or 8 days step. There are also available products within BioPAR of Geoland2 FP7 Project as: Leaf Area Index (LAI), the Fraction of green Vegetation Cover (FCover), the fraction of absorbed photosynthetically active radiation (FAPAR) and the Normalized Differential Vegetation Index (NDVI). Figure 4 presents the distribution of NDVI over Europe showing the condition of grasslands at the first decade of 2003 from BioPar Product. New satellites from the group of Sentinel satellites give regularly data for the whole glob within Copernicus Programme. The data from Sentinel-1 satellite with active microwave sensor have been applied for the test sites.

For the Norwegian test sites MODIS 16-day interval NDVI data (max NDVI over each 16-day period) were downloaded for North Norway from the US Geological Survey website for all 16-day periods from January 2002 until December 2015.

4. Methodology

Monitoring of grasslands status is of great importance in environment and climate change studies. Changes in air temperature and precipitation cause
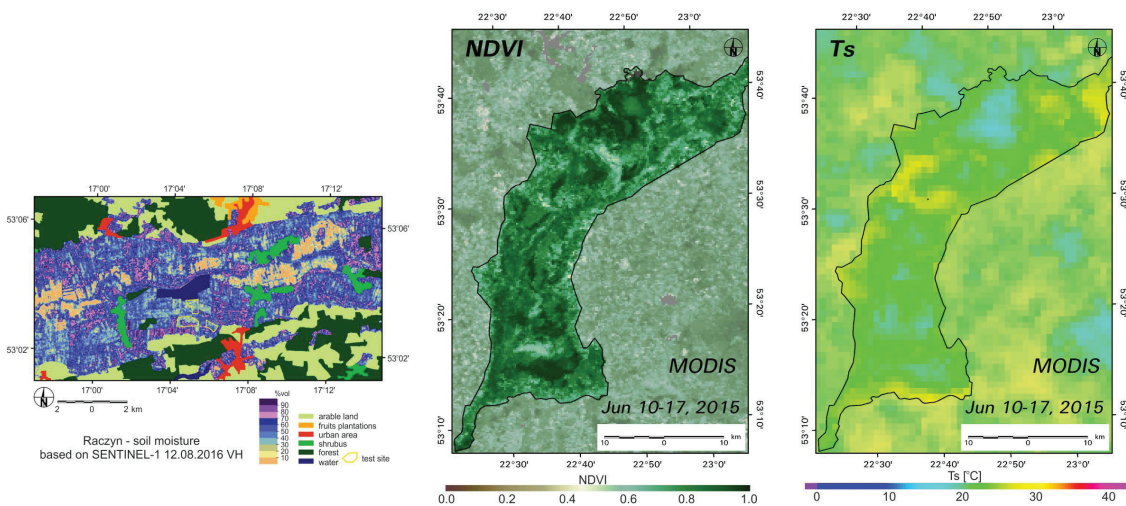
Fig. 3. Soil moisture for Raczyn test site based on modelling Sentinel-1 satellite data (left), NDVI (middle), and surface temperature TS(right) from Terra MODIS for Biebrza test site

increase in evapotranspiration influencing the water balance cycle. The extremes of the weather in winter, often lack of snow cover together with low temperatures as well as often occurrence of the increased air temperatures early in spring, cause shifts in phenology and disturbance in water balance of the grasslands areas which influence the sward dry matter yield. Also lack of precipitation and increase of temperature later in spring and summer cause diminishing of moisture causing changing water conditions in some of the areas (Kundzewicz and Matczak, 2012). In some areas, climate change may result in higher and more intense precipitation, especially during autumn and winter. This could increase risk of water logging condition, run-off of nutrients and problems for farm operations, and thereby reduce yield. Proper management of grasslands requires rapid data about growth conditions and prognosis of yield. Remote sensing methods play a significant role, because of spatial and temporal coverage capability. Satellite-based radiometers are useful for measuring vegetation characteristics over time across larger areas. Satellite imagery has been used to assess forage production levels over large areas by calculating the Normalized Difference Vegetation Index (NDVI) (Smit et al., 2008) or the Enhanced Vegetation Index (EVI) (Kawamura et al., 2005). This tech-

nology may also be used to assess the forage grassland production on farm, regional and national levels.

Regular monitoring of land cover in European countries started in 1985 by the CORINE programme which was initiated in the European Union. CORINE was a prototype project working on many different environmental issues. The CORINE databases and several of its programmes have been taken over by the European Environment Agency (EEA). The product as High Resolution Layer (HRL) have been done for grasslands (Langanke, 2013).

In the holistic approach of grassland monitoring many characteristics should be collected in different surveying methods: type of grassland (permanent or temporal), land use, yield [t ha^{-1}], intensity of exploitation, number of cuts/harvests (times per year), volume of cut grass, grazing status (grazed or not grazed), volume of grazed grass, legal status, other land cover (e.g. percentage of tree and shrub cover), soil type, nitrogen input levels as fertilizer [kg N], species composition, percentage of clover or other N fixing plants, grazing intensity (stocking density), management intensity, manure input levels, ecosystem types, species richness, moisture content/water storage in the soil/groundwater depth, O_2 released/CO_2 fixed, Net Primary Productivity.

K. Dabrowska-Zielinska, P. Golinski, M. Jørgensen,
J. Mølmann, G. Taff, S. Twardy, M. Budzynska,
M. Czerwinski, M. Kopacz, R. Kurnicki, W. Kowalik,
M. Tomaszewska, A. Malinska, B. Golinska, M. Gatkowska

Geoinformation Issues
Vol. 8, No 1 (8), 55–71/2016

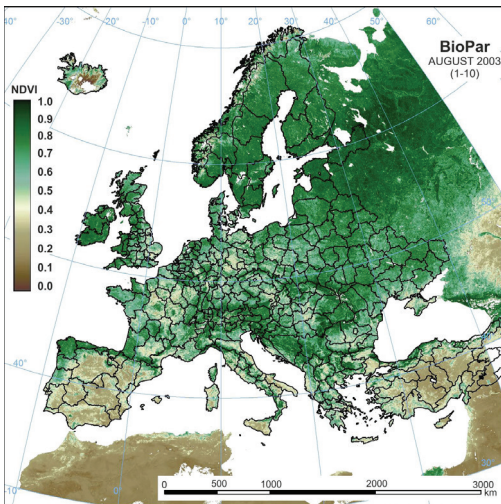Most of this information could come from remote sensing.

Fig. 4. NDVI distribution at the first decade of August 2003 from BioPar Product

In-situ measured soil-vegetation parameters and satellite observations have been combined and analysed to quantify the spatial and temporal variability of grassland conditions, as reflected in variations of surface temperature (Ts), soil moisture, biomass, and subsequently the yield. Spatial information on ecosystems concerning numerous biophysical parameters and their temporal changes is important for recognition of the state of environment and for determination the direction and cause of its changes.

The FINEGRASS project have been realised within Polish-Norwegian research cooperation. The newest and most innovative remote sensing and in-situ based methods have been applied on the national, regional and field grassland scales and has been designed to serve as an important tool in grassland management on all these levels. It covered the following areas:

– Assessment of impact of climate change on grassland growth conditions in different habitat types (lowland valley, lowland non-valley, mountainous, Central Europe vs. Northern Norway);
– Estimation of the influence of grassland growth conditions on biomass increase, phenology and grassland yield;
– Development of method of grassland yield forecast based on RS data;
– Scientific description of the observed changes in grassland growth and development which influence the methods for management of grassland areas; elaboration of a reasonable model of grassland development and usage in the changing environment;
– Elaboration of the prognosis of environmental effects which are the consequence of a changing environment that affect modification in management of grasslands.

Half of 45 types of grassland in Poland are of semi-natural character. The applications of remote sensing observations were the main tool for examining the differences in grasslands biomass for the whole country. To get the spatial distribution of grasslands areas the CORINE database has been used as the geographical information system to provide information on grasslands areas. In Poland grasslands cover about 13% of the country area (22% of the agriculturally utilized area). The CLC Grassland Layer was intersected with NOAA. AVHRR data with resolution of 1000 m to create the grassland-mask. The pixels which characterized the grassland area were these, with the minimum of 50% of grassland. One of the objectives of the project was the assessment of vegetation indices derived from satellite data and describe the temporal and spatial variation of these indices. NOAA. AVHRR satellite data (since 1997) have been applied and current images recorded in visible and thermal channels have been used for calculation of vegetation indices for analysing these indices for each year with the step of 10 days. Also 8 days Terra MODIS data, NDVI, Ts have been applied (Fig. 3). The 10-day mosaic of NDVI, Ts (surface temperature) (Fig. 5), VCI (Vegetation Condition Index), and TCI (Temperature Condition Index) has been elaborated. The grasslands mosaics were overlaid on DTM for the whole country. The vegetation indices were calculated also for NUTS2. The areas of climatic zones for Poland have been established for evaluating the vegetation indices within these zones (Fig. 11).

For each of the administrative divisions and climatic regions, Ts was averaged for the grassland pixels, and the trend between 1997 and 2015 was analysed.
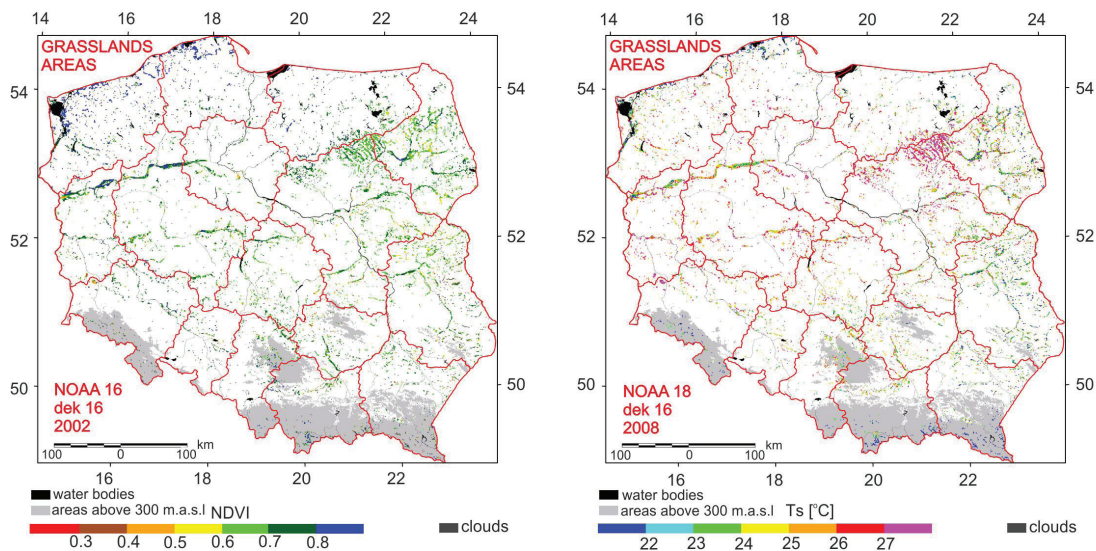
Fig. 5. NDVI and Ts of NOAA/AVHRR for grasslands – 16 decade in 2002 and 2008

Norwegian research

For the Norwegian test sites MODIS 16-day interval NDVI data were loaded into ArcGIS software, mapped and overlaid with all other dates within each year. A maximum NDVI was also calculated and mapped for each pixel for each year. A set of vegetation index maps was created for each 16-day time interval, and the maximum NDVI for each year between 2002–2015 was also created. MODIS 16-day NDVI data were used in conjunction with a ground-truth phenology dataset at Holt to assess trends in snowmelt and green-up between the years 2000 and 2012.

5. Results and Discussion

5.1. Yield forecast

The vegetation indices have been applied to forecast the yield for the region. For NUTS2 in Poland, the biomass calculated for each year (1997-2015) applying NOAA.AVHRR data has been compared to biomass from official Polish Central Statistical Office data. The high accuracy obtained indicates the great possibility of using satellite data for the biomass assessment. The model for biomass (grass-

land yield) prediction applying NDVI and Ts data for NUTS2 4, was developed based on Principal Component Analysis (PCA)

$$
\begin{aligned}
\text{Yield} = {} & 27.9 + 3.58\,\text{NDVI}\_7 + 2.0\,\text{NDVI}\_8 + \\
& + 0.62\,\text{NDVI}\_9 + 1.53\,\text{NDVI}\_10 + \\
& + 3.77\,\text{NDVI}\_11 + 3.50\,\text{NDVI}\_12 + \\
& + 0.52\,\text{NDVI}\_13 + 0.83\,\text{NDVI}\_14 - \\
& - 0.42\,\text{NDVI}\_15 + 0.016\,\text{Ts}\_7 - \quad (1) \\
& - 0.016\,\text{Ts}\_8 - 0.014\,\text{Ts}\_9 - \\
& - 0.024\,\text{Ts}\_10 - 0.02\,\text{Ts}\_11 - \\
& - 0.036\,\text{Ts}\_12 - 0.04\,\text{Ts}\_13 - \\
& - 0.055\,\text{Ts}\_14 - 0.028\,\text{Ts}\_15
\end{aligned}
$$

The important period for yield forecast was found out. The PC1 is the NDVI in March; PC2 is NDVI in April when the vegetation develops, PC3 is surface temperature (Ts) in May (possible drought effect).

In the model, the Principal Components PC1, PC2, PC3 are linear combinations of decadal NDVI and Ts data, ordered in accordance with the magnitude of correlation between the components and the primary variables (factor loadings) (Table 2)

$$\text{Yield} = 27.9 + 0.73\,\text{PC1} + 0.95\,\text{PC2} - 0.67\,\text{PC3} \quad (2)$$

K. Dabrowska-Zielinska, P. Golinski, M. Jørgensen,
J. Mølmann, G. Taff, S. Twardy, M. Budzynska,
M. Czerwinski, M. Kopacz, R. Kurnicki, W. Kowalik,
M. Tomaszewska, A. Malinska, B. Golinska, M. Gatkowska

Geoinformation Issues
Vol. 8, No 1 (8), 55–71/2016

Table 2. Correlation coefficients between NDVI and Ts
for PC1, PC2 and PC3

	Factor loadings		
	1	2	3
NDVI_7	0.91	0.16	0.05
NDVI_8	0.45	0.27	0.01
NDVI_9	0.27	0.25	0.23
NDVI_10	0.00	0.51	0.04
NDVI_11	0.01	0.88	0.00
NDVI_12	0.29	0.86	0.22
NDVI_13	0.08	0.48	0.69
NDVI_14	0.24	0.45	0.71
NDVI_15	0.21	0.41	0.58
TS_7	0.44	0.17	0.30
TS_8	0.02	0.10	0.40
TS_9	0.11	0.24	0.48
TS_10	0.34	0.28	0.63
TS_11	0.00	0.14	0.79
TS_12	0.08	0.03	0.86
TS_13	0.22	0.18	0.88
TS_14	0.10	0.21	0.86
TS_15	0.13	0.24	0.68
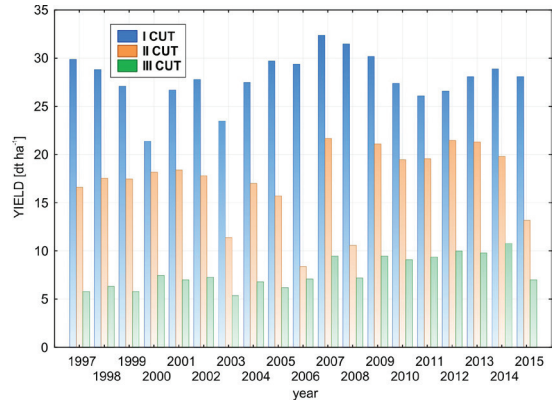
Fig. 7. Yields of grassland at PL41 NUTS2 region
in Wielkopolskie voivodship
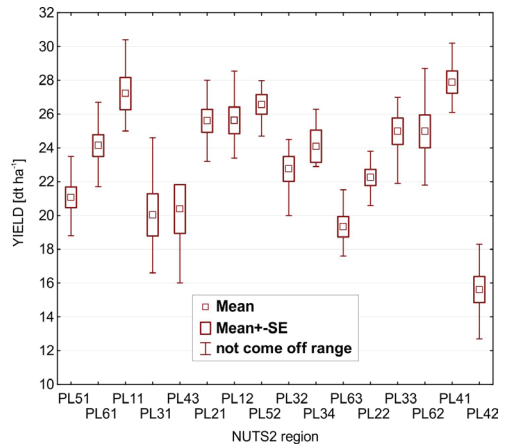
Fig. 8. Yields of grassland (I CUT in 1997–2015)
in Polish voivodships

1997–2015 and the box-plot (Fig. 8) illustrates the information of the Central Statistical Office data for grassland yields in the Polish voivodships. It was found that the yield fluctuates during the years.

The first cut (I CUT) has the highest values and it differs between NUTS2 regions analysed.

5.2. Temporal changes of vegetation parameters and trends in meteorological parameters

It was important to examine the influence of climate change on grasslands growth. The trends in grasslands growth during the years of MODIS acquisition for different 8-days periods have been
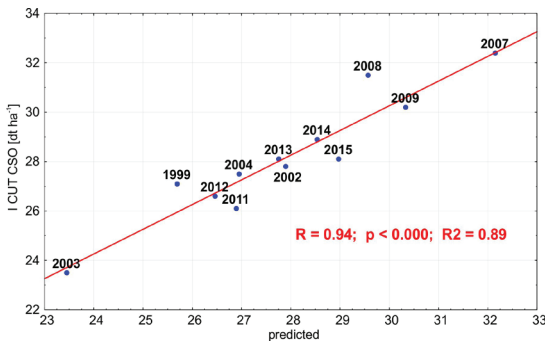

Fig. 6. The relation between predicted and measured values of yield of grassland in the first cut at PL41 NUTS2 region in the 1997-2015

The errors MAPE = 4.1% and MPE = 0.7% were estimated. The measured data processed were published by the Central Statistical Office.

Bars diagram in Figure 7 shows the yields in Wielkopolskie voivodship (PL41) during the period
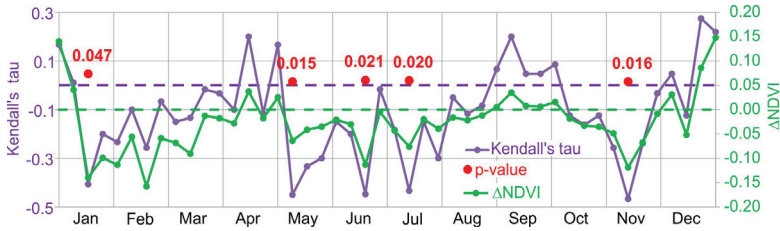
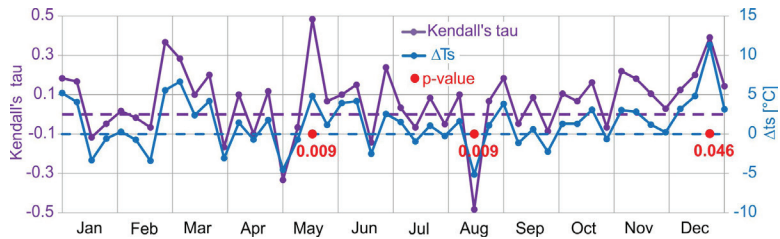Fig. 9. NDVI trends for Wielkopolskie voivodship from MODIS 8-day data

Fig. 10. Ts trends for Wielkopolskie voivodship from MODIS 8-day data

investigated. Figures 9 and 10 present correlation coefficient Kendall's tau and increase or decrease noted in February, May and December, and decreasing trend in August. Presentation of those trends of the values of NDVI and Ts resulting from the trends in Wielkopolskie voivodship during the period 2001–2016. The NDVI and Ts have been calculated using MODIS 8-day data. Significant (p-value less than 0.05) decreasing trends for NDVI, have been found in January, beginning of May, June, July and November, while for Ts the increasing trends showed that for the first important cut of grassland its growth conditions are diminished.

The start of vegetation and grassland development has also been described within the climatic zones of Poland (Fig. 11) to find the differences in grassland growth and development in particular zones.

The satellite vegetation indices developed on the basis of NOAA satellite data for the grassland-mask were averaged for the climatic regions. The results were compared to the weather parameters modelled by European Centre for Medium-Range Weather Forecasts (ECMWF). ECMWF is an independent intergovernmental organisation supported by 34 European countries. ECMWF produce numerical weather forecasts, monitor the Earth-system and maintain an archive of meteorological data.

The data from EMCWF data base, which are originally provided in 0.1 degree grid were interpolated and also averaged in climatic regions in Poland for the grassland-mask.

Figure 12 presents two maps: on the right – the deviation of air temperature (Ta) in June 2003 from the average air temperature for the time 1997–2014 done for climatic regions from ECMWF data, on the left – the deviation of surface temperature Ts of grasslands areas calculated from NOAA.AVHRR data from the average for the examined period of time (1997–2014). The surface temperature of grasslands and air temperature for June 2003 exceeds the average temperature. The western part of Poland has larger temperature differences and it shows good agreement between air temperature and surface temperature of grasslands.

The effect of climate conditions in 50-years period on yield of grassland located on mineral and organic soils in Central Poland was analysed. Special attention was paid to the historical data received in the Experimental Station in Brody belonging to the Department of Grassland and Natural Landscape Sciences of PULS. First of all the database of meteorological data (average daily air temperature, sum of precipitation for each decade, average daily soil temperature at 5 and 10 cm depth, number of days with precipitation for each

K. Dabrowska-Zielinska, P. Golinski, M. Jørgensen,
J. Mølmann, G. Taff, S. Twardy, M. Budzynska,
M. Czerwinski, M. Kopacz, R. Kurnicki, W. Kowalik,
M. Tomaszewska, A. Malinska, B. Golinska, M. Gatkowska

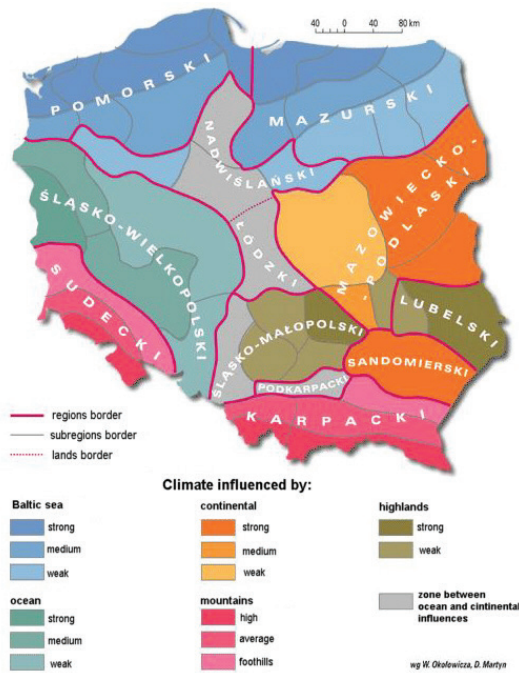Geoinformation Issues
Vol. 8, No 1 (8), 55–71/2016

Fig. 11. Climatic regions in Poland according to Okolowicz and Martyn (1989)

month) in the period 1959–2014 from meteorological station in PULS Experimental Station in Brody was created. Climate changes were investigated by the analysis of the long-term course of mean monthly and annual temperature, monthly precipitation sum and SPEI. For grassland growth
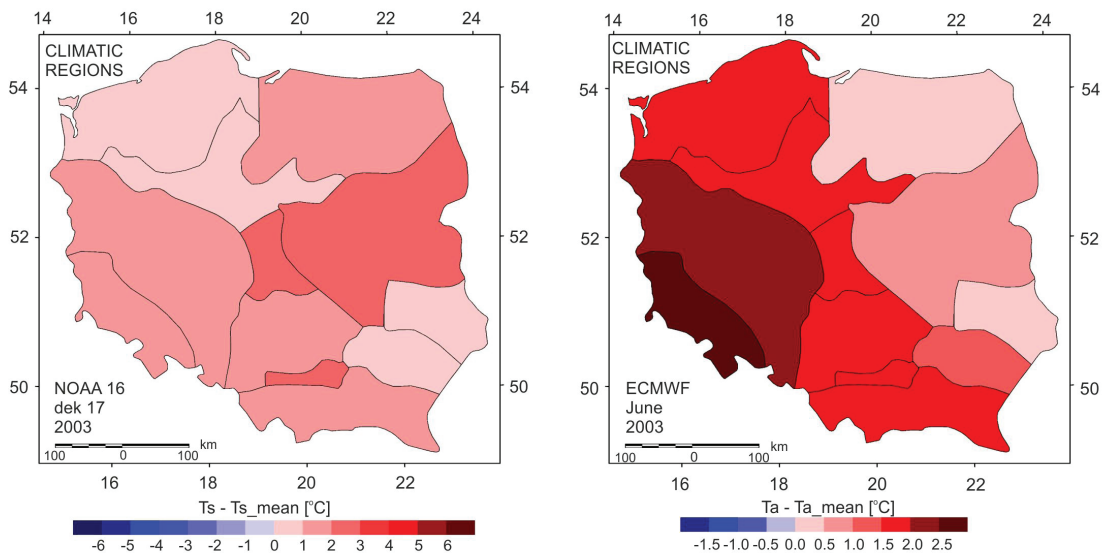

Fig. 12. Differences in surface (Ts) and air (Ta) temperature for the grasslands in Poland

in temperate climatic zones, the crucial factor is the amount and distribution of precipitation. The one-month SPEI calculated for each month of a year was used to determine which period of vegetative season lasting about 230 days (end of March until the beginning of November) had the highest impact on grassland yield. The Pearson's correlation coefficients between years and one-month SPEI for twelve months (January-December) were as follows: 0.29, 0.27, 0.18, -0.25, -0.07, 0.01, 0.05, 0.17, 0.07, -0.08, -0.07, 0.01. The results obtained indicate that drought conditions, which have high impact on annual grassland yield occurred in spring (April–May). The results obtained presented in Figures 9 and 10 are comparable with the results of trends derived from MODIS satellite data for NUTS2. Figure 13 presents the results of regressions of annual grassland yield located on mineral and organic soils against the SPEI. It has been confirmed, that weather conditions characterized by SPEI had significant effect on grassland yield located on mineral soils in all analysed periods, particularly April–September. Concluding, climate change at the analysed site in Central Poland in 50-years period reflected by increasing air temperature and precipitation had significant impact on grassland productivity located on mineral soils. The effect of climate change on grassland productivity located on organic soils was not significant.

For the case of precipitation and temperature the average 30-years (1985–2014) decade values were

calculated. Based on differences between value of individual decades and multi-year averages, the decades with extreme values were indicated. The following threshold of differences was applied for precipitation ±20 mm, and for temperatures ±5°C. Juxtaposition of the above-mentioned climate stations was complemented by the results obtained from the Climate Station in Jaworki, owned by the Institute of Technology and Life Sciences (altitude approx. 600 m a.s.l., coordinates 49.408537°N, 20.560620°E). Figure 14 presents the coefficient of the determination obtained for temperature trends based on multi-year data for 11 (left) and 17 (right) decade. It shows that the stronger temperature trends in decade 17 are at the western part of Poland.

5.3. Trends in Norwegian grasslands

In Norway suitable grassland study sites with sufficient size for Landsat 8 and MODIS spatial resolution have been identified. These sites were located in the Troms County within Tromsø region, Harstad region and Vesterålen region. For meteorological stations localised near selected farms in Norway temperature data from 1991–2015 from Holt (Tromsø region) have been analysed and found a trend of earlier period of growth start in spring and increasing the temperature sum in the growing season during the last 10 years, however, with large variation between years. Temperature of
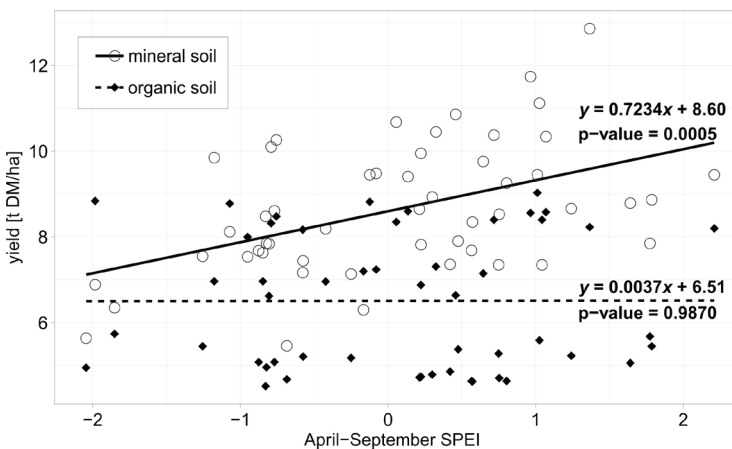

Fig. 13. Relation between annual grassland productivity and SPEI for 6-months period from April to September in the background of habitat type regarding of soil conditions

K. Dabrowska-Zielinska, P. Golinski, M. Jørgensen,
J. Mølmann, G. Taff, S. Twardy, M. Budzynska,
M. Czerwinski, M. Kopacz, R. Kurnicki, W. Kowalik,
M. Tomaszewska, A. Malinska, B. Golinska, M. Gatkowska
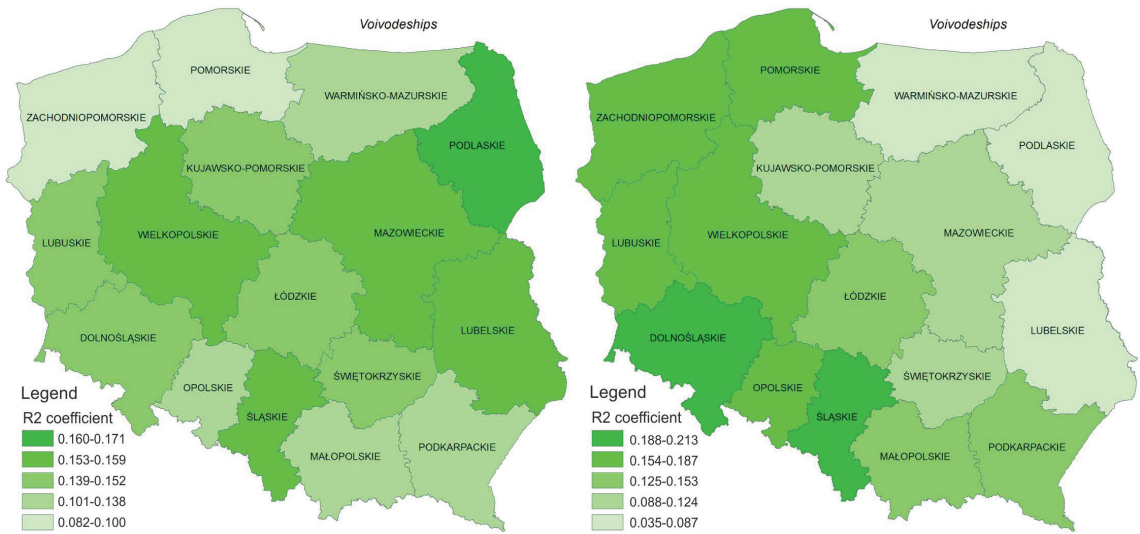
Geoinformation Issues
Vol. 8, No 1 (8), 55–71/2016

Fig. 14. Trends in air temperature in the 11 (left) and 17 (right) decade for the 30-year period

summer months (June and July) do not seem higher than during the reference period 1961–1990, but spring months (April and May) and autumn months (August and September) have a clear increasing trend.

The NDVI data from MODIS were overlaid with all other dates within each year. A maximum NDVI was also calculated and mapped for each pixel for each year. A set of NDVI maps was created for each 16-day time interval, and the maximum NDVI for each year between 2002–2015 was also created. MODIS 16-day NDVI data were used in conjunction with a ground-truth phenology dataset at Holt (Tromsø region) to assess trends in snowmelt and green-up between the years 2000 and 2012. Figure 15 presents results of these trends observed at Holt. Fluctuation of mean green-up and snowmelt dates can be noted. The earliest date have been observed

in the year 2003 for green-up and in the year 2004 for snowmelt. Since these dates increasing trends have been observed – the dates of green-up and snowmelt became later on.

6. Conclusions

As a result of this study the following conclusions were drawn:
– Significant trends in air temperature (Ta) in NUTS2 in Poland has been found;
– Significant decreasing trends for NDVI has been found in January, May, June, July and November, while for surface temperature (Ts) the increasing trends – in February, May and December – have been noted for NUTS2 in Poland;
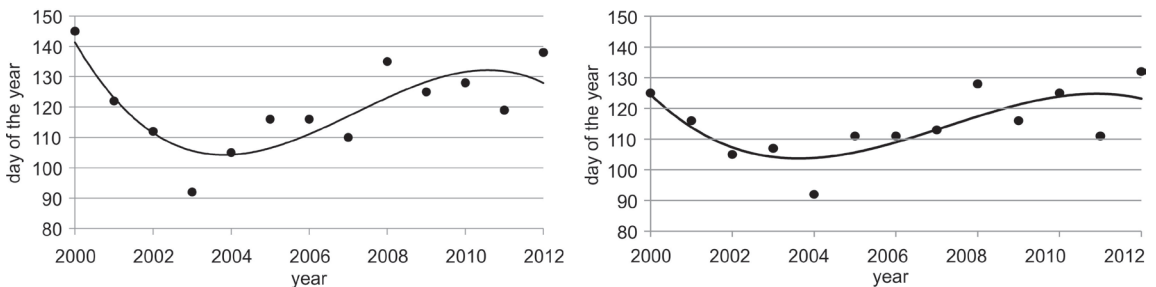

Fig. 15. Trends of green-up (left) and snowmelt (right) of northern Norway (Holt) assessed, based on MODIS NDVI data

- Comparable results between the deviation of surface temperature (Ts) of grasslands from NOAA satellite and mean temperature (Ts–Ts_mean) and deviation of air temperature (Ta) from the mean temperature have been observed;
- Significant positive relationship between the (April-September) standardized precipitation evapotranspiration index (SPEI) and annual grassland yields located on mineral soil in Poland has been found;
- In Norway, temperature data present a trend towards earlier growth start in spring and increasing temperature sum in the growing season during the last ten years have been observed with large variation between years;
- MODIS 16-day NDVI time series present consistent trends at the Holt research station in Northern Norway towards earlier snowmelt and green-up in the early 2000's, somewhat later snowmelt and green-up in the late 2000's, and then again towards earlier snowmelt and green-up in the early 2010's.

Climate changes in Poland may affect positively and negatively the grassland productivity. The projected climate scenarios point in different directions. It is therefore necessary to build new and efficient methods that can be used to monitor the productivity of grasslands to understand trends and anomalies that are likely to continue into the future. This can help in planning for agricultural practices, can be an efficient tool in decision support system of grassland management and offsetting financial risks on large scales.

References

Bignal E., Mc Cracken D., (1996): *Low intensity farming systems in the conservation of the country site*, Journal of Applied Ecology, 33, pp. 413–424.

FAOSTAT (2009): *Statistical Database 2007*, Rome.

FAO (2007): *State of the World's Forests 2007*, Rome.

Huyghe C., De Vliegher A., Goliński P., (2014): *European grasslands overview: temperate region*, Grassland Science in Europe 19, pp. 29–40.

Kawamura K., Akiyama T., Yokota H., Tsutsumi M., Yasuda T., Watanabe O., Wang G., Wang S., (2005): *Monitoring of forage conditions with MODIS imagery in the Xilingol steppe, Inner Mongolia*, International Journal of Remote Sensing 26, 7, pp. 1423–1436.

Kundzewicz Z.W., Matczak P., (2012): *Climate change regional review: Poland*, WIRES Climate Change, Willey, DOI: 10.1002/wcc.175View.

Langanke T., (2013): *GIO land (GMES/Copernicus initial operations land) High Resolution Layers*, GIO land team at the EEA, Copenhagen, pp. 13.

Okolowicz W., Martyn D., (1989): *Climatic regions* (in Polish), In: H. Górski and P. Melnicka (Eds.), Atlas geograficzny Polski, PPWiK, Warszawa-Wrocław.

O'Mara F.P., (2012): *The role of grasslands in food security and climate change*, Annals of Botany 110, pp. 1263–1270.

Paustian K., Collins H.P., Paul E.A., (1997): *Soil organic matter in temperate agroecosystems*. In: E.A. Paul, K. Paustian, E.T. Elliot and C.V. Cole (Eds.), Boca Raton, USA, CRC Press LLC, pp. 15–49.

Smit H.J., Metzger M.J., Ewert F., (2008): *Spatial distribution of grassland productivity and land use in Europe*, Agricultural Systems 98, pp. 208–219.

Soer, (2015): *The European environment – state and outlook 2015 A comprehensive assessment of the European environment's state, trends and prospects, in a global context*, Report EEA

Sombroek W.G., Nachtergaele F.O., Hebel A., (1993): *Amounts, dynamics and sequestrations of carbon in tropical and subtropical soils*, Ambio 22, pp. 417–426.

Souchere V., King Ch., Dubreuill N., Lecomte-Morel V., Bissonnais Y., Chalat M., (2003): *Grassland and crop trends: role of the European Union Common Agricultural Policy and consequences for runoff and soil erosion*, Environment Science and Policy, Vol 6, Issue 1.

Sousanna J.F., Klumpp K., Ehrhardt F., (2014): *The role of grassland in mitigating climate change*, Grassland Science in Europe, Vol. 19 EGF at 50: The future of European Grasslands, (Ed) A. Hopkin.

Acknowledgements

K. Dabrowska-Zielinska, P. Golinski, M. Jørgensen,
J. Mølmann, G. Taff, S. Twardy, M. Budzynska,
M. Czerwinski, M. Kopacz, R. Kurnicki, W. Kowalik,
M. Tomaszewska, A. Malinska, B. Golinska, M. Gatkowska

Znaczenie monitoringu użytków zielonych w kontekście zmian klimatycznych w Europie – Projekt FINEGRASS

Katarzyna Dąbrowska-Zielińska
Instytut Geodezji i Kartografii, ul. Modzelewskiego 27, 02-679, Warszawa
Tel.: +48 22 3291974, Fax: +48 22 3291950, E-mail: katarzyna.dabrowska-zielinska@igik.edu.pl

Piotr Goliński
Uniwersytet Przyrodniczy w Poznaniu, Katedra Łąkarstwa i Krajobrazu Przyrodniczego, ul. Dojazd 11, 60-632 Poznań
Tel.+48 618487414, Fax: +48 61 8487612, E-mail: pgolinsk@up.poznan.pl

Marit Jørgensen
Norwegian Institute of Bioeconomy Research - NIBIO, Holt, Tromsø, P.O. Box 115, NO-1431 Ås Norway
Tel.: +47 92867101, E-mail: marit.jorgensen@nibio.no

Jorgen Mølmann
Norwegian Institute of Bioeconomy Research - NIBIO, Holt, Tromsø, P.O. Box 115, NO-1431 Ås Norway
Tel.: +47 92867101, E-mail: jorgen.molmann@nibio.no

Gregory Taff
Norwegian Institute of Bioeconomy Research - NIBIO, Holt, Tromsø, P.O. Box 115, NO-1431 Ås Norway
Tel.: +47 92867101, E-mail: gregory.taff@nibio.no

Stanisław Twardy
Instytut Technologiczno-Przyrodniczy, Małopolski Ośrodek Badawczy, ul. Ułanów 21B, 31-450 Kraków
Tel.: +48 12 4128459, E-mail: itepkrak@itep.edu.pl

Maria Budzyńska
Instytut Geodezji i Kartografii, ul. Modzelewskiego 27, 02-679, Warszawa
Tel.: +48 22 3291974, Fax: +48 22 3291992, E-mail: maria.budzynska@igik.edu.pl

Marek Czerwiński
Uniwersytet Przyrodniczy w Poznaniu, Katedra Łąkarstwa i Krajobrazu Przyrodniczego, ul Dojazd 11 60-632 Poznań
Tel.: +48 618487513, E-mail: marek.czerwinski@up.poznan.pl

Marek Kopacz
Instytut Technologiczno-Przyrodniczy, Małopolski Ośrodek Badawczy, ul. Ułanów 21B, 31-450 Kraków
Tel.: +48 12 4128459, E-mail: m.kopacz@itep.edu.pl

Robert Kurnicki
Instytut Technologiczno-Przyrodniczy, Małopolski Ośrodek Badawczy, ul. Ułanów 21B, 31-450 Kraków
Tel.: +48 12 4128459, E-mail: itepkrak@itep.edu.pl

Wanda Kowalik
Instytut Geodezji i Kartografii, ul. Modzelewskiego 27, 02-679, Warszawa
Tel.: +48 22 3291974, Fax: +48 22 3291978, E-mail: wanda.kowalik@igik.edu.pl

Monika Tomaszewska
Instytut Geodezji i Kartografii, ul. Modzelewskiego 27, 02-679, Warszawa
Tel.: +48 22 3291974, Fax: +48 22 3291978, E-mail: monika.tomaszewska@igik.edu.pl

Alicja Malińska
Instytut Geodezji i Kartografii, ul. Modzelewskiego 27, 02-679, Warszawa
Tel.: +48 22 3291977, Fax: +48 22 3291977, E-mail: alicja.malinska @igik.edu.pl

Barbara Golińska
Uniwersytet Przyrodniczy w Poznaniu, Katedra Łąkarstwa i Krajobrazu Przyrodniczego, ul. Dojazd 11, 60-632 Poznań
Tel.: +48 61 8487586, E-mail: bgolinsk@up.poznan.pl

Martyna Gatkowska
Instytut Geodezji i Kartografii, ul. Modzelewskiego 27, 02-679, Warszawa
Tel.: +48 22 3291974, Fax: +48 22 3291975, E-mail: martyna.gatkowska@igik.edu.pl

Streszczenie: Celem badań była ocena wpływu zmian klimatycznych na wzrost użytków zielonych, ich warunki wodne i biomasę. Prognozowanie biomasy i określanie wpływu klimatu na jej rozwój jest ważnym zadaniem w zarządzaniu użytkami zielonymi w skali kraju, regionu i pojedynczego gospodarstwa łąkarskiego. Metody teledetekcji umożliwiają ocenę warunków wzrostu roślin na podstawie danych satelitarnych NOAA. AVHRR i Terra.MODIS. Rozmieszczenie użytków zielonych w Polsce zostało pobrane z bazy Corine Land Cover (CLC). Wskaźnik zieleni NDVI oraz temperatura powierzchni czynnej Ts zostały obliczone z ww. danych satelitarnych. W celu określenia trendów zmian klimatycznych zebrano dane meteorologiczne dla obszaru Polski i) z lat 1997–2015 oraz ii) 1985–2014. W wyniku przeprowadzonych analiz otrzymano: znaczące trendy temperatury powietrza (Ta) dla regionów statystycznych (NUTS2); znaczący trend rosnący temperatury powierzchni czynnej (Ts). Dla lat 1997–2015 otrzymano porównywalne wyniki pomiędzy Ts i Ts_mean oraz Ta i Ta_mean oraz znaczącą zależność dodatnią pomiędzy wskaźnikiem (z okresu kwiecień-wrzesień) standaryzowanego klimatycznego bilansu wodnego (SPEI) a produkcyjnością użytków zielonych. Dla obszaru Norwegii otrzymano trend wcześniejszego startu wegetacji na wiosnę i rosnący trend sumy temperatur powietrza w sezonie wegetacyjnym w ostatnim dziesięcioleciu, z tym, że z dużymi wahaniami w poszczególnych latach. W północnej Norwegii zanotowano również od roku 1991 trend coraz cieplejszych wiosen i jesieni. Zmiany klimatyczne mogą wpływać zarówno pozytywnie jak i negatywnie na produkcyjność użytków zielonych. Proponowane nowe metody bazujące na danych satelitarnych mogą być zastosowane do monitorowania produkcyjności użytków zielonych w celu rozpoznania trendów i anomalii klimatycznych, które mogą się zdarzyć w przyszłości, jak również mogą pomóc w planowaniu produkcji rolniczej w celu uniknięcia strat finansowych na dużą skalę.

Słowa kluczowe: użytki zielone, biomasa, NDVI, Ts, Ta, opady, SPEI, zmiany klimatyczne