REMOTE SENSING BASED NET PRIMARY PRODUCTIVITY MODELLING AND DERIVATION OF ABOVE-GROUND BIOMASS ESTIMATES FOR KAZAKHSTAN

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ABSTRACT

In this study we present results of above-ground biomass (AGB) estimation for Kazakhstan. The biomass estimation approach is based on Net Primary Productivity (NPP) data, plants' Relative Growth Rates (RGRs), and fractional cover information. The application of the methodological concept is demonstrated for three study areas in semi-arid Kazakhstan. For the validation of the AGB estimates, field data were collected in Kazakhstan in June 2011. The validation showed the high importance of accurate fractional cover information, especially for shrub biomass estimation. A classification of different herbaceous vegetation communities would improve grass biomass estimates. Providing that the required information regarding vegetation distribution and fractional cover is available, the method will allow for repeated and large-area biomass estimation for natural vegetation in Kazakhstan and other semi-arid environments.

1. INTRODUCTION

Previous studies on biomass estimation revealed several challenges for remote-sensing based biomass estimation in semi-arid regions. Most important for repeatable application and coverage of large areas is the transferability of biomass estimation approaches. Modelling approaches are among the methods that obtained most promising results. Nevertheless, modelling approaches have not been extensively analysed in the context of biomass estimation for semi-arid regions yet [1].

Net Primary Productivity (NPP) models are commonly applied for large areas. They are suitable for obtaining NPP time-series for several years. Remote-sensing based NPP models allow for regional NPP calculation. This information may be of value for the estimation of standing biomass, because NPP is closely related to above-ground biomass (AGB) [2].

The most relevant time for biomass estimation is at peak biomass or at maximum productivity. For Kazakhstan, the period of maximum vegetation productivity is in June. The aim of this study was, thus, to develop a method for estimation of standing biomass for the period of maximum vegetation growth.

2. STUDY AREAS

Three study areas were defined within Kazakhstan for application of the developed biomass estimation approach. The climate of Kazakhstan is extremely continental with high summer temperatures and freezing winters for most parts of the country. Precipitation shows an irregular distribution. Annual precipitation ranges between 100 and 400 mm, except for the mountainous regions in the South and East.

The vegetation zones of Kazakhstan show a clear north-to-south distribution. In the North a small strip belongs to the forest steppe. Further south follow large areas of the characteristic steppe and semi-desert. The most southern parts of Kazakhstan belong mainly to the southern semi-desert zone.

The three chosen study areas can be mainly characterised by semi-arid climate and are covered by predominantly natural vegetation. The location of the three study areas is shown in figure 1. The first study area lies in Central Kazakhstan in the Karaganda oblast between the cities of Balkhash and Karaganda (46°–50°N and 72°–76°E). The second study area is situated in South Kazakhstan in the Zhambyl oblast (43°–45°N and 72°–75°E). A third study area was defined in West Kazakhstan. This study area spreads along the Ural River between the cities of Atyrau, at the northern shore of the Caspian Sea, and Chapaev near Kazakhstan's northern border to Russia (47°–51°N and 50°–53°E).

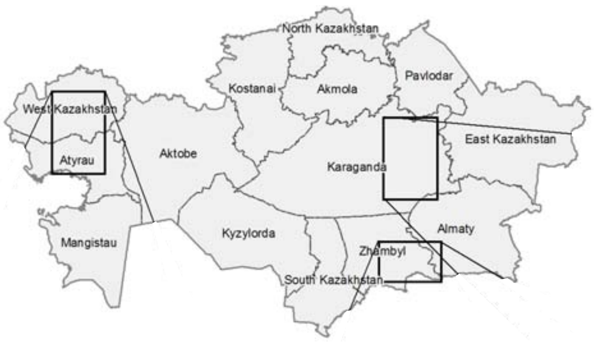

Figure 1. Location of the three study areas within Kazakhstan

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3. DATA AND METHODS

The biomass estimation approach developed in this study is based on NPP data, plants' Relative Growth Rates (RGRs), and fractional cover information.

3.1. NPP Modelling

NPP is calculated with the model BETHY/DLR (Biosphere Energy Transfer Hydrology Model; [3]), based on meteorological data (air temperature, wind speed, cloud coverage, precipitation) from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-Interim reanalysis, Leaf Area Index (LAI) 8-day composites from MODIS, and a regional land cover and land use classification for Central Asia [4]. During pre-processing the MODIS LAI data were mosaicked and gaps and outliers in the time-series were identified and corrected applying a harmonic analysis. Further input data for BETHY/DLR comprise a digital elevation model and a soil type map. Based on these input data BETHY/DLR models NPP on a daily basis with ~0.00833° spatial resolution. For each land cover pixel, NPP of two fractional vegetation types can be calculated.

The model has previously been applied for Kazakhstan within a model comparison [5] and for analysis of NPP dynamics [6]. Validation of modelled NPP results for Central Kazakhstan was performed by [7] and showed a strong correlation between modelled NPP and field data.

3.2. Field data

For the validation of the AGB estimates, field data were collected from the three study areas in Kazakhstan in June 2011. A total of 30 test sites were located in regions with relatively homogeneous vegetation cover, which span a wide range of typical biomass amounts for arid and semi-arid Kazakhstan.

The approach for biomass field data collection followed a stratified random sampling design [8], which combines destructive measurements of 1 m^2 sample plots with non-destructive stratification along transects [7], [9]. Dry weight biomass was obtained after oven drying for 48 hours at 60°C.

3.3. Biomass estimation approach

The biomass estimation procedure aims at estimating the above-ground biomass of herbaceous (grass/herbs) and woody (shrubs) vegetation for Kazakhstan for the period of maximum vegetation growth. The methodological concept is based on the NPP time-series, information about fractional cover of herbaceous and woody vegetation, and plants' relative growth rates (RGRs).

Relative growth rates of plants have been widely studied in plant physiology. The RGR of a plant is defined as the mass increase per standing biomass per unit of time, for example as g g^{-1} d^{-1}. Some studies consider total plant biomass (TPB), while others relate the increase only to the above-ground biomass present, as shown in equation 1 [10].

$$RGR_{AGB} = \frac{1}{AGB}\frac{dTPB}{dt} \quad (1)$$

NPP for grass and shrubs was modelled separately for each pixel with BETHY/DLR. Thus, it is possible to apply RGR values separately for these two vegetation types to derive grass and shrub biomass.

From the daily NPP time-series, the maximum daily NPP values for grass and shrubs for the period of maximum vegetation productivity (e.g. June 2011 in Kazakhstan) are extracted.

The maximum daily NPP values are then combined with information about relative fractional cover of grass and shrubs. This information is used to scale the NPP of grass and shrubs according to their relative fractional cover. This results in maximum daily NPP values for the grass fraction and the shrub fraction within a pixel. Two approaches were tested within this study: first, with constant fractional cover values as defined in the land cover map [4] - second, with variable fractional cover values from field estimation [9].

Maximum RGRs for individual species are available in the literature (see [9]). The RGRs are often derived from seedling experiments. Thus, an adjustment has to be applied, which converts RGR_{max} of seedlings to RGR_{max} of established plants ($r_{Est./Seed}$). Another conversion of the RGR values is necessary for values from studies that aim at deriving RGR_{TPB} instead of RGR_{AGB} ($r_{AGB/TPB}$). The necessary conversion factors have been derived based on information available in the literature.

The next step is the calculation of average maximum RGR_{AGB} values for the two plant life-forms of grasses and shrubs. Finally, the maximum NPP values and the maximum RGR_{AGB} values are combined to estimate the AGB. The approach can be summarized in the following equation 2.

$$Biomass = \frac{NPP_{\max} \cdot FC}{RGR_{TPB,\max} \cdot r_{Est./Seed} \cdot r_{AGB/TPB}} \quad (2)$$

The two values of grass and shrubs AGB are finally summed to obtain the total standing AGB of grass and shrubs.

4. RESULTS AND DISCUSSION

The developed approach was applied to estimate biomass for the three study areas in Kazakhstan. The results of the above-ground biomass estimation for grass and shrub biomass are presented in figure 2.

The validation with field data showed that the NPP-based above-ground grass biomass estimates are lower than the field-observed grass biomass for most test sites (figure 3). This indicates that the NPP input is too low and/or that the applied RGRs for grass are too high. To reduce the error associated with the RGR values, more experimental studies with plants typical for the study areas in Kazakhstan are needed. The moderate overall correlation between modelled grass biomass and field-observed grass biomass (R=0.64) might be caused by a high variation of herbaceous species present within the test sites. For NPP calculation with BETHY/DLR based on the Central Asia land cover and land use map, only two grass types are distinguished. A map that provides information on the spatial distribution of different vegetation types and the separate modelling of additional vegetation types with BETHY/DLR would be needed to improve the grass biomass results.

The validation of the shrub biomass estimates (figure 4) showed a large difference between the results obtained with fractional cover information based on the land cover map (R=0.33) and the estimates obtained with fractional cover from field observations (R=0.83). These results reveal the high importance of accurate fractional cover information for shrub biomass estimation. The accuracy for individual sites is obviously not sufficient for reliable shrub biomass estimation. Unfortunately, a suitable fractional cover dataset currently not exists for Kazakhstan. Such information can, however, be derived from remote sensing. Provided that accurate shrub fractional cover is available, the developed approach seems to yield good estimates of above-ground shrub biomass.

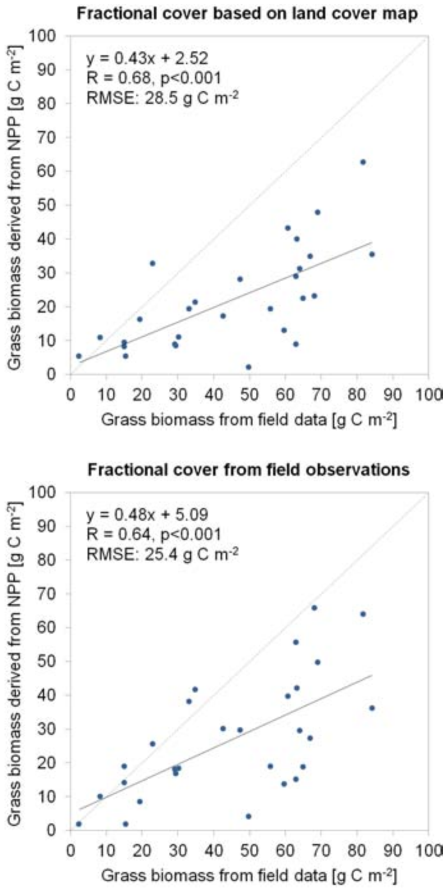

Figure 3: Correlation between grass biomass derived from NPP data and grass biomass from field observation.

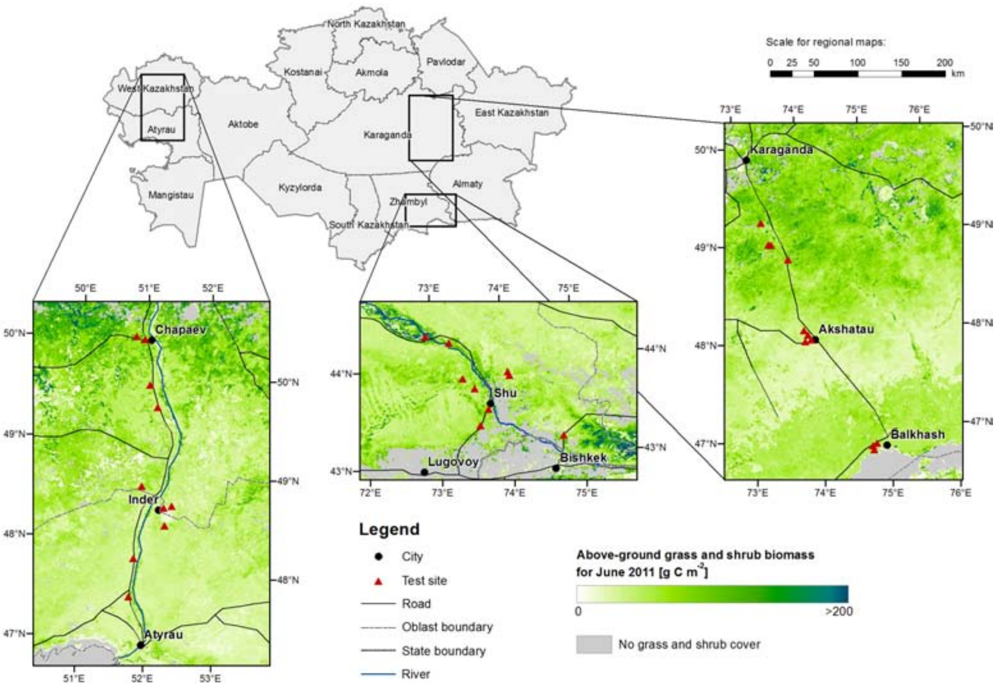

Figure 2: Above-ground grass and shrub biomass for June 2011 derived for the three study areas.

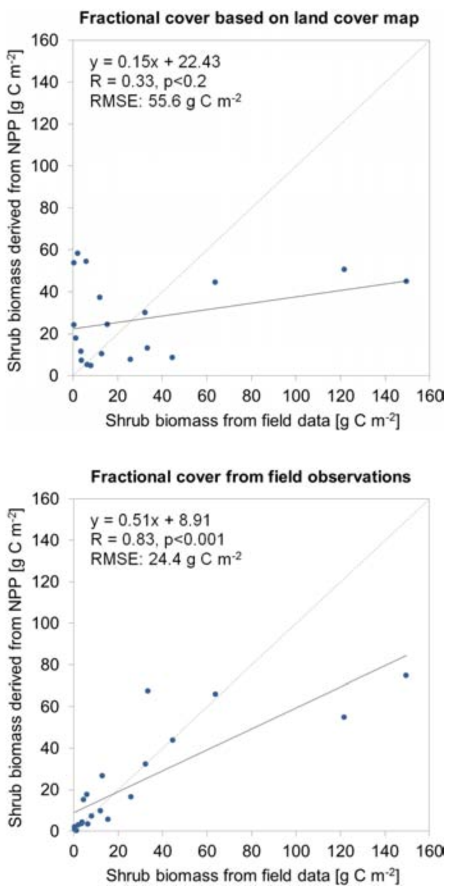

Figure 4: Correlation between shrub biomass derived from NPP data and shrub biomass from field observation.

5. CONCLUSIONS

The validation with field data showed the high importance of accurate fractional cover information. This information is especially important for estimation of woody biomass. A classification of different herbaceous vegetation communities is needed for a better representation of the NPP variability within the large and diverse steppe areas in Kazakhstan. This in turn will improve the herbaceous biomass estimates.

The developed method is potentially transferable. Providing that the required information regarding vegetation distribution and fractional cover is available, the method will allow for repeated and large-area biomass estimation for natural vegetation in Kazakhstan and other semi-arid environments. Future research could comprise to use Envisat MERIS and Sentinel-3-OLCI data to derive LAI time series as input for the model.

6. ACKNOWLEDGEMENTS

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