Forest ecosystem health assessment by exergy approach

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ABSTRACT

The plant cover is the main absorbing landscape surface. Morphological and biochemical changes in this surface are associated with the extraction of information from the environment, including the solar spectrum. Interaction of the solar radiation with vegetation is resulting as a new composition of the spectrum of outgoing radiation. The exergy of the solar radiation, reflected by the surface of forest ecosystem, has been calculated by using digital data, recorded by the remote sensing satellites. In the study this approach has been applied to the assessment of the forest ecosystem health in the North-East part of the Czech Republic on the base of Landsat TM and ETM data. Changes of exergy values indicated the changes in the forest ecosystem processes.

INTRODUCTION

The forest ecosystem as an important natural resource provides valuable ecological functions. Therefore it is necessary to monitor the forest ecosystem health state.
Exergy is demonstrated to be a useful measurable parameter reflecting the state of the ecosystem and allowing estimation of the severity of its anthropogenic damage. According to recent studies (1,2,3,4) exergy is shown to have advantages such as good theoretical basis in thermodynamics, close relation to information theory, rather high correlation with others ecosystem goal functions and relative ease of computation with remote sensing data.
The ecosystem exergy is a measure of its deviation from thermodynamic equilibrium with the environment, and represents the maximum capacity of energy to perform useful work as the system proceeds to equilibrium, with irreversibility increasing its entropy at the expense of exergy. Taken by itself, the total exergy of an ecosystem is a measure of the change in entropy content from the equilibrium and the actual state.
In the study this approach has been applied to the assessment of the forest ecosystem health.

METHODS

Study area
The study area is located in Beskids Mountains, the North-East part of the Czech Republic at latitude 49.50N and longitude 18.80E. The mountains consist of a plateau, gradually sloping towards Poland and Slovakia side. The altitude varies from 500 to 900 m. The dominant forest type is even aged monoculture Norway spruce (Picea abies) followed by European beech (Fagus sylvatica) with insignificant transition to Scotch pine (Pinus sylvestris), Silver fir (Abies alba Mill.), European larch (Larix decidua) and ash (Fraxinus excelsior). Forests in this area are characterized by highly variable tree vigor and mortality rates due to severe airborne pollution during communist times, as well as unsustainable forest management (5,6).
Data
Landsat TM and ETM data (Augusts 1987, 2001, 2002, 2003, 2010, 2011) were used to calculate the ecosystem exergy.

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Exergy mapping

The important basic conclusion (Jørgensen and Svirizhev, 2004) is as follows: the productivity of ecosystem changes due to anthropogenic loading. To put it in other words, ecosystem can decrease (or increase in case of fertilization) its biomass productivity, depending on the amount and type of anthropogenic loading. It means that the solar exergy input to ecosystem is spent on: 1) the standard entropy removing from ecosystem (in other case a degradation of biomass of ecosystem must take place); 2) the removing of the additional entropy induced by anthropogenic loading. As a result of loading, the productivity of ecosystem decreases. If the productivity of the ecosystem biomass under anthropogenic loading reaches zero, the further anthropogenic loading increase will result in the degradation of ecosystem biomass.

The calculation of exergy of the reflected solar radiation can be measured using the technique described by S. Yorgensen and Yu. Svirezhev. The technique is based on the multispectral images for a unit of surface which is performed by evaluating the “distance” between the real frequency distribution of absorption spectrum of solar energy and the “equilibrium” frequency distribution. The degree of difference between the distributions is measured by the increment of Kullback entropy. The increment is zero when the frequency distribution of incoming radiation is equivalent to the frequency distribution of reflected radiation across the spectrum (meaning that the information receptor is equivalent to the information transmitter). If the Kullback entropy increment is positive, then there is an increment of information at the level of receptor and the reflective surface is in non-equilibrium state relative to the radiation spectrum. The Kullback’s measure (К, nit) is calculated as:

$$K = \sum_{i=1}^{n} p_i \, log\left(\frac{p_i}{p_i^0}\right), \quad [1]$$

where p_i^0, p_i are probabilities before and after the interaction respectively.

The exergy of solar radiation (Ex) is estimated as:

$$Ex = E^{out}\left(K + ln\frac{E^{out}}{E^{in}}\right) + R, \quad [2]$$

where E^{in} – incoming solar radiation, E^{out} – reflected solar radiation, R = E^{in} – E^{out} - absorbed energy, K – Kullback’s measure, E^{out}/E^{in} – albedo. The surface albedo can be mapped by using the standard MODIS Level 1B product, described in (7). The result of mapping of Ex is represented in Figure 1.

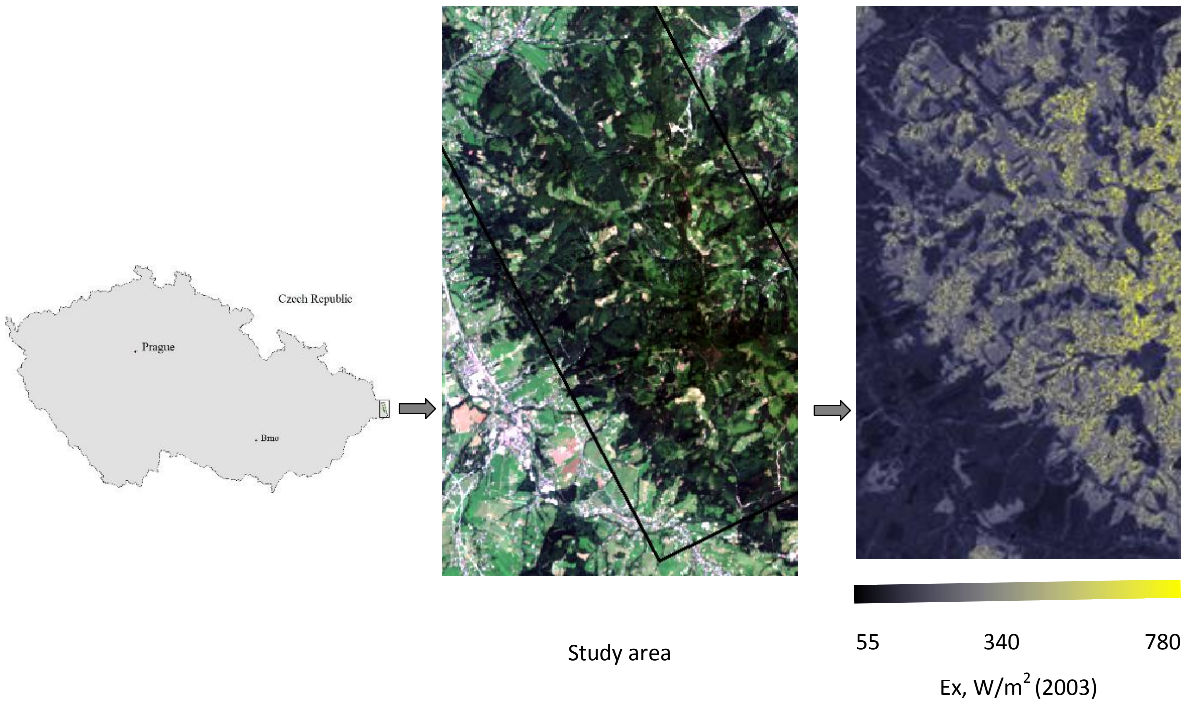

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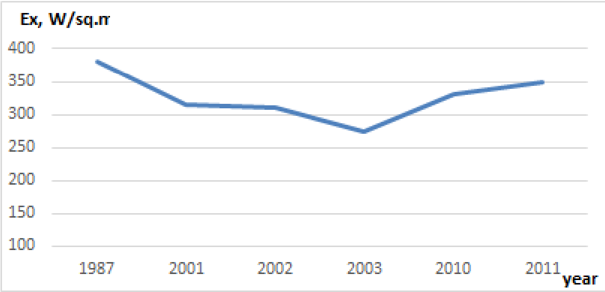
Figure 1: Example of the ecosystem exergy calculation (Ex)

RESULTS

The change detection analysis demonstrates significant exergy variations in comparison with exergy values from 1987 till 2011 (Fig.2). These variations are interpreted as an exergy consumption for the transpiration and the carbon deposition, which determined the past and current health of the mountain forest ecosystem.

On the base of exergy values changes we can indicate the changes in the forest ecosystem process. For example, extreme weather conditions in 2003 accelerated extensive bark beetle outbreaks (5). Simultaneously the strong decline of the exergy curve was obtained. Moreover, previous study reported (9) about the recovered biomass from the past years to 2010 that corresponded to increasing the exergy consumption for the transpiration and the carbon deposition the same year.

Summarizing, this study demonstrated the calculation of exergy values using the time series Landsat satellite data. Exergy variation could be an indicator of the ecosystem changes and applied to the analysis of the forest ecosystem health.



Figue 2: Average values of exergy calculated for the whole study area

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