International Environmental Modelling and Software Society (iEMSs)
2012 International Congress on Environmental Modelling and Software
Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany
R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.)
http://www.iemss.org/society/index.php/iemss-2012-proceedings

Spatio-temporal Characterisation of Ecosystem Functions Based on Macro-habitats

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Abstract: Analysis and forecast of the spatial distribution and dynamics of ecosystem services is an important element of sustainable land management. The aim of this paper is to analyse the spatial and temporal variability of various ecosystem functions using indices derived from remote sensing products. These are applied in macro habitat types in a test area in the River Dee catchment in the north-east of Scotland, with a wide range of morphological features, soils and habitats and providing multi-functional ecosystem services (ESs), such as water quality, soil health, and biodiversity. A set of indices, single and multi-date, were derived from remotely sensed data (from the Terra Moderate Resolution Imaging Spectro-radiometer; MODIS) and tested with respect to their potential for providing information relevant to analysing a targeted set of ecosystem functions. The indices considered were: i) Enhanced Vegetation Index, ii) primary productivity and iii) derived drought indices, such as the Normalised Difference Water Index. Representative climatic conditions were compared for two years. The macro habitats were derived from a detailed land cover and habitat dataset. The results provided a spatial measure of ecosystem functions in the test area with dynamic temporal modelling and estimation of uncertainty.

Keywords: remote sensing; ecological classification; climate change

1 INTRODUCTION

The Ecosystem Approach (EA) is a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use. The link between ecosystem services and their biophysical underpinning, including biodiversity and ecosystem productivity, is a major focus at present for both applied and fundamental research.

Analysis and forecasting of the spatial distribution and dynamics of ecosystem services is an important element of sustainable land management. Recent studies have noted that the most successful and promising approach to estimating such properties continuously over time and space should include a combination of remote sensing and modelling methods [Potapov et al., 2009; Westermann et al., 2011]. Remote sensing data provide information for spatially distributed variables across different spatio-temporal scales that can be used for eco-hydrological modelling, such as estimates of water and carbon stocks, climatic variables and information on land cover [Hu et al., 2009], forest and soil monitoring and modelling.

The aim of this paper is to analyse the spatial and temporal variability of various ecosystem functions using indices derived from remote sensing products. These are applied to macro habitat types in the test area.

2 METHODOLOGY

The test area is situated in the River Dee catchment in the north-east of Scotland, with a wide range of morphological features, soils and habitats and providing multiple ecosystem services (ESs), such as water quality, soil health, and biodiversity. A set of indices, single and multi-date, were derived from the Terra Moderate Resolution Imaging Spectroradiometer (MODIS) 8 days composite products, and tested with respect to their potential for providing information relevant to analysing a targeted set of ecosystem functions. The indices considered were:

1. Enhanced Vegetation Index [EVI; Huete et al., 2002],
2. Gross Primary Productivity [GPP; Running et al., 1999], and
3. derived drought indices, such as the Normalised Difference Water Index [Gao, 1996]

$$NDWI = \frac{\rho_{NIR} - \rho_{SWIR}}{\rho_{NIR} + \rho_{SWIR}} \tag{1}$$

Representative climatic conditions were compared for two extreme years, i.e. 2003 for dry and 2008 for wet conditions. The results are presented and discussed for three of the indices, EVI, NDWI and GPP, as example of vegetation and drought indices.

The macro habitats were derived from a detailed land cover and habitat dataset at a resolution of 10m [Land Cover of Great Britain 2007; Morton et al., 2011]. The habitats considered (Figure 1 were: 1. forests: broadleaves and coniferous; 2. arable; 3. grassland: improved, rough, neutral, acid and calcareous; 4. bog and heather; 5. montane and 6. urban, suburban, rock and littoral areas.

The MODIS products used were summarised by land use category for each day of the year (DOY) for the two years using median, lower and upper quantiles (Figure 2). The quantile values were used to calculate the variability in each category with the following equation:

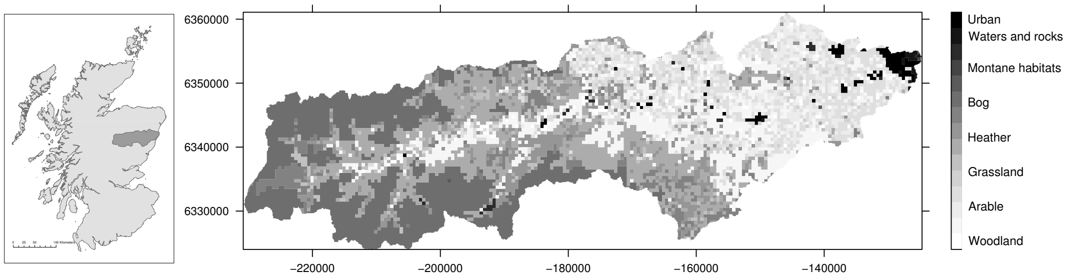
$$variability = quantile_{upper} - quantile_{lower} \tag{2}$$

The study was implemented using open source software: GRASS [GRASS Development Team, 2011] for GIS analysis, R [R Development Core Team, 2011] for statistical and spatial analysis, and PostGIS for data organisation and storage.

3 RESULTS

The results provided a spatial measure of ecosystem functions in the test area with dynamic temporal modelling and estimation of uncertainty obtained with eq. 2. The results were used to model the availability of ecosystem functions using macro habitats.

Figure 3 shows the median value for EVI in the different habitat patches as an overview for 23 dates for year 2003. This allows interpretation of broad differences through the year.



(a) Dee catchment (b) Map of considered habitats

Figure 1: Location map of the test area. The coordinates are projected according to the MODIS sinusoidal grid.

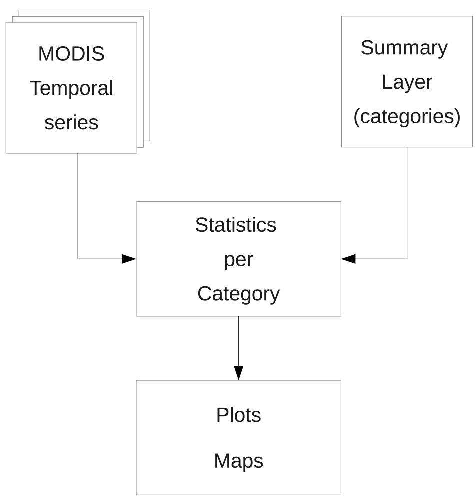


Figure 2: Description of the procedure followed.

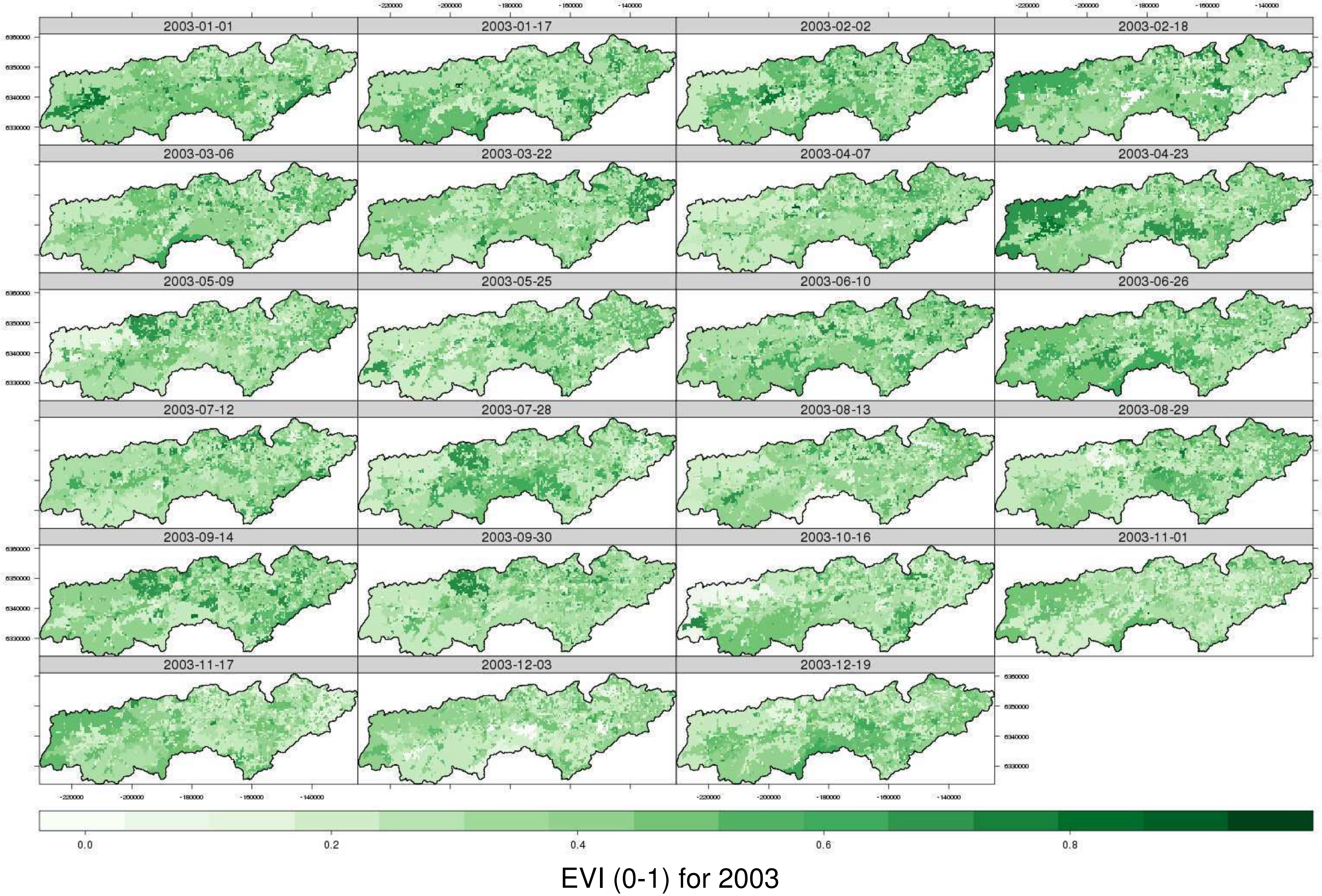


Figure 3: Spatial distribution of EVI values (0-1 range) in macro-habitats for 2003. Only the data for 2003 are shown here.

The spatio-temporal trend is evident with important changes especially in the montane and bog habitats. The variability is rather low indicating the lack of extreme values.

The median values for NDWI in the different habitat patches for year 2003 (not shown here) are similar. The spatio-temporal trend is broadly uniform with changes for mountain habitats. Dryer areas are located in the mountain habitats, where soils are thinner with lower buffer capacity for drought events. The variability is low with higher values in the montane areas and next to the coast.

Figure 4 shows the EVI values for 2003 and 2008 for six representative habitats. In 2003 it is possible to identify a peak in the summer season, especially for agricultural land use, grassland and broadleaved woodlands. Coniferous woodland, bogs and montane habitats presented a more uniform temporal pattern. However, the variability (as calculated with eq. 2) is high. The temporal trend for 2008 is different, with a less pronounced peak in the summer and with secondary peaks, probably reflecting the wetter climate for that year.

Figure 5 shows the NDWI values for 2003 and 2008 for six representative habitats. In 2003 it is possible to identify a clear peak for agricultural land use, also visible for grassland and broadleaved woodlands. The temporal pattern for 2008 is more scattered, presenting numerous small peaks linked with the precipitation pattern. 5Also in the case of NDWI, the variability of the values is rather high.

The temporal pattern of the GPP values for 2003 and 2008 for the six representative habitats for both 2003 and 2008 have some similarity to the one presented for EVI (Figure 4). However the variability in the values is even higher, indicating the difficulties of measuring this parameter at a resolution of 500m. The pixels are thus a mix of different land use, increasing the variability of the values.

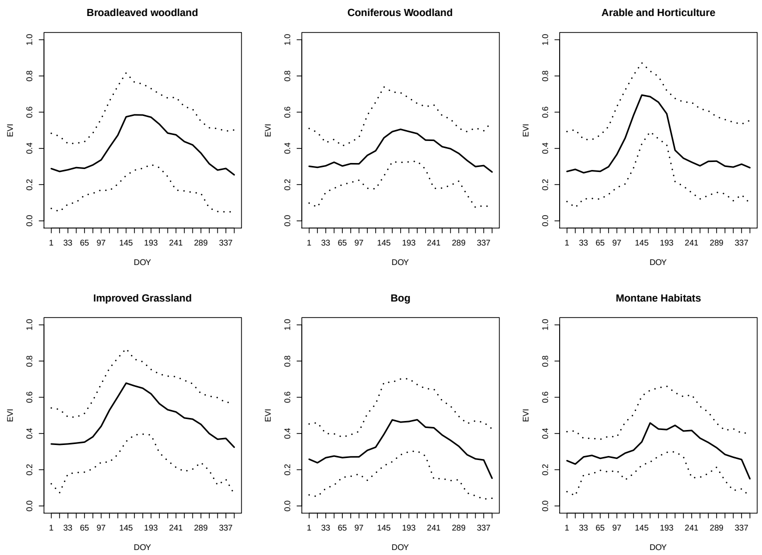
4 Concluding remarks and future work

It is important to better understand how the quality, configuration and dynamics of ecosystems functions vary within landscapes to support decision-making. The delivery of some of the ecosystem functions depends on their spatial context. International initiatives have highlighted major scientific challenges in characterising, quantifying, monitoring and mapping stocks and flows of ecosystem functions accounting for both temporal and spatial variability. Only few studies approached the variability of provisioning of ecosystem functions over time [Lautenbach et al., 2011].

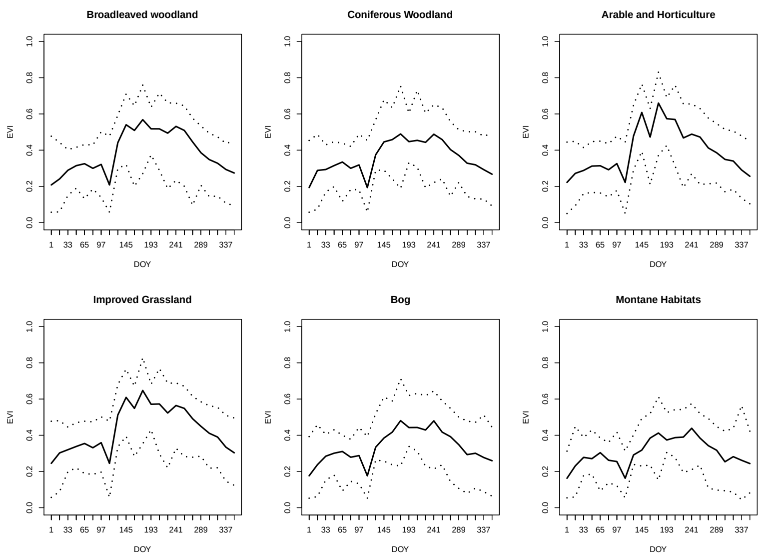
The ecosystem functions in the test area were summarised through a spatial measure coupled with dynamic temporal modelling and estimation of uncertainty. The results were useful for characterising the habitats and to measure the availability of ecosystem functions provided by macro habitats, focussing on spatial and temporal variability.

The work presented is a preliminary test run for only two extreme years. The results showed different temporal patterns according to the climate conditions of each year. Further work is needed to: 1. summarise the results for more years; 2. measure the capability of the obtained results to differentiate between habitats in various conditions; and 3. characterise and measure the availability of ecosystem functions by other type of data, such as soil types.

Finally the results obtained need to be linked to impact models of direct and indirect changes in land use due to climate change [see e.g. Gimona et al., 2012].

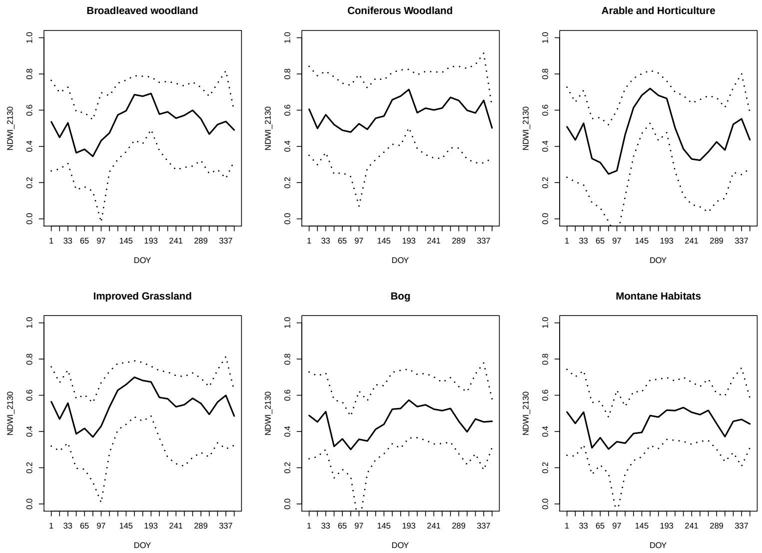


(a) EVI 2003

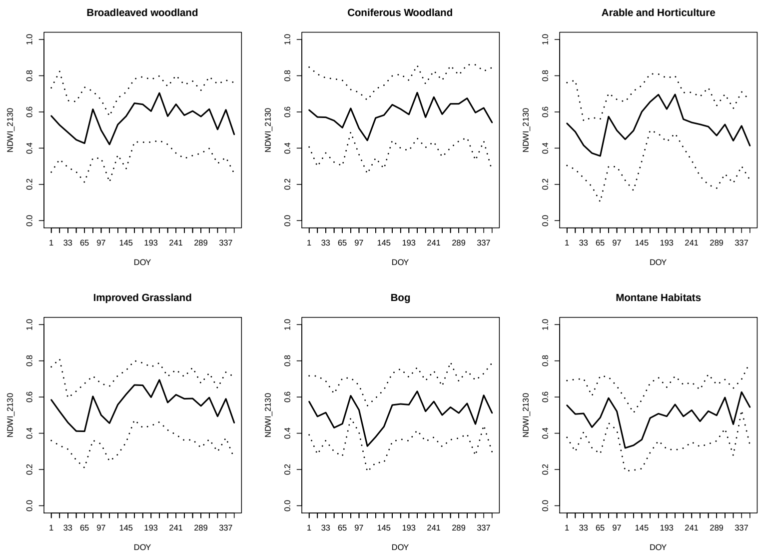


(b) EVI 2008

Figure 4: EVI values with confidence intervals (quantiles of the distribution) for six representatives macro-habitats: (a) 2003, (b) 2008.



(a) NDWI 2003



(b) NDWI 2008

Figure 5: NDWI values with confidence intervals (quantiles of the distribution) for six representatives macro-habitats: (a) 2003, (b) 2008.

ACKNOWLEDGMENTS

This work was funded by the Scottish Government Environment, Land use and Rural Stewardship research programme. MODIS data are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center (lpdaac.usgs.gov).

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