Spatial and Temporal Variability of Global Ecosystem Functional Types

Shanley D. Thompson[1], Trisalyn A. Nelson[2], Nicholas C. Coops[3], Michael A. Wulder[4] , Trevor C. Lantz[5]

[1]Geography, University of Victoria sdthomps@uvic.ca
[2]Geography, University of Victoria trisalyn@uvic.ca
[3]Forest Resources Management, University of British Columbia nicholas.coops@ubc.ca
[4]Canadian Forest Service-Pacific Forestry Centre, Natural Resources Canada mwulder@nrcan.gc.ca
[5]Environmental Studies, University of Victoria tlantz@uvic.ca

Abstract

Ecosystem functions provide a range of services vital to human well-being. Remote sensing of ecosystem functional types provides a framework for monitoring and predicting changes to ecosystem services at broad scales, frequent time steps and in a spatially continuous manner. In this research, we seek to understand the spatial distribution and temporal dynamics of ecosystem functional types at a global scale. We developed a global classification of ecosystem functional types by clustering nine years of remotely sensed estimates of ecosystem productivity, with and without topography. Changes occurring within the functional types over nine years (2003 to 2011) were then analyzed. When topography was excluded, changes were apparent in the distribution of functional classes (clusters) between 2003 and 2011. Further exploration of the effects of static versus dynamic variables is one area of recommended research. We also recommend continued and more detailed monitoring in areas where change was detected to determine potential effects on ecosystem service provision.

Background and Relevance

Human well-being depends on essential ecosystem services such as water regulation, food production, and climatic regulation (Millennium Ecosystem Assessment, 2005). Provision of these services is influenced by the diversity of *functional traits* within an ecosystem (de Bello et al., 2010; Díaz et al., 2007; Tilman, 2001). Functional traits include characteristics such as vegetation height, woodiness, leaf size, root depth, dispersal mode, regeneration mode, photosynthetic rate, and phenology (Chapin, Bret-Harte, Hobbie, & Zhong, 1996; Díaz et al., 2004). Compared to other biodiversity measures such as species richness and relative abundance, functional diversity more directly relates to ecosystem function, process, stability and service delivery (de Bello et al., 2010; Diaz & Cabido, 2001; Hooper et al., 2005). Monitoring changes in functional diversity over time is therefore very important. The objective of this study is to assess global ecosystem function stability over approximately the past decade. To meet this objective, we map ecosystem functional types using remotely sensed estimates of total and seasonality of primary productivity and topography, and assess changes in these functional types between 2003 and 2011.

Methods and Data

Classification of ecosystem functional types used several remotely sensed measures. Rather than a bottom-up approach based on individually measured plant functional traits, remotely sensed functional classifications are a top-down approach using measures expressing the most dominant and most visible functional traits at the canopy, stand, or ecosystem level (Alcaraz-Segura, Paruelo, Epstein, & Cabello, 2013; Ustin & Gamon, 2010). The remote sensing approach is useful for estimating ecosystem function across broad areas in a spatially continuous and repeatable manner, enabling monitoring of ecosystem function dynamics over time (Ivits, Cherlet, Mehl, & Sommer, 2013; Paruelo, Jobbágy, & Sala, 2001).

Key inputs to the functional type classification were the global FPAR data from the Moderate Resolution Imaging Spectrometer (MODIS), available annually between 2000 and 2012 at a spatial resolution of 0.05 degrees. FPAR is the Fraction of Photosynthetically Active Radiation absorbed by the canopy. It is a biophysical variable that depends on vegetation type and structure and is used in estimating ecosystem productivity and biogeochemical cycling (Huete, Didan, van Leeuwen, Miura, & Glenn, 2011; Myneni et al., 2002). From these data, we calculated total annual FPAR ($FPAR_{sum}$), and annual coefficient of variation of FPAR ($FPAR_{cv}$), following examples for use in biodiversity(Coops, Wulder, Duro, Han, & Berry, 2008) and functional diversity models (Alcaraz-Segura et al., 2013).

We also tested the utility of topographic data, which may cause fine-scale spatial heterogeneity in the distribution of functional traits (Díaz et al., 2007; Lavorel & Garnier, 2002; Lavorel et al., 2011). Topography data was acquired from the Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010), which primarily uses data from the Shuttle Radar Topography Mission (SRTM) (Danielson & Gesch, 2011). Maximum and minimum elevation layers, available at 30 arc seconds spatial resolution, were coarsened to 0.05 degree spatial resolution to match the resolution of the MODIS imagery and used to calculate elevation range.

The global ecosystem functional types were created using multivariate clustering of the annual averages of the input variables for 2003 and 2011, once including, and once excluding elevation range. For each model run, data from all years were clustered together to reduce spurious change detection that can result due to the inherent variability of clustering (Mills et al., 2013; Rinsurongkawong & Eick, 2010). Because the magnitude and range of values of the input variables are quite different form one another, the variables were standardized to z-scores prior to clustering. Two-step clustering in SPSS was chosen because it can handle very large amounts of data as well as both continuous and categorical data. In two-step clustering, raw data points are first partitioned into a set of pre-clusters. Then, a hierarchical agglomerative clustering method consecutively joins the pre-clusters into a smaller number of clusters based on their distance in feature space (Mooi & Sarstedt, 2011).

Results and Conclusion

We generated a map of 15 ecosystem functional types for 2003 and 2011. The functional types differentiate between major biomes such as tropical and subtropical forests, temperate coniferous, broadleaf, and mixed forests, temperate grasslands and shrublands, boreal forests and tundra. When elevation range was incorporated into the cluster analysis, no change in the distribution of functional classes was detected between 2003 and 2011. When elevation range was excluded from the analysis, clusters did change over time, particularly in temperate and Polar Regions.

These findings demonstrate the importance of careful selection of input variables in cluster analysis (i.e., static versus dynamic) when change detection is the goal. We recommend more detailed *in-situ* monitoring in the areas where change was detected in order to determine the true magnitude of change, and the severity of possible threats to ecosystem function and the provision of ecosystem services. As the archive of remotely sensed data increases over time, our quantitative, transparent analysis could be repeated with relative ease to monitor future changes.

References

Alcaraz-Segura, D., Paruelo, J., Epstein, H., & Cabello, J. (2013). Environmental and Human Controls of Ecosystem Functional Diversity in Temperate South America. *Remote Sensing*, *5*, 127–154. doi:10.3390/rs5010127

Chapin, F. S. I., Bret-Harte, M. S., Hobbie, S. E., & Zhong, H. (1996). Plant functional types as predictors of transient responses of arctic vegetation to global change. *Journal of Vegetation Science*, *7*(3), 347–358. doi:10.2307/3236278

Coops, N. C., Wulder, M. A., Duro, D. C., Han, T., & Berry, S. (2008). The development of a Canadian dynamic habitat index using multi-temporal satellite estimates of canopy light absorbance. *Ecological Indicators*, *8*(5), 754–766. doi:10.1016/j.ecolind.2008.01.007

Danielson, J. J., & Gesch, D. B. (2011). *Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010): U.S. Geological Survey Open-File Report 2011-1073* (p. 26). U.S. Geological Survey, Reston, Virginia.

De Bello, F., Lavorel, S., Díaz, S., Harrington, R., Cornelissen, J. H. C., Bardgett, R. D., … Harrison, P. a. (2010). Towards an assessment of multiple ecosystem processes and services via functional traits. *Biodiversity and Conservation*, *19*(10), 2873–2893. doi:10.1007/s10531-010-9850-9

Diaz, S., & Cabido, M. (2001). Vive la différence: plant functional diversity matters to ecosystem processes. *Trends in Ecology & Evolution*, *16*(11), 646–655. doi:10.1016/S0169-5347(01)02283-2

Díaz, S., Hodgson, J. G., Thompson, K., Cabido, M., Cornelissen, J. H. C., Jalili, A., … Zak, M. R. (2004). The plant traits that drive ecosystems: Evidence from three continents. *Journal of Vegetation Science*, *15*(3), 295. doi:10.1658/1100-9233(2004)015[0295:TPTTDE]2.0.CO;2

Díaz, S., Lavorel, S., de Bello, F., Quétier, F., Grigulis, K., & Robson, T. M. (2007). Incorporating plant functional diversity effects in ecosystem service assessments. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(52), 20684–9. doi:10.1073/pnas.0704716104

Hooper, D., Chapin, F. S. I., Ewel, J., Hector, A., Inchausti, P., Lavorel, S., ... Wardle, D. (2005). Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecological Monographs*, *75*(1), 3–35.

Huete, A., Didan, K., van Leeuwen, W., Miura, T., & Glenn, E. (2011). MODIS Vegetation Indices. In B. Ramachandran (Ed.), *Land Remote Sensing and Global Environmental Change, Remote Sensing and Digital Image Processing* (pp. 579–602). Springer. doi:10.1007/978-1-4419-6749-7

Ivits, E., Cherlet, M., Mehl, W., & Sommer, S. (2013). Ecosystem functional units characterized by satellite observed phenology and productivity gradients: A case study for Europe. *Ecological Indicators*, *27*, 17–28. doi:10.1016/j.ecolind.2012.11.010

Lavorel, S., & Garnier, E. (2002). Predicting changes in community composition and ecosystem functioning from plant traits: revisiting the Holy Grail. *Functional Ecology*, *16*, 545–556. doi:10.1046/j.1365-2435.2002.00664.x

Lavorel, S., Grigulis, K., Lamarque, P., Colace, M.-P., Garden, D., Girel, J., ... Douzet, R. (2011). Using plant functional traits to understand the landscape distribution of multiple ecosystem services. *Journal of Ecology*, *99*(1), 135–147. doi:10.1111/j.1365-2745.2010.01753.x

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: synthesis*. Island Press, Washington, DC.

Mills, R. T., Kumar, J., Hoffman, F. M., Hargrove, W. W., Spruce, J. P., & Norman, S. P. (2013). Identification and Visualization of Dominant Patterns and Anomalies in Remotely Sensed Vegetation Phenology Using a Parallel Tool for Principal Components Analysis. *Procedia Computer Science*, *18*, 2396–2405. doi:10.1016/j.procs.2013.05.411

Mooi, E., & Sarstedt, M. (2011). Chapter 9: Cluster Analysis. In *A Concise Guide to Market Research*. Berlin Heidelberg: Springer-Verlag.

Myneni, R., Hoffman, S., Knyazikhin, Y., Privette, J., Glassy, J., Tian, Y., ... Running, S. (2002). Global products of vegetation leaf area and fraction absorbed PAR from year one of MODIS data. *Remote Sensing of Environment*, *83*, 214–231.

Paruelo, J. M., Jobbágy, E. G., & Sala, O. E. (2001). Current Distribution of Ecosystem Functional Types in Temperate South America. *Ecosystems*, *4*(7), 683–698. doi:10.1007/s10021-001-0037-9

Rinsurongkawong, V., & Eick, C. F. (2010). Correspondence Clustering: An Approach to Cluster Multiple Related Spatial Datasets. In *Advances in Knowledge Discovery and Data Mining. 14th Pacific-Asia Conference, PAKDD 2010, Hyderabad, India, June 21-24, 2010. Proceedings. Part I* (pp. 216–227).

Tilman, D. (2001). Functional Diversity. In S. Levin (Ed.), *Encyclopedia of Biodiversity, Volume 3* (pp. 109–120). Academic Press.

Ustin, S. L., & Gamon, J. A. (2010). Remote sensing of plant functional types. *New Phytologist*, *186*, 795–816. doi:10.1111/j.1469-8137.2010.03284.x