Seasonal changes in functional diversity at the ecosystem level from MODIS-Land LAI and FPAR: A case study in the NE region of Rio Grande do Sul, Southern Brazil.

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Introduction. The term 'ecosystem' in this paper implies an abstract construct denoting a convolution of both physical and biological components in an environment, considered in relation to each other as a unit. From the reciprocal interactions emerge the spatio-temporal pattern of biomass, carbon gains and energy exchange, which we signify by the term 'ecosystem functioning'. The seasonal dynamics of ecosystem level attributes, such as the Leaf Area Index (LAI) or the Fraction of Photosynthetically Active Radiation (FPAR), captured by time-series of hyperspectral satellite images (MODIS-Land 12Q1 dataset), provide a suitable approach to characterization of ecosystem functioning. Pixels in MODIS-Land 12Q1 images can be classified as to delineate ecological entities with similar temporal trends of LAI and FPAR, regarding each class as being internally homogeneous in terms of functioning in the defined context. In this paper, we assess the diversity of such functionally-defined ecological entities on a seasonal gradient in the annual cycle of 2002. The site of interest is located in the north-east region of Rio Grande do Sul, Brazil. The actual study area, which has been described as transitional between herbaceous-dominated and forested subtropical ecosystems, encloses a high diversity of land-cover types, defined by the dominant structural vegetation traits . That the vegetation cover diversity is closely connected to the local wide-spectrum settings of the physical environment and land-use patterns is well known. What is not so well known is how closely that diversity corresponds to a similarly intense spatio-temporal variability of the functional entities. This is the issue what we wish to argue from a broad ecological science point of view.

Objectives. 1- To describe the seasonal trends of the ecosystem level attributes LAI and FPAR. 2- To classify MODIS-Land 12Q1 imagery into seasonal functional types (SFTs), according to the ecosystem-level variables: LAI, FPAR and their interactions (product moments). 3- To depict temporal trends of the SFTs diversity within and between land-cover types. 4- To advance on the interpretation of the causal relationships between the SFTs diversity and specific variables of the physical environmental and land-use patterns in time and space.

Methods. A time-series of Modis-Land 12Q1 images (pixel size 1 km^2 and 8d of temporal resolution) covering the year of 2002 and the area between 28 and 30° Lat. S., and 51 to 49° Long. W. of Rio Grande do Sul, was projected into the Lat-Long WGS84 system. Out of the time-series, divided into 4 seasons of 24 images each (12 for LAI and 12 for FPAR, coupled by corresponding dates), mean seasonal values of LAI (μL_{hi}) and FPAR (μF_{hi}), as well as the product moment of the variables (S_{hi}, see formula below) was calculated for each pixel.

$S_{hi} = \sum_{j=1}^{n} \left(L_{hij} - mL_{hi}\right) * \left(F_{hij} - mF_{hi}\right)$ where h = 1, 2, 3, 4 for seasons, i = 1, 2, …, 23923 for pixels, and j = 1, 2, …, 12 for observations within each season.

According to a digital elevation model of the same spatial resolution (available at the NOAA site: http://www.ngdc.noaa.gov/cgi-bin/seg/ff/nph-newform.pl/seg/topo/customdatacd), the area was divided into three strata: lowland (< 100 m asl), Serra Geral (100 to 700 m asl) and high tableland (>700 m asl). Stratified sampling was performed, retrieving a sample of 250 pixels, each described by LAI, FPAR and S. The sample per stratum was subjected to cluster analysis (Ward's method) after data normalization, on a per-season basis; sharpness of group partitioning was assessed using bootstrap resampling. Pixels belonging to sharp clusters, were used to create SFT signature files. In the signature files μL_{hi}, μF_{hi}, S_{hi} and altitude (A_i) were linearly rescaled within the interval 0 and 255. These were taken as pseudo-bands. Supervised classifications, using a Minimum Distance algorithm, allowed to obtain 4 SFT maps (1 per season). The SFTs were characterized in terms of their spatial average of μL_{hi}, μF_{hi} and S_{hi}: respectively μL_{hT}, μF_{hT} and S_{hT}, where the subscript T indicates the corresponding SFT. A Principal Coordinates Analysis was performed on the matrix of μL_{hT}, μF_{hT} and S_{hT} to reveal seasonal trends for the descriptors which served as the base of the classification.

LANDSAT TM Composites at 1:250,000 comprising the same area (available at http://www.cdbrasil.cnpm.embrapa.br/) were georeferenced, divided into component bands, mosaicked and resampled to fit the MODIS imagery resolution and projection. With a simple ISODATA routine of unsupervised classification, a land-cover map was produced and its accuracy weighted on the base of field observations. Classes so obtained were cross-tabulated against the SFT maps; we retrieved 4 contingency tables of absolute frequencies (number of pixels) of land-cover classes (columns) vs SFTs (rows), which were normalized both within land-cover classes and within SFTs. In three random samples of 200 pixels each, SFT frequencies in the land-cover classes, normalized within columns, were subjected to a randomization test to see whether the land cover types differed, in each season, in terms of their SFTs composition. With the data normalized within rows, cluster analysis of SFTs (Ward's method) allowed to see whether the seasonal functional types could be grouped by their association with particular land-covers classes. Partition levels were also tested for significance by bootstrap resampling. Finally, we calculated diversity values (H*) for the seasonal functional types for the whole area and for each land-cover, in a per-season basis: $H^* = H / \ln s$ where $H = \sum_{i=1}^{S} P_i * \ln P_i$, ln is the natural logarithm and P_i is the relative frequency of each *i* seasonal functional type in the study site; in this way, we assess the temporal variation of the functional entities spatial distribution.

Results. The number of seasonal functional types varied along the annual cycle, from a minimum of six, in summer, to a maximum of 11 during autumn; spring and winter both had identified 10 SFTs. Evidences of significant differences in SFT composition, among land-cover classes, were found for all seasons ($P = 0.05$), as well as evidences of the SFT's association with particular land-covers (partition levels significant at $P_{null} = 0.1$): on the base of their normalized frequencies of land cover types within SFT's, up to five sharp clusters of SFT's were found in autumn, while just three in summer and four during spring and winter. Notwithstanding that, there is no clear seasonal trend of LAI and FPAR associated with land-cover: both variables seems to be strongly controlled by local factors of the environment operating at finer spatial scales than those reflected by the land-cover classes. As expected, higher values of both LAI and FPAR were found during summer. However, some summer SFT's fell in the ordination diagram closer to winter and spring SFT's, probably those for which water deficit in summer was a forceful constraining factor. Some autumn and spring SFT's with higher values of FPAR, appeared associated with natural grasslands, whereas SFT's more related with the forest cover fell closer to the positive domain of the second ordination axis, mainly determined by LAI. Regarding the spatial patterns of SFT richness, there were substantial changes throughout 2002: although natural grasslands and mosaics of secondary forests / fallows kept the higher values in almost all seasons (H* raging from 0.76 to 0.92), the unit of croplands attained a very high H* (0.82) in summer to later sharply decrease as to reach 0.65 in spring. Mixed units of grassland / shrublands exhibited the largest variation: from 0.46 to 0.73, followed by the unit dominated by forests (forest remnants plus forest plantations) in which H* ranged from 0.64 to 0.85.

Conclusions. Spatio-temporal patterns of functional units in the study area are rather complex. There were no patterns of SFT's behavior, distribution and diversity found that could be simply related to climate or land-cover. Further analyses are needed to isolate the effects of climate and landscape from the local environmental factors within land-cover types. Furthermore, to make an accurate identification of ecosystem types, on a functional basis, it will be necessary to follow *functional trajectories* (trajectories of SFT's) in the annual cycle and group the spatial units accordingly. MODIS datasets offer an unique opportunity to perform this type of analysis.