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# LINKING BIOCHEMICAL AND BIOPHYSICAL VARIABLES DERIVED FROM IMAGING SPECTROMETERS TO ECOLOGICAL MODELS - HE HYECO'04 GROUP SHOOT

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## ABSTRACT

We report on the first results of the HyEco'04 campaign carried out in summer 2004 as a joint activity of a bi-national team of Belgian and Dutch researchers. This integrated approach of assessing the complexity of managed natural ecosystems is a demonstrator case for recent focus of airborne imaging spectroscopy activities on ecotones. The floodplain Millingerwaard located east to the city of Nijmegen along the river Rhine has been chosen to demonstrate the potential of imaging spectrometer data to support ecological modelling.

Several ground support teams supported the data acquisition of the Hymap sensor during its overflight on two days in July and August 2004. Field measurements concentrated on two approaches: first, radiometric measurements supporting the linking between soil-vegetation-atmosphere transfer modelling (e.g., sunphotometer, leaf optical properties measurements, canopy reflectance, structural parameter measurements (gap fraction, leaf angle distribution, leaf area index) have been performed and secondly supporting additional measurements on vegetation (species mapping, destructive biomass sampling) and soil (moisture, temperature) have been performed.

First, we will report on the data quality evaluation of the various data sources and their integration into an integrated system, dealing with various aspects of spatial sampling schemes and potential spatial discontinuities, as well as uncertainty measures. Secondly, we discuss two examples of spatially distributed products derived from either ground based measurements and inventory mapping, extrapolated to the full coverage of the test site or imaging spectrometer derived products. The resulting products are discussed in view of potential incorporation into land-biosphere models, where high or even unknown uncertainty in input data, and limited availability of geographically explicit input data are usually the limiting factors for the application of ecological models on a larger spatial extent (e.g. national).

## INTRODUCTION

The preservation of biodiversity is an increasingly important topic in European policy. Natural areas are constantly undergoing changes, mostly driven by socio-economic changes, and many of these changes lead to a reduction of the biodiversity. Ecological models are used to assess present-day biodiversity and to make projections of biodiversity into the future through scenario-analysis. These models require a wide range of input data that are both abiotic (e.g. soil type, soil moisture and management) and biotic (both biophysical e.g. vegetation structure or biomass, and biochemical e.g. chlorophyll or nitrogen content). A typical application in the Netherlands is the nationwide, geographically explicit evaluation of economic scenarios using the model SMART-SUMO (1). Target variables to be evaluated may be biodiversity or biodiversity-related (e.g. the probability of a certain ecosystem types to occur), but they may also be related to climatic drivers, e.g. carbon sequestration by natural vegetation.

However, ecological models have a strong need for high quality input data that are often unavailable at present. Lack of initialisation data and high or unknown uncertainty in geographically explicit input data are the limiting factors for the application of ecological models on different scale-levels (e.g. regional or continental). Quantitative remote sensing in general and imaging spectroscopy in particular has the promise to fill this information gap (2). Examples have been presented for both biochemical variables like C/N ratio (3), canopy nitrogen concentration (4), and biophysical parameters like vegetation structure (5), LAI (6-8) and biomass (9). These studies have shown that biochemical and biophysical variables can be measured with a quantifiable uncertainty and incorporated in land-biosphere models (10).

This paper describes the first results of the HyEco'04 campaign that was carried out in the summer of 2004. The objective of this project was to explore the use of hyperspectral sensors to retrieve biochemical and biophysical variables as input for ecological models at the local scale-level. Imaging spectrometer data with the HyMap sensor were acquired for the floodplain Millingerwaard that has an important function as nature reserve. Imaging spectrometer acquisition was supported through an intensive field sampling campaign for validation and calibration. We will report on the parameters that were measured during the field campaign and give a short description of the data quality evaluation of the various data sources. Two examples of imaging spectrometer derived products, net primary production (NPP) and vegetation structure will be presented and their potential incorporation into land-biosphere models (SMART-SUMO) will be discussed.

## METHODS

### Study site

During the summer of 2004 an imaging spectrometer campaign was carried out in the floodplain Millingerwaard along the river Waal the main tributary of the Rhine in the Netherlands. The floodplain Millingerwaard (700 ha) is part of the Gelderse Poort nature reserve, a crossing-border nature rehabilitation area located between the cities Arnhem, Nijmegen and Emmerich (Figure 1). Nature rehabilitation means that step by step, individual floodplains are taken out of agricultural production and are allowed to undergo their natural succession. This has resulted for the Millingerwaard in a heterogeneous landscape with river dunes along the river, a large softwood forest in the eastern part along the winterdike and in the intermediate area in a mosaic pattern of different succession stages (pioneer, grassland, shrubs). In addition, several man-made lakes, e.g., old clay pits, are present. Nature management (e.g., grazing) within the floodplain is aiming at improvement of biodiversity. However under the condition that the discharge capacity of the river should be above the critical safety levels during flooding events.

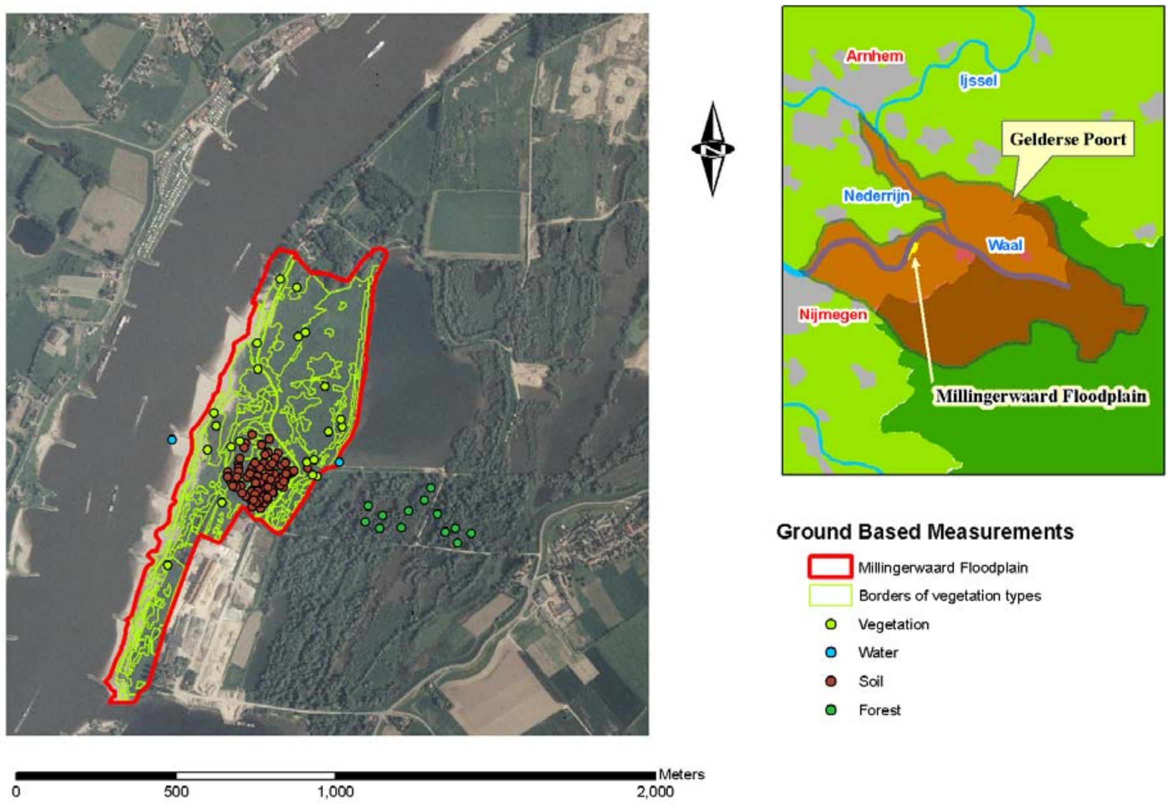



*Figure 1: Ground sampling locations (Table 1) within the floodplain Millingerwaard for vegetation (radiometric, description, sampling), forest (canopy structure), soil (moisture, temperature) and water (level). The inset (left) shows the location of the Millingerwaard along the river Waal.*

### Field measurements

Several ground teams supported the field data acquisition around the overflight of the Hymap sensor (Table 1). Based on the available vegetation map for the Millingerwaard (2002) and a preliminary survey in the area, 21 locations with specific vegetation structure types were selected. For every location, a plot of 5 x 5 m was selected with a relatively homogeneous (vegetation) cover. Spectral properties were measured during the overflight of 28$^{th}$ of July using a field spectrometer (ASD FieldSpec Pro FR). For every plot, 10 measurements were performed, whereby each measurement is the average of 15 readings at the same spot. Sampling was carried out from the outside of the plot to the centre. An sub-area of 1 x 1 m in the centre was left untouched and located with a pole. This sub-area was used in a latter stage for vegetation description and sampling. Spectra were collected by holding the ASD fibre probe in nadir position (zenith = 0; azimuth = 0) and with a distance of ~100 cm above the ground (GFOV = ~44 cm). Leaf reflectance spectra were collected over fresh leaves with a white and black background using the Fieldspec Pro using a contact-probe with an internal light source (11). Spectra for the main 6 vegetation species within the area including 3 forest species were collected: *Calamagrostics epigejos, Rubus caesius, Urtica dioica, Populus nigra, Salix fragilis and Salix alba*. Both for the canopy and leaf spectra a quality check was carried out (wrong measurements, spectral outlyers, removal of water absorption bands) and spectra were stored in a spectral library.

*Table 1: Overview of the operational equipment during the two Hymap image acquisition dates of 28th of July and 2nd of August 2004 in the Millingerwaard.*

| | Instrument | # locations | date | variables |
|---|---|---|---|---|
| atmospheric conditions | sunphotometer | 1 | 2/8 2004 | aerosol optical thickness |
| radiometric correction | Fieldspec FR | 19 (5x5 m) | 28/7 and 2/8 2004 | VNIR spectra (sand, clay, asphalt, water) |
| radiometric vegetation | Fieldspec FR | 21 (5x5 m) | 28/7 2004 | top-of-canopy and leaf spectra (VNIR) |
| canopy structure | hemispherical camera | 13 (20x20 m) | 28/7 – 6/8 2004 | LAI, gap fraction, leaf angle distribution |
| vegetation description | Braun-Blanquet method | 21 (2x2 m) | 13-16/8 2004 | structure, species composition |
| sampling vegetation | laboratory analysis | 21 (0.5x0.5 m) | 13-16/8 2004 | biomass, N and P concentration |
| surface characteristics | theta probe, temperature gun | 86 | 28/7 2004 | soil moisture and temperature |
| Image spectrometry | HyMap (5 m) | 2 flight-lines | | specifications |
| Acquisition time | | 28/7 13:30 | 2/8 10:30 | 126 bands |
| Quality flight line 1 | | okay | cloud cover (not used) | 450-2480 nm |
| Quality flight line 2 | | cloud cover (partly used) | okay | bandwidth 15-20 nm |

In the two week period after the image acquisition, vegetation descriptions were made for the 21 locations according to the method of Braun-Blanquet (12). A detailed description of the used methodology can be found in (13). Afterwards, vegetation biomass was sampled in three subplots measuring 0.5 x 0.5 m. Biomass was clipped at 0.5 cm above the ground level and stored in paper bags. The collected material was air-dried, first for 5 days at room temperature in open bags, and subsequently for 24 h at 70ºC, and weighed to obtain the dry biomass (g). The remaining plant material was analysed for total concentrations N, P, K, Ca and Mg (mmol/kg).

Forest canopy structure was characterized in 13 plots using measurements of a digital hemispherical camera (14). The sample plots were randomly selected following a sampling scheme to cover the representative soft wood canopy densities (Figure 1). Each plot was sampled according to the VALERI protocol resulting in156 points (i.e. 13 plots, each plot with 12 sub-sampling points) for which pictures with a hemispherical camera are taken up, down and with an angle of 57 degrees. Subsequently, the CAN-EYE software was used to derive LAI, fcover, and gap fraction for the 13 plots. Results of this analysis are presented in (14).

To assess the eco-hydrological conditions of a valley area within the Millingerwaard (Figure 1) several hydrological field parameters were measured: soil moisture, surface and vegetation temperature and (ground)water levels (along a transect) (13). Measured soil moisture values and patterns will be correlated to spectral information. Comparison of patterns from hydrological conditions, vegetation and spectral data will be assessed on basis of the methodologies developed by (15).

## Imaging spectrometer data

Imaging spectrometer data for the Millingerwaard were acquired on 28th of July and 2nd of August 2004 with the HyMap sensor (Integrated Spectronics, Australia). The spectrometer was operated onboard the DLR (German Aerospace Centre) Dornier DO-228 aircraft. Because several large clouds were present in the second flight-line on the 28th July, a second flight was made on the 2nd of August. During this flight several small clouds were present in the southern part of the first flight line. The presented results in this paper are based on the first flight line for HyMap acquisition on 28th of July 2004. A complete spectrum over the range of 450-2480 nm is recorded with a bandwidth of 15-20 nm by 4 spectrographic modules. Each module provides 32 spectral channels giving a total of 128 spectral measurements for each pixel. However, the delivered data contains 126 bands because the first and last band of the first spectrometer are deleted during preprocessing. Ground resolution of the images is 5 m. The flight line was oriented close to the solar principal plane to minimize directional effects. The HyMap images were geo-atmospherically processed with the modules PARGE and ATCOR4 to obtain geocoded top-of-canopy reflectance data (16,17). Visibility was estimated by combining sun photometer measurements (Table 1) with Modtran4 radiative transfer simulation following the approach of (18). Visibility during the flight of 2$^{nd}$ of August was 15 km. An image quality assessment (13) revealed that based on the SNR per individual band 9 of the 126 bands should be used with caution, due to significant spatial noise. Consequently, subsequent analyses were restricted to the remaining 117 bands.

### Data processing

The vegetation structure types that are present within the Millingerwaard were derived from the HyMap image using Spectral Angle Mapping (SAM) classification. Pre-processing was applied to improve the performance of the SAM classification (19). Selection of pure vegetation pixels was done by applying a vegetation mask based on a NDVI threshold (NDVI > 0.2). Mixed soil-vegetation pixels, i.e. pixels mainly having a soil signature but also having a certain percentage vegetation, were also excluded from classification. Therefore, pixels having reflectance values greater than 7.4% in the red band at wavelength 665 nm (band 13), were excluded. Bands which do not directly contribute to the information content needed for vegetation classification were removed, i.e. the noisy bands 1-3 in the blue region from 442 nm till 466 nm and bands 32-126 in the NIR and SWIR region from 896 nm till 2482 nm. Next a minimum noise fraction (MNF) was calculated where after the first 6 bands were used for SAM classification. The spectra of the 21 measured ground truth points were used as reference spectra. Finally, the classification result was filtered by a 3x3 majority filter to remove the isolated classified pixels.

For the vegetation units in the Millingerwaard, the Net Primary Production (NPP) was derived from the HyMap images. We used one of the most common methods (20, 21) to derive NPP from incoming photosynthetically active radiation (PAR, MJ/m$^3$) and the fraction of PAR absorbed by the canopy (fAPAR):

$$NPP = PAR_i \cdot fAPAR \cdot \varepsilon \qquad (1)$$

where ε (g/MJ) is the conversion efficiency of absorbed PAR into organic dry matter. It was assumed that ε is constant over all vegetation structure types and equals 1.5 g/MJ. $PAR_i$ was derived from meteorological observations in the field. The value for fAPAR is linearly related to NDVI:

$$fAPAR = a + b \cdot NDVI \qquad (2)$$

where a and b are constants that were derived from (21), and were set at respectively, -0.025 and 1.25. A growing season of 180 days was assumed and vegetation growth was at its peak during image acquisition. NPP was calculated for the individual pixels in the HyMap scene. In comparison, NPP was derived for the 21 vegetation sampling locations using the vegetation succession model SMART-SUMO (22, 1).

## RESULTS

### Classification of vegetation types

Vegetation structure is an important parameter that is often required as basis input for vegetation modelling. Based on the acquired HyMap image in combination with the 21 classified vegetation relevees, vegetation structure types for the Millingerwaard were classified using SAM (Figure 2, left). Results were compared with the vegetation map (23) that was made for the year 2002 (Figure 2, right). Although for the vegetation map 2002 a more extensive typology was used (14 vs. 25), comparable spatial patterns can be observed in the two maps. In addition, for certain vegetation types development between 2002 and 2004 can be observed. For example, in the northern part of the Millingerwaard, there is a development of forest (see red circle Figure 2), while to the south of this forested area, the process of shrub encroachment results in more a heterogeneous composition of vegetation.

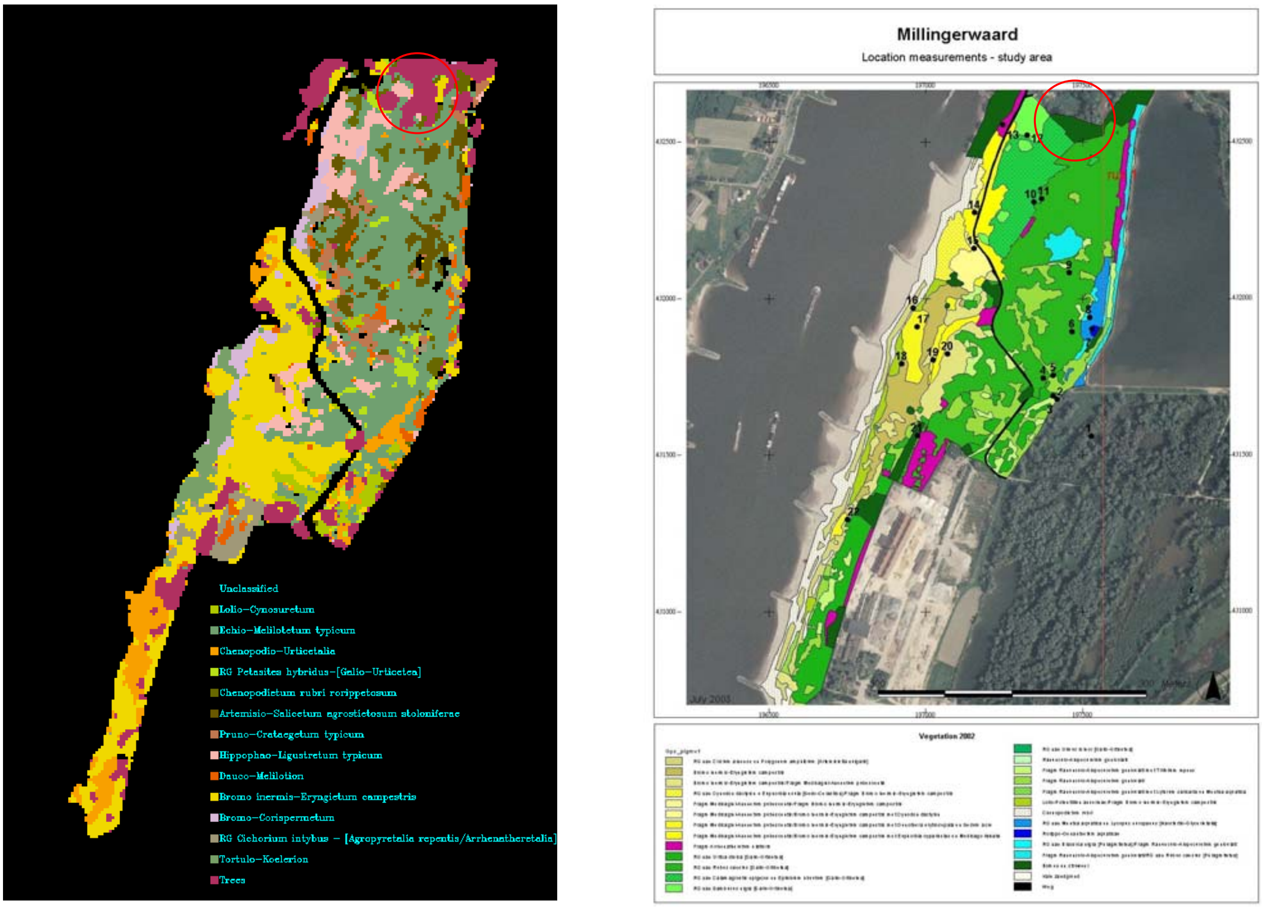
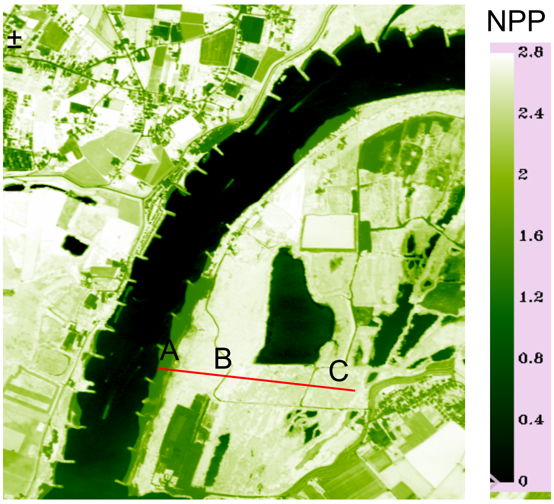



*Figure 2: Left: Classified vegetation types in the Millingerwaard based on HyMap image using 21 reference spectra (Figure 1) and SAM. Right: Vegetation map for 2002 based on description of vegetation relevees and aerial photographs (23).*

### Comparison of NPP derived from HyMap and SMART-SUMO model

The spatial continuous map for NPP within the Millingerwaard shows some clearly distinct units along a transect perpendicular to the river (Figure 3, left). Along the river, the sandy river beaches have a low productivity (A), in contrast to the vegetation units of grass- and shrub land area which show a very high productivity (B). For this area, the spatial variability is relatively homogenous. Within the softwood forest area (C), small scale variation of NPP is higher due to the heterogeneous canopy cover of mainly willow trees (*Salix fragilis and Salix alba).* NPP derived from HyMap was compared to NPP calculated using the vegetation model SMART-SUMO (Figure 3, right). The vegetation model was used to calculate NPP for the 21 described and sampled vegetation plots. The resulting relation is satisfactory: values are in the same order of magnitude, however model results from SMART-SUMO show a larger variation (0.5-8.5 ton/ha/year) compared to HyMap derived NPP (0.1-2.6 ton/ha/year). This is mainly caused by the fact that several factors for the imaging spectroscopy derived NPP were not directly measured in the field but taken from more general values in literature. In addition, for all vegetation structure types the same parameters were applied while in reality differences between vegetation types should be taken into account (20). In addition, results for the comparison of biomass derived from HyMap and SMART-SUMO modelled biomass values for the 21 vegetation locations are described in (22).



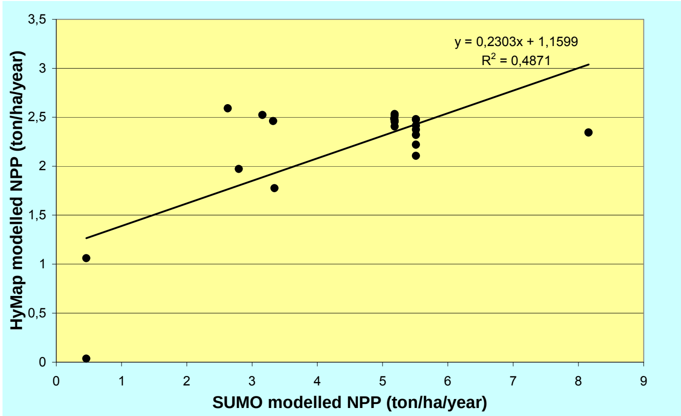




*Figure 3: Left: Net Primary Production (ton/ha/year) derived from HyMap in the Millingerwaard. Differences along transect are described in text. Right: Relation between NPP derived from HyMap and NPP estimated using the vegetation succession model SMART-SUMO for 21 vegetation plots (Figure 1).*

## CONCLUSIONS

Imaging spectrometer data acquired by the HyMap sensor in the Millingerwaard were used to demonstrate the capability of remote sensing to provide biophysical vegetation parameters as input for ecological modelling. Data quality analysis of the field measurements shows that especially the vegetation heterogeneity results in discontinuities when data acquired at different scale-levels are compared, e.g., biomass at 0.5 m vs. TOC reflectance at 4 m. Except for a small number of bands, the acquired HyMap images are of good quality. First results show that spatial continuous maps of NPP and LAI (14) in the Millingerwaard can be provided. However for NPP additional biome specific information for the HyMap should be included to make a more accurate parameter estimation. Although the Millingerwaard has a complex spatial distribution of the vegetation structure, first results of the classification of the vegetation structure using SAM shows a good comparison within the 2002 vegetation map for the floodplain.

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