EVALUATING THE GROSS PRIMARY PRODUCTION (GPP) IN DIFFERENT AGRICULTURAL LAND USE TYPES IN THE VIETNAMESE MEKONG DELTA USING VEGETATION PHOTOSYNTHESIS MODEL (VPM)

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ABSTRACT: Research aims to estimate the gross primary production (GPP) on different agricultural land use types in the Vietnamese Mekong Delta (VMD) using the vegetation photosynthesis model (VPM). The data of air temperature and the Photosynthetically active radiation (PAR) collected at the meteorological stations in VMD were used to calculate the effect of temperature on plants (T_{scalar}). The Land Surface Water Index (LSWI), and the Enhanced Vegetation Index (EVI) extracted from remote sensing data (MODIS MOD09A1) were used to calculate the effect of water (W_{scalar}) and growth stages (P_{scalar}). The light use efficiency (ε_g) on different agricultural land use types is calculated through the optimal amount of light combined with temperature and water for each growth stage. The GPP was then calculated using PAR, ε_g and EVI. The result shows that, by 2018, GPP was estimated at 8,093.67 tons C/year in the VMD. In which, the double rice crop accounts for about 3,282.14 tons C/year (40.55%), triple rice crop about 3,240.25 tons C/year (40%), Rice - Upland crop about 201.19 tons C/year year (2.49%), Rice - Shrimp about 376.26 tons C/year (4.65%), and forest with about 993.82 tons C/year (12.28%). In general, rice cultivation contributed the largest share to the gross primary production for the whole region (80.96%). This study also indicates that GPP estimation from the VPM model can be used to consider carbon uptake in the large region which is supported for environment management.

1. INTRODUCTION

Carbon dioxide (CO_2) is one of the important greenhouse gases that strongly affect climate change. Gross primary production (GPP) plays an important role in controlling the exchange of carbon dioxide in the atmosphere which provides an additional ability of CO_2 from the human source. Estimating variation of the GPP of land cover is useful for improving knowledge of the terrestrial ecosystem response to climate change. In the Vietnamese Mekong Delta (VMD), the effect of extreme climate (El Niño) causes high temperatures in the winter and low precipitation in the summer, decreasing total rainy days, the start of the rainy season lately as well as the end of rainy season sooner (Le Huy Ba et al, 2017; Stojanovic et al., 2020). How extreme climate conditions affect the different agricultural land use types in general, and the carbon absorbed in particular still being concerned by the scientists. The Vegetation Photosynthesis Model (VPM) was applied to many areas to calculate the Carbon absorbed in different vegetation types around the world (Xiao et al., 2004; Jingqing et al., 2014). This study aims at the initial analysis on the variation of modeling gross primary production on different agricultural land use types in the VMD using the VPM model experiment. The result will help to improve our understanding of key feedback mechanisms of the different agricultural land use types through the GPP value curves under extreme climate and the impact of climate change.

2. MATERIAL AND METHODS

2.1 Study site

The Vietnamese Mekong delta (VMD) is made up of 13 provinces: Long An, Tien Giang, Ben Tre, Hau Giang, Kien Giang, An Giang, Dong Thap, Tra Vinh, Soc Trang, Vinh Long, Can Tho, Bac Lieu, and Ca Mau (Figure 1). It is located in $8^0 30' – 11^0$ N and $104^0 30' – 107^0$ E. VMD, is approximately 40,000 square kilometers (km^2) in area. It is known as one of the widest and richest deltas in Asean, it is considered as the biggest granary of Vietnam, it provides 60% of the nation's rice production. For the agricultural land use in Mekong Delta, annual crops accounted for above 50% of total land areas in which rice crop areas occupied 90%. Rice has been considered a main crop of Mekong Delta farmers. The rice cultivation area is about 4.4 million hectares yearly in the Southern of Vietnam, with over 93% from the VMD. There are three main rice crops in the year including Winter-Spring, Summer-Autumn, and Autumn-Winter (General Statistics Office, 2013).

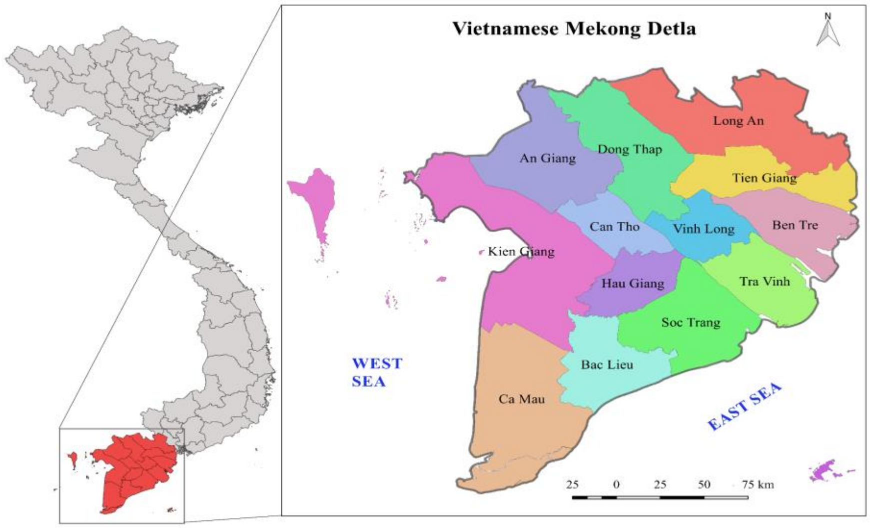

Figure 1: Location of the Vietnamese Mekong Delta

2.2 Materials

MODIS data: This study used surface reflectance of MODIS MOD09A1 within 07 bands from band 1 to band 7 (wavelength at 648 nm; 858 nm; 470 nm; 555 nm; 1,240 nm; 1,640 nm; 2,130 nm, respectively) at 500 m resolution imagery captured in an 8-day composite period. The data were downloaded from the US Geological Survey (https://earthexplorer.usgs.gov/) in the Vietnamese Mekong Delta region in 2018.

Climate data and others:

- The incident photosynthetically active radiation (PAR), the maximum temperature (T_{max}), the minimum temperature (T_{min}), and the optimal temperature (T_{opt}) were collected from the Hydrometeorological stations in the VMD region.
- The VMD land use map was collected for extracting the different agricultural land use types to import the VPM model.

2.3 Methods

Pre-processing data: The MODIS MOD09A1 images with the latitude and longitude format were adjusted to UTM (Universal Transverse Mercator) projection, datum WGS-84, Zone 48 North using MODIS Reprojection Tool **(**MRT). Mosaicking and selecting regions of interest in the study area were also included in the pre-processing steps.

Estimating of the Vegetation Photosynthesis Model: The VPM proposed by (Xiao et al., 2004) for the estimation of GPP over the photosynthetically active period of vegetation was used in this study equation (1):

$$GPP = \varepsilon_g \times FAPAR_{PAV} \times PAR \quad (1)$$

Where:
PAR: the incident photosynthetically active radiation (μmol/m^2/s)
$FAPAR_{PAV}$: within the photosynthetically active period of vegetation was estimated as a linear function of Enhanced Vegetation Index (EVI) equation (2).

$$EVI = 2.5\frac{NIR-RED}{1+NIR+6RED-7.5BLUE} \quad (-1 \leq EVI \leq 1) \text{ (Xiao et al., 2004)} \tag{2}$$

Light use efficiency (ε_g): is affected by temperature (T_{scalar}), water (W_{scalar}) and leaf phenology (leaf age) (P_{scalar}). The formula for calculating ε_g is as follows equation (3):

$$\varepsilon_g = \varepsilon_0 * T_{scalar} * W_{scalar} * P_{scalar} \tag{3}$$

+ Maximum light use efficiency (ε_0) for each agriculture land use type is different, this study is used ε_0 following the results of Zhang et al (2017), in particular ε_0_rice crop = 0.42 g C/mol APAR, ε_0_rice-upland = 0.63 g C/mol APAR, ε_0_forest = 0.42 g C/mol APAR.
+ T_{scalar} for the effects of temperature based on the maximum temperature, the minimum temperature, and the optimal temperature using the following equation (4) (Raich et al., 1991):

$$T_{scalar} = ((T-T_{min})(T-T_{max}))/([(T-T_{min})(T-T_{max})]-(T-T_{opt})^2) \tag{4}$$

+ P_{scalar} for the effects of leaf phenology is calculated according to the growing up time (P_{scalar} = (1+LSWI)/2) (Xiao et al., 2004) and after that (P_{Scalar} = 1). In which LSWI is land surface water index which calculated from satellite images by the equation (5):

$$LSWI = \frac{NIR-SWIR}{NIR+SWIR} \quad (-1 \leq LSWI \leq 1) \text{ (Xiao et al., 2004)} \tag{5}$$

+ W_{scalar} for the effects of land surface water using equation (6):

$$W_{scalar} = (1 + LSWI)/(1 + LSWI_{max}) \text{ (Xiao et al., 2004)} \tag{6}$$

All the above parameters were imported into the VPM model (Figure 2) to calculate the GPP value of the agricultural land use types covering a specific unit area (g C/m^2). The main types of agricultural land use are determined based on the land use map of the Mekong Delta region, specifically including double rice crops (Winter Spring-Summer Autumn), triple rice crops (Winter Spring-Summer Autumn-Autumn Winter), Rice - Shrimp, Rice - Upland crop, and Forest. The character of surrounding pixels within the buffer zone of 10 km from the center of the observed meteorological station were considered as representing for each agricultural land type to estimate GPP. The GPP of each agricultural land type were then calculated by multiplying the total of their areas.

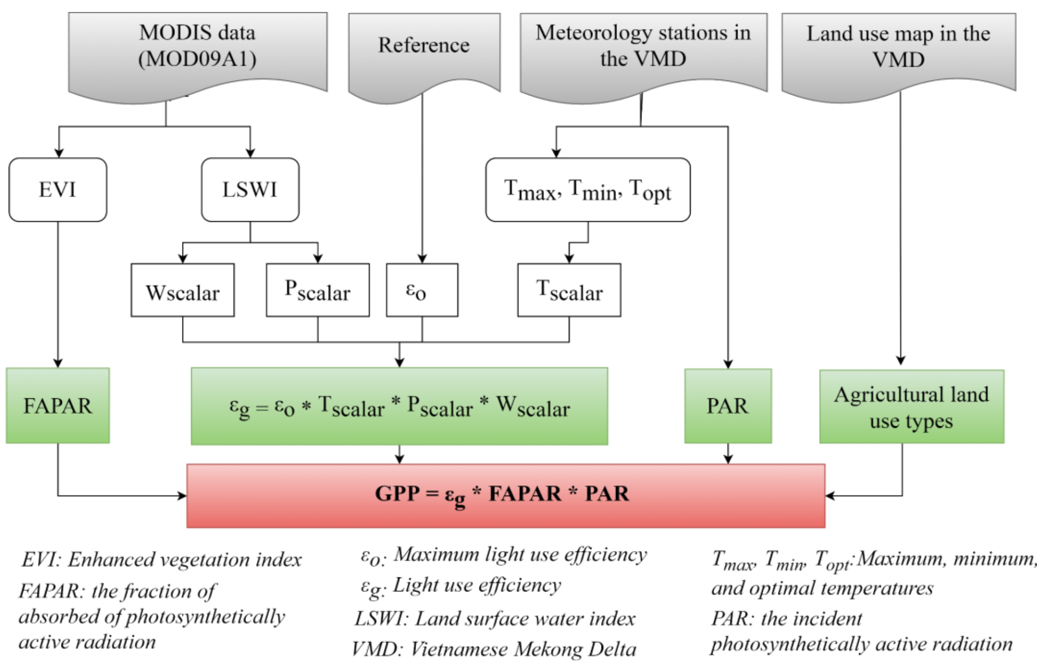

Figure 2: The concept of modeling gross primary production using VPM model

3. RESULTS AND DISCUSSION

3.1 The variation of GPP in different agricultural land use types in the VMD

The agricultural land use types play an important role and have different contributions to carbon uptake in the Mekong Delta. In 2018, GPP of double rice crops (Winter Spring-Summer Autumn) reached the highest value in March and July; GPP of triple rice crops (Winter Spring-Summer Autumn-Autumn Winter) reached the highest value in February, July, and November; The peak of GPP of rice – upland crop was in February, late October and early November; The peak of Rice – Shrimp GPP was found in the months nearly end of year (October, November); Forest GPP was stable at high value throughout all months of year 2018.

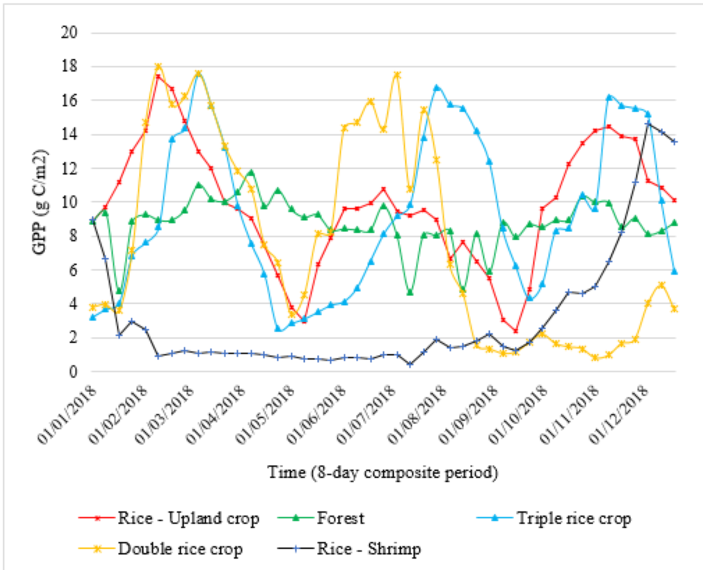

Figure 3: GPP patterns on different agricultura; land use types in the VMD in 2018

Double rice crop (Winter Spring- Spring Autumn): GPP curve of double rice crop started increasing in January, May corresponding to the sowing time of rice crops (Figure 3 on yellow curve). The GPP value of the double rice crop reached the peak in the middle of February (18.01 g C/m^2/8 days) during the Winter-Spring season, and early July (17.46 g C/m^2/8 days) during the Summer-Autumn season. The obtained peak value of GPP corresponds to the period of panicle initiation, booting and flowering stage where rice has the highest photosynthetic capacity. GPP was obtained by converting light energy into plant biomass. Light intensity directly affects the photosynthesis of rice plants at different growth stages such as the stage of tillering, stem elongation, panicle initiation, booting, flowering and mature grain stage. The paddy rice needs the greatest solar energy intensity from the period of panicle initiation to 10 days before flowering time (Nguyen Ngoc De, 2008). This result highlights the variation of estimated GPP value using VPM model from low to high corresponding to a rice growth cycle. The GPP value was low at the beginning of the season of tillering when the chlorophyll content was low, then gradually increasing during tillering to stem elongation, reaching its maximum during the panicle initiation to flowering stage.

Triple rice crop (Winter Spring- Spring Autumn- Autumn Winter): The triple rice crop was distributed in the provinces of An Giang, Ben Tre, Can Tho, and Dong Thap, Kien Giang and Hau Giang. The GPP of triple rice crop variates follows a sinusoidal pattern with three times reaching the maximum value representing the growth cycle in each growing season (blue curve). GPP of triple rice crop in Winter-Spring season reached the highest value at 17.56 g C/m2/8 days, which higher than in comparing to other seasons , rice GPP in Summer-Autumn season reach the highest value at 16.73 g C/m2/8 days and Autumn-Winter season at 16.17 g C/m2/8 days. The variation in GPP values over time of year was similar to the pattern of double rice crops whereas GPP gradually increased to a maximum during the period of panicle initiation, booting and flowering stage, and decreasing towards the end of the season (rice ripening and harvesting).

Rice – Upland crop: The highest GPP of rice dủing Winter-Spring and Autumn-Winter season were observed at the end of February (17.39 g C/m^2/8 days) and middle of November (14.37 g C/m^2/8 days), respectively. The GPP then gradually decreased and falled to the lowest in the period of post-harvesting. The upland crop was cultivated in small areas of farming, mixed with different upland types. Hence, the study included main crops such as maize, watermelon, potatoes into a group of upland crops. GPP of upland crop cultivation was also varied according to the rules of plant growth cycle. The GPP of rice-upland during the cultivation period was higher than the period of noncultivation (7 - 10 g C/m^2/8 days during cultivation), and covered at 2.35 g C/m^2/8 days during the noncultivation and the transition time between each crop.

Rice - Shrimp: The shrimp farming was conducted from February to September, corresponding to the stable low GPP value (0.8 - 1.2 g C/m2/8 days). According to Huynh Kim Huong et al (2016), the average time for shrimp farming is 6 to 8 months. Shrimp farming did not absorb the carbon, however the GPP value shown in Figure 3 (black curve) presents for the carbon uptake of plants surrounding the shrimp farm. The graph curve of GPP in this model increases gradually from the end of September corresponding to the beginning of the Autumn-Winter rice season. The GPP value then reached the peaks in December (14.16 g C/m2/8 days) corresponding to the panicle initiation, booting and flowering stage.

Forest: Forest is the type of vegetation cover with least variation among the green cover most of the time throughout the year. However, due to the characteristics of the mixed forests in the VMD, the GPP values have quite changed in some growing time according to the seasons (green curve in Figure 3), and the averaged GPP value is approximately 8 gC/m^2/8 days but there are slight fluctuations at some times of the year (Figure 3e). Simultaneously, the amount of the incident photosynthetically active radiation decreased at the time of the strong rainy season according to data from the hydrometeorological center in 2018, whereby the GPP at that time also decreased accordingly in August, September.

3.2 Spatial variation of total GPP of different agricultural land use **types in the VMD**

In 2018, average estimated GPP of different agricultural land use types in the VMD was over 1,100 gC/m^2 (Figure 4), whereby the rice-upland crop took the largest amount of carbon uptake while rice-shrimp had the lowest amount of GPP.

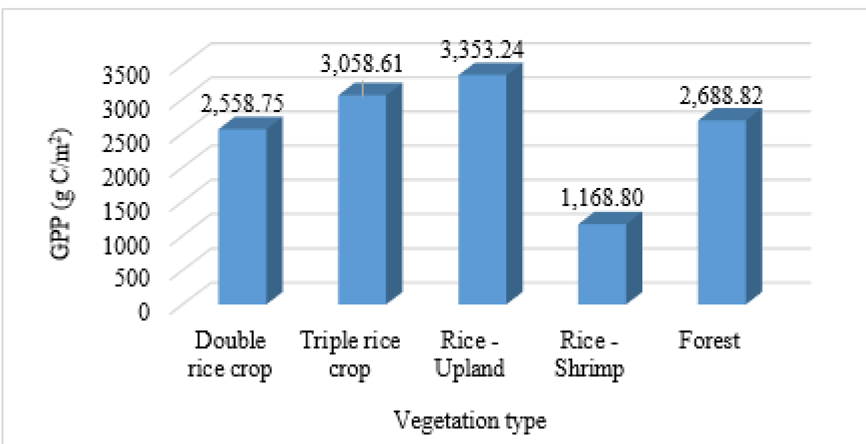

Figure 4: Total GPP per each square meter by vegetation types in the VMD

The total GPP of agricultural land use was estimated at about 8,093.67 tons C/year in 2018. In which, GPP of the double rice crop was about 3,282.14 tons C/year (40.55%), triple rice crop was about 3,240.25 tons C/year (40%), rice - Upland crop was about 201.19 tons C/year (2.49%), rice - shrimp was about 376.26 tons C/year (4.65%), and forest at 993.82 tons C/year (12.28%). Thereby, rice farming had the largest contribution to the GPP in the year 2018 in Mekong Delta, accounting for more than 80% of the total GPP per year (Figure 5).

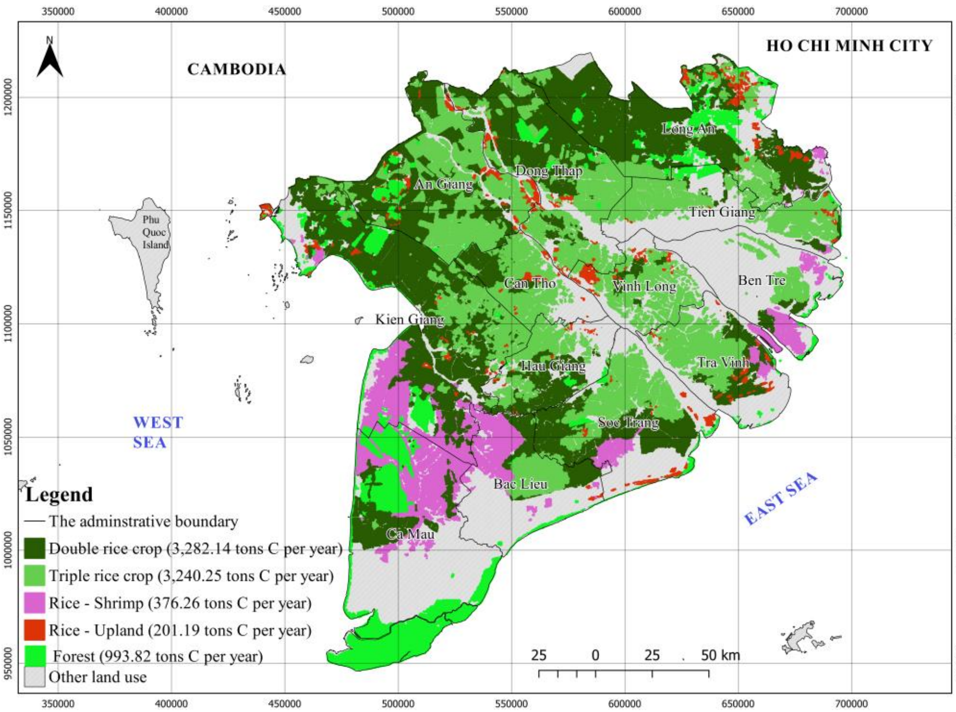

Figure 5: Spatial distribution of GPP of agricultural land use types in the VMD in 2018

4. CONCLUSION

The VPM model was used to estimate the total amount of GPP for different agricultural land use types in the VMD, the ratio of carbon uptake depends on the characteristics of the growing season and the total area in each land use type. The GPP value reaches the peak in February, March, July, August, October, and November. The total GPP provided more than 8 tons C/year. The initial application of the VPM model in the VMD has shown limited input data for the model, requiring measuring for optimal light use efficiency is needed for future research. Research outcomes is useful information and serves as a basis for further studies to assess the influence of extreme climate factors on the change in gross primary production (GPP) of the VMD.

REFERENCES

General Statistics Office. 2013. Planted area of cereals by province. Ha Noi Statistical Publishing house.

Huynh Kim Huong, Le Quoc Viet, Do Thi Thanh Huong, and Tran Ngoc Hai. 2016. Technical and financial aspects of the freshwater prawn-rice-tiger shrimp farming systems in Bac Lieu province. Can Tho University Journal of Science. 43b: 97-105 (In Vietnamese)

Jingqing, C., Huimin, Y., Shaoqiang, W., Yanni, G., Mei, H., Junbang, W., & Xiangming, X. 2014. Estimation of gross primary productivity in Chinese terrestrial ecosystems by using VPM model. Quaternary Sciences, 34(4), 732-742.

Le Huy Ba, Luong Van Viet, Nguyen Xuan Hoan. 2017. Drought and saline intrusion in the Mekong Delta: Theoretical and practical basis. Ho Chi Minh National University Publishing house, 525 pages. https://books.google.com.vn/books?id=GYGrtAEACAAJ

Nguyen Ngoc De. 2008. Rice syllabus. Can Tho University Publishing house, 187 pages (In Vietnamese).

Raich, J. W. 1991. Potential net primary productivity in South America: application of a global model. Ecological Applications, 1(4), 399–429. https://doi.org/10.2307/1941899

Stojanovic, M., Liberato, M. L. R., Sorí, R., Vázquez, M., Phan, V. T., Duong, V. H., Hoang, C. T., Nguyen, P. N. B., Nieto, R., and Gimeno, L. 2020. Trends and Extremes of Drought Episodes in Vietnam Sub-Regions during 1980–2017 at Different Timescales. Water. 12(3):813. https://doi.org/10.3390/w12030813

Xiao, X., Zhang, Q., Braswell, B., Urbanski, S., Boles, S., Wofsy, S., Moore, B., & Ojima, D. 2004. Modeling gross primary production of temperate deciduous broadleaf forest using satellite images and climate data. Remote Sensing of Environment, 91(2), 256–270. https://doi.org/10.1016/j.rse.2004.03.010

Zhang, Y., Xiao, X., Wu, X., Zhou, S., Zhang, G., Qin, Y., & Dong, J. 2017. A global moderate resolution dataset of gross primary production of vegetation for 2000-2016. Scientific Data, 4, 170165. https://doi.org/10.1038/sdata.2017.165