MAPPING PADDY RICE CROPPING PATTERNS OF THE MEKONG DELTA USING TIME-SERIES AVHRR DATA

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ABSTRACT: Variation and trends in the cropping patterns of paddy rice is necessary for analysis gas emission variation, supply baseline information for planning and monitoring, and crop management. This research aimed to depict and map transformation in paddy rice cropping patterns of Mekong delta using the series of Land Long Term Data Record. The data were processed from June 1981, to December 2011 in second steps:(1) data pre-processing to build the smooth AVHRR Normalized Difference Vegetation index(NDVI) time-series data; (2) rice crop identification. The results indicated that the spatial distributions of the rice cropping systems are highly related with water regime from the Hau and Tien rivers, and soil condition along coastal areas. Before 1990s, the upper area of the delta which is prone to flooding and small areas along south-eastern coast have the double cropping system, while areas in the western and the south-eastern parts mostly have a single cropping system. Only a fraction of areas have a triple rice cropping system. From 1991 to 2011, the areas of triple-cropped rice increased remarkably, while those of the single-cropped rice decrease due to farmers using the high-yielding modern varieties and better water control. Our study demonstrates the high potential of NOAA Advanced Very High Resolution Radiometer (AVHRR) reduced resolution data to discriminate and map paddy rice cropping patterns, and shows variation and trends of it in Mekong delta clearly.

1. INTRODUCTION

Rice is the primary energy intake of more than half of the world's population. Asia represents the largest producing and consuming region. To meet the needs of the growing world population, the developing countries have launched the Green Revolution to improve the crop yields. During the period, the spread of modern high-yielding rice varieties with short duration, the applying of chemical fertilize, and the development of irrigation system have result in a linear increase of the crop production (+0.05 ton/ha/year) published by the FAO (Food and Agriculture Organization of the United Nations,2009). The transformation of cropping systems (from single to double or triple cropping) and an increase in proportion of rice area account for a drastic growth of rice yields. Vietnam, as the world's fifth-largest rice-producing country and one of the world's leading rice exporters, has to increase the cropping intensity at limited arable land to guarantee rice production. Mekong Delta (MD), the largest rice-production region in Vietnam, producing about 52% of Vietnam rice, has the highest cropping intensity in the world (Maclean et al., 2002). However, rapid shifts in cropping patterns of paddy rice may have negative effects on environment and quality of surface water, consequently influencing food security and agriculture ecosystem. Also, over 10% of the total greenhouse gas methane flux to atmosphere comes from seasonally flooded rice paddies. (Xiao, 2005) It may have significant impacts on atmosphere chemistry and global climate. Therefore, the long time-series variation of rice cropping systems can be used to trace gas emission and provide real-time and objective information with policy makers to publish more effective guidelines to ensure both domestic and world food security. But the traditional method of obtaining rice cropping patterns in MD is time-consuming and very expensive.

Optical satellite remote sensing has provided an efficient and objective means to monitor the crop on the earth at regional and global scales. To map the rice cropping systems, the first step is to identify the rice paddies and the second is to discriminate the rice cropping systems based on the physical or signal features of rice paddy. Xiao, X.M. et al. (2005) depicted the spatial distribution of rice paddies in southern China based on the features of the time series of multiple vegetation index such as Enhanced Vegetation index (EVI), Normalized difference vegetation index (NDVI) and the Land Surface Water Index(LSWI) from NASA EOS Terra Moderate Resolution Imaging Spectroradimeter (MODIS). Sakamoto et al. (2009) estimated crop phenology and evaluated the spatial distribution of cropping systems by detecting the local maximal points in smoothed EVI profile based on wavelet filter. Chen et al. (2011) classified the rice cropping systems by linear mixture model using the time-series NDVI profiles from MODIS 250-m data filtering by empirical mode decomposition and wavelet filter. But these studies only mapped the spatial treats of paddy rice using multiple or short time-series data.

In particular, the NOAA/AVHRR is a good choice to provide long term data for the goals on depicting the crop changed trends because of its high temporal resolution and long term (1981-current) global coverage. The time series of NDVI from Land Long Term Data Record (LTDR) has been used to observe the long-term changes in rice phenology (Singh et al. 2006). Vrieling et al. (2008) examine the trends in agriculture production of Africa using 26 years of NDVI data. Furthermore, to extract useful information from time-series NDVI profile, we need reduce miscellaneous noise components caused by aerosols and bidirectional reflectance distribution factors using noise-filtering techniques, such as the empirical mode decomposition (EMD), the iterative Savitzky-Golay algorithm, Fourier transforms. The wavelet transform also can be used to remove noise efficiently and locate the signal in time and space domain. The wavelet-smoothed time-series is widely used in agriculture applications, including identifying the start of growing season and the heading date of rice (Sakamoto et al., 2009. Galford et al., 2008. Chen et al., 2011).

In this study, our main purpose is to describe the variation of the paddy rice cropping systems in MD from 1982 to 2011 using the wavelet-smoothed AVHRR-NDVI time-series profile.

2. STUDY AREA, DATA AND METHODS

2.1 Study Area

Our study area is the Mekong Delta, the largest rice-production area in Vietnam. It produces about 52% of Vietnam rice and has the highest cropping intensity (183%) in the world (Maclean et al., 2002).

The Mekong Delta is located in southernmost area of Vietnam, with latitude from 8.5° to 11.0° and between 104.5° to 106.64° and surrounded by the South China Sea, the Gulf of Thailand and Cambodia. It occupies an area of approximately 40,000 km^2 and has 13 provinces with Can Tho and Hau Giang being split from the former Can Tho province in 2004. The climate is tropical monsoonal with an average precipitation of about 1440mm and temperature of about 27° C. The region is characterized by two seasons which are wet season, lasting from May to October, and dry season from November to April in the nest year. The terrain is very flat and low-lying with most of land below 20m beyond sea level.

Closely 72% of the total area in MD is tillable land, of which 90% is used for rice cultivation (Son et al., 2014). Before 1967, most of the delta had single cropping patterns while few area had double cropping patterns, using the photo-sensitive local variety of rice, which has a growing period of 160 days to 240 days. The introduction of non-photosensitive high-yield rice varieties since the Green Revolution, and the development of technical components such as chemical inputs, irrigation and drainage systems, have allowed to prevalent adoption of the double and triple rice cropping systems. The Mekong Delta has highly variable soils, of which alluvial, acid-sulfate, and saline soils are predominate. This may have important impacts on the distribution of the rice cropping patterns.

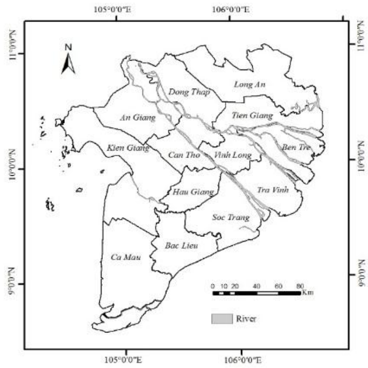

Figure 1. The Mekong Delta Showing Provinces and Main Rivers

2.2 Image Data

We use the 0.05° resolution daily NDVI version4 products from 1982 to 2011 exclude 2000 derived from NASA's Land Long Term Data Record (LTDR) project (downloaded from http://ltdr.nascom.nasa.gov/ltdr/productSearch.html). LTDR apply the AVHRR and MODIS with differing spatial resolutions of 4km Global Area Coverage (GAC,1981-present), 1km High Resolution Picture Transmission(HRPT) and Local Area Coverage(LAC1992-1998), 250m to 1km MODIS(2000-present), with a gap in the data record being filled using a SPOT VEGETATION surface reflectance product(1km) generated by the European GEOLAND2 project.

In the production of NDVI products (AVH013), sensor calibration, cloud screening, georeferencing, atmospheric corrections for gas, water vapor and aerosol, and the bidirectional reflectance distribution function (BRDF) corrections are implemented. Each daily NDVI product includes NDVI data and quality assessment file which is used for removing pixels impacted by artifacts.

2.3 Methodologies

2.3.1 Data pre-processing: Three steps are composed of the data pre-processing: 1) removing bad pixels impacted by artifacts using the quality assessment file and excessive noisy points identified if they exceeded a 0.15 change threshold in NDVI from the value; 2) obtaining the 8-days composite products by synthesizing daily NDVI data using maximum-value composite method; 3) filling the gap through linear interpolation.

2.3.2 Creating a wavelet-smoothed NDVI time series: In this paper, we choose a discrete wavelet transform to reduce noise from the data. A wavelet transform W(a,b) express the features of input signal in time and scale domain. The input signal $\emptyset(x)$ is transformed in the wavelet transform as Eq. (1).

$$\mathrm{W(a,b)} = \frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty} \varphi(\frac{x-b}{a})\,\emptyset(x)dx \tag{1}$$

Where a is a scaling parameters and b is a shifting parameters, respectively. And the φ represents a mother wavelet. According to Sakamoto et al. (2005), the shape of Coiflet mother wavelet is similar to the peaks in agriculture phenology. The wavelet also needs a power threshold to determine how much of the signal is retained during the wavelet transform. To reduce the noise and capture trends in the NDVI time series, we applied 85% power wavelets because of its higher accuracy to detect cropping patterns (Galford et al., 2008).

2.3.2 Extracting the heading date: The MD has three major rice cropping seasons: Summer-Autumn, Autumn-Winter and Winter-Spring, with the growing period from April to August, between August and December, and from November to April in the next year, respectively. Therefore, we defined forty-six 8-day NDVI composites in the year and the first eight 8-day NDVI composites in the next year as a complete period to extract rice cropping systems. In addition, there is few built-up or other crop areas bigger than a pixel in the image with 0.05° spatial resolution. The growing period of rice encompasses the vegetative, reproductive and ripening stage. After transplanting, rice plant height grows rapidly until leaf development reach the heading phase. Then according to features of the spectral reflectance of paddy fields in time-series data, the maximum NDVI implies round the heading date (Sakamoto et al., 2005). Therefore, we obtain the rice cropping patterns by following steps:

(1) Selected the local maximal points with NDVI value greater than or equal to the threshold, which is 0.49, 0.52, and 0.58 for 1982-1984, 1985-1999, and 2001-2011 respectively, as candidates of the occurrence of rice-heading seasons in multi-cropping seasons in complete period.
(2) Calculated the interval between the probable rice-heading dates. Because the rice growth cycle in this region is ranging from 90 to 120 day. Therefore, the interval was less than eleven 8-day composites, the procedure repeated calculating the interval between the dates with bigger NDVI value and the next probable heading date.
(3) Detected rice cropping systems by the number of the rice-heading dates satisfied the step (1) and (2).

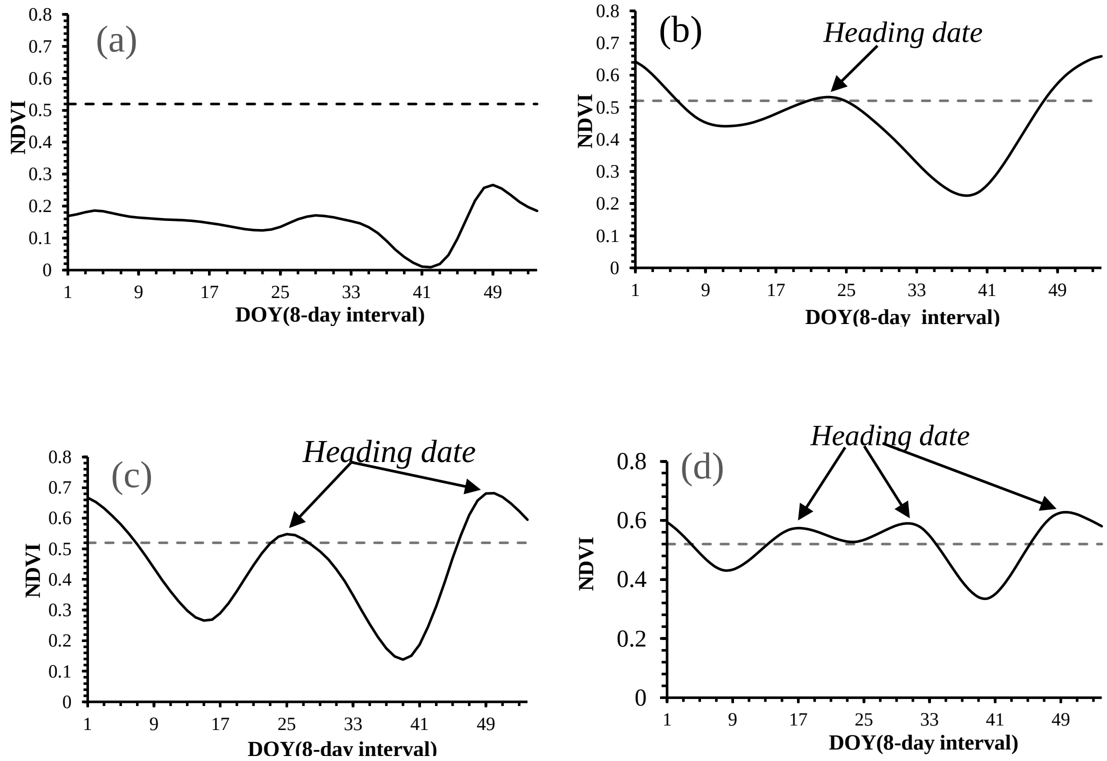

Figure 2. Smoothed NDVI Profiles (January, 1995, to March, 1996) Show the Method Used for Identification of Rice Cropping Patterns in MD: (a) shrimp farm and mangrove, (b) single-cropped rice, (c) double-cropped rice, (d) triple-cropped rice.

3. Results

3.1The Trend of Rice Cropping Patterns

The procedure was applied to recognize the rice cropping systems per pixel, dividing to non-rice without shrimp farm and mangrove, single-cropped rice, double-cropped rice, triple-cropped rice. Figure. 3 presents the variation of rice cropping patterns from 1982 to 2011 using the three year average area of different rice cropping patterns. The no rice area shows a clear decrease and mainly shifts to the double or triple rice cropping system area. The area of triple rice cropping system has an obvious increase while the area of double rice cropping system has a slight growth. Additionally, the area of single rice patterns shows a slight growth.

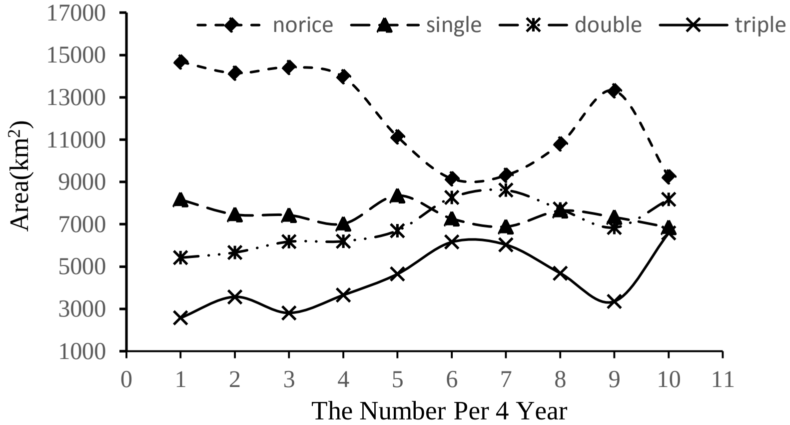

Figure. 3 The Variation of Rice Cropping Patterns in MD from 1982 to 2011

3.2 The Change in the Distribution of Multiple Rice Cropping Systems

To describe the trend in the distribution of rice cropping patterns better, we only choose six result images with 4 years interval (Figure. 4). Before 1990, a large part of the delta converted the non-arable land into planting rice area, leading to much of the growth in rice production. In the 1990s, the triple rice cropping system increased remarkably, particularly distributed in the region between Mekong and Bassac rivers. This may be caused by the flood-prone ecosystem in the region turning into an irrigated ecosystem and farmers using high-yielding modern varieties with short-duration. On the other hand, the double rice cropping systems has gradually become the main cropping system in the study area. From 2001 onwards, the rice cropping patterns show a clear shift between double and triple rice cropping systems.

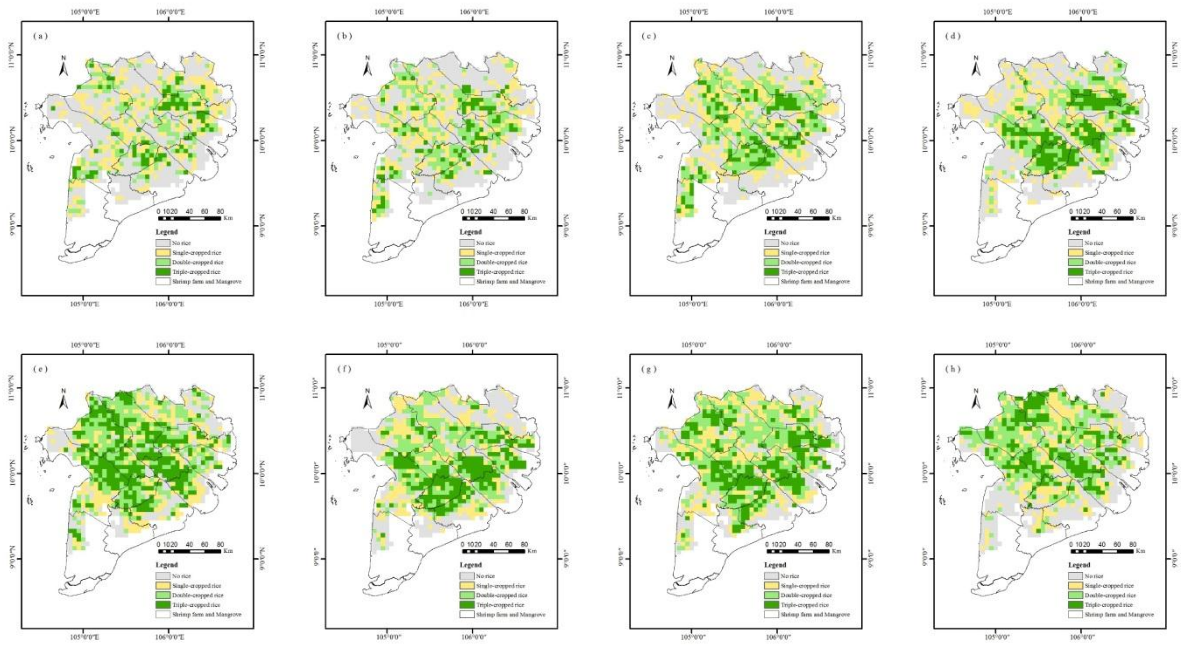

Figure.4 Spatial Distribution of Cropping Patterns in MD: (a) 1983, (b) 1986, (c) 1990, (d) 1994, (e) 1998, (f) 2002, (g) 2006 and (h) 2010

4. Conclusion

In this study, we succeed in describing the trend of the rice cropping patterns from 1982 to 2011 in the Mekong Delta using the NDVI products from LTDR. However, there are a number of factors affect the identification and discrimination of the rice cropping systems, such as the coarse spatial resolution of the data and small farm size in the region, leading to the low precision in the area. Therefore, we would try to explore a new way to map the rice cropping patterns using a finer spatial resolution data. It also can be a reference data for verifying the results in the thesis.

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