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Mapping rice paddy extent and intensification in the Vietnamese Mekong River Delta with dense time stacks of Landsat data

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ABSTRACT

Rice is a staple food crop for the majority of the world's population, yet paddy fields are threatened by urban expansion, climate change, and degraded agricultural land. Vietnam, one of the largest exporters of rice globally, grows most of its rice in the Mekong River Delta, but this low-lying and heavily populated area is susceptible to major land cover changes. To properly monitor and manage rice crops in this region, remote sensing with satellite imagery has been particularly useful; however, most efforts to map regional paddy area utilize coarse resolution MODIS or AVHRR data due to their high temporal frequency. Because the average size of a rice paddy field in the region is smaller than a coarse resolution pixel, we map the Mekong study area using finer-scale Landsat data collected across multiple growing seasons. First, we exploit dense Landsat time stacks for circa 2000 and circa 2010 to map rice paddy extent using vegetation trajectories, then combine these pixel-based rice maps with image-based segments to generate a polygon-based rice map. The results show that this method can map rice paddies with over 90% overall accuracy (and errors of omission and commission ranging from 6 to 25%) at a finer spatial resolution than previous efforts. Next, we differentiate between single-, double-, and triple-cropped rice paddies in the delta using a supervised classification based on exemplars of these different cropping trends. From circa 2000 to circa 2010, we find that triple-cropped rice fields have nearly doubled in area from one-third to nearly two-thirds of paddy area. Our work also highlights the importance of scenes that capture flooded fields, and the utility of cloud-covered scenes within the dense time stacks of data, to achieve higher classification accuracies. Methods to map rice paddies are vital to understanding the sustainability of these agricultural systems, and the work presented here makes strides toward routine monitoring at a field-level resolution.

1. Introduction

Globally, rice (*Oryza sativa*) is one of the most widely harvested and nutritionally important food sources. It accounts for 20% of the world's calorie supply, and has been called “the most important food crop for the poor,” since it is the staple food item for over 900 million people who subsist on less than 1.25 USD per day (Dawe, Pandey, & Nelson, 2010). Moreover, the five countries with the largest exports of rice (Thailand, Vietnam, India, United States, Pakistan) account for approximately four-fifths of trade (Dorosh & Wailes, 2010). To this end, changes to rice output in any one these five countries greatly alter the global rice market, which in turn has ramifications for vulnerable populations dependent on rice for sustenance. Further affecting rice-reliant populations, recent research demonstrates that rising temperatures may decrease rice yields (even when fertilization from higher levels of CO_2 is considered), while rising seas could inundate low-lying rice fields (Long, Ainsworth, Leakey, Nösberger, & Ort, 2006; Peng et al., 2004; Wassmann et al., 2009). Because rice is so susceptible to impending climate change, rapid and efficient monitoring of these crop systems is critical for (1) continued management of paddy fields; (2) understanding the efficacy of different policy levers; and (3) illuminating broader issues of food security, agricultural sustainability, and ongoing climate change.

Land use changes coupled with rapid economic development have affected rice production globally, but these impacts are best exemplified in Vietnam. As a result of economic reforms instituted in the late 1980s targeting the agricultural sector, rice production in Vietnam grew by >25% between 2000 and 2011, while the area devoted to rice paddies remained nearly constant (General Statistics Office of Vietnam, 2011b). Much of this change can be attributed to the Green Revolution including new rice varieties, irrigation, pesticides, and fertilizers, all of which were adopted by Vietnamese farmers after market liberalization (Cleaver, 1972; Hazell, 2010). For example, while none of Vietnam's rice area was planted with modern rice varieties during the Communist regime, now 89% of rice seeds are modern varieties that provide higher

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yields and shorter growing periods, allowing for multiple harvests per year (Dawe, 2002). Moreover, in 1975, only 16% of agricultural land was irrigated and 50.7 kg/ha of fertilizer was applied. By 1995, these numbers had reached nearly 30% for irrigation and 214 kg/ha for fertilizer application (Rosegrant & Hazell, 2000). These advancements have allowed the Mekong Delta to emerge as one of the most intensely cultivated regions in the world for rice, and one of only a handful of places to practice triple-cropping rice agriculture (Dawe et al., 2010).

While this vast transformation has pushed Vietnam to the world stage, the sustainability and effective management of rice production in the Mekong Delta requires accurate information on location and cultivation practices at the scale of individual fields. Remote sensing, either alone or in combination with annual surveys, offers the most practical means of monitoring rice production in the region. Synoptic coverage, repeated observations, and the archival nature of observations are some of the key attributes of remote sensing that allow rice monitoring over large areas. What remains unknown, however, is the timing and the number of observations required for satellite imagery to accurately capture the vegetation phenology associated with rice cultivation. This issue is particularly important in the Mekong Delta where the monsoonal climatic conditions lead to persistent cloud cover that obscures the land surface over a significant period of time.

With these issues in mind, the goal of this work is to develop a change detection strategy involving dense time stacks of Landsat (30-m) data to monitor changes in rice paddy area as well as shifts in the number of annual harvests for two time points (circa 2000, circa 2010) at fine spatial scales in the Mekong Delta. In the first step, we take advantage of object-oriented image classification algorithms to map the areal extent of rice paddy agriculture. Second, we develop a new approach to count the number of annual rice harvests using an incomplete – due to clouds and Scan Line Corrector (SLC)-off gaps – set of observations to determine rice-cropping intensity. When applied to the two time periods (2000, 2010), these methods allow us to determine how the areal extent of rice paddy has changed, and whether crop rotations intensified over the ten-year study period. We hypothesize that the number of cropping rotations has increased due to the adoption of Green Revolution technologies (e.g. rice cultivars with a short 100-day growing period), and the construction of dikes and sluices that protect paddy from flooding and saltwater intrusion.

This study builds upon methods developed for MODIS data that exploit spectral–temporal indices from satellite data to map rice paddy and cropping rotations (Xiao et al., 2005; Xiao, et al., 2006). Since the average area of rice fields in the Mekong Delta is only one half-hectare, it is critical to map this region at a finer resolution than past efforts with MODIS. Therefore, we expand and refine the MODIS approach in three ways: (1) we adapt the method for use with Landsat data by segmenting the image data into individual fields to provide greater spatial detail for mapping complex, highly heterogeneous landscapes; (2) we map multiple time points (2000, 2010), and test the ability of our approach to capture change through time, and most critically, (3) we distinguish whether fields are cultivated once, twice, or three times per year to provide valuable information on changes in cropping

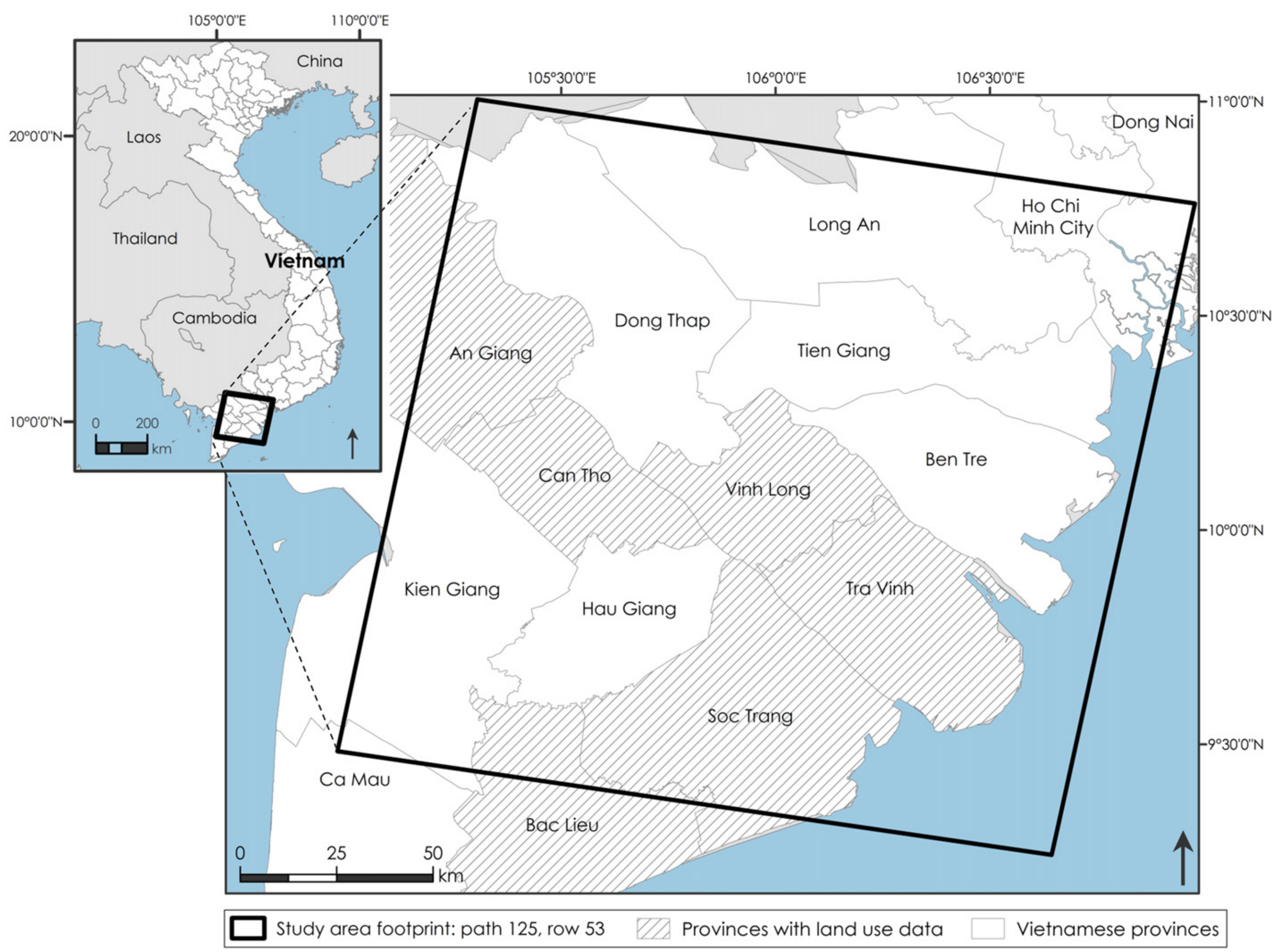

Fig. 1. The Mekong River Delta in Southern Vietnam. In this study we focus on the 12-province area within Landsat path 125, row 53.