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Research Paper

Ecosystem services in peri-urban landscapes: The effects of agricultural landscape change on ecosystem services in Taiwan's western coastal plain

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HIGHLIGHTS

- Peri-urban farmlands are important green infrastructure for providing ecosystem services.
- The agro-ecosystem services of paddy rice fields can be assessed by landscape metrics.
- Three landscape metrics are proposed as guidelines to maintain agro-ecosystem services.

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ABSTRACT

Farmland within urban peri-urban areas can be understood as part of a green infrastructure that provides agro-ecosystem services to benefit the urban population. The growing influence of cities on peri-urban agricultural lands has had significant effects on agricultural land transformation with an associated loss in agro-ecosystem services. The loss of ecosystem services could result in an increase in a city's vulnerability to climate change. More than one sixth of the agricultural lands in Taiwan's western plain have been converted to other uses from 1970 to 2006. We hypothesize that planning guidelines based on landscape ecology could help to plan the optimal spatial configuration of paddy rice land uses in peri-urban areas. In order to study the effects of agricultural landscape changes on ecosystem services in peri-urban areas, this study selected appropriate landscape metrics to assess ecosystem services with landscape composition and configuration metrics for each of the research sites. This research has shown that because agro-ecosystem services are related with the spatial configuration of paddy rice fields, by planning agricultural land use change to optimize spatial configuration, agro-ecosystem services can be maintained. Guidelines are offered to manage agroecosystem services within a context of land use change.

1. Introduction

During the 20th century, the world's population has increasingly become concentrated in urban areas (Seto & Fragkias, 2005; United Nations, 2008). The growth and expansion of metropolitan regions where agricultural and non-agricultural activities are spatially integrated makes the distinction between rural and urban land uses problematic (Firman, 1996; Hugo, 1996; Tacoli, 1998). Peri-urban areas, which often include valuable protected biotopes, forested hills, preserved woodlands, prime agricultural lands and important wetlands, often provide essential ecosystem services for urban residents (Douglas, 2006; Huang, Wang, & Budd, 2009). Peri-urban areas therefore represent highly complex territorial spaces from economic, environmental and social viewpoints. But while complex, both urban and peri-urban communities depend on the many agro-ecosystem services provided by agricultural land (Tacoli, 1998).

The importance of maintaining ecosystem services to cope with global environmental change has garnered much attention in recent years and many classification and assessment systems for ecosystem functions and services have been developed (e.g. Costanza et al., 1997; Daily, 1997; De Groot, Wilson, & Boumans, 2002; Millennium Ecosystem Assessment, 2005). Changes in land use have massively altered natural and semi-natural environments, significantly altering biogeochemical flows (Kroeger & Casey, 2007;

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Martínez et al., 2009). Landscape ecology focuses on how heterogeneous landscapes and individual landscape elements change, and how these changes affect landscape and ecosystem functions (Forman & Godron, 1986). The integration of landscape ecology into urban studies can inform an understanding of the effects of landscape change on ecological processes (Yu & Ng, 2007). The size and spatial configuration of a landscape not only directly impacts energy and material flows such as carbon emissions and infrastructure demands, but also affects particular ecosystem services provided by natural or agricultural areas, and therefore has consequences on the functioning of the Earth as a system (Seto & Fragkias, 2005). Because of the increasing concentrations of population and economic activities in urban areas, land cover change in peri-urban areas is inevitable. Unplanned land cover change leads to unplanned environmental degradation and ecosystem services loss. Therefore, the allocation of land for new development and the way peri-urban farm land is configured have become significant planning issues.

Although agriculture is often seen as a managed ecosystem embedded in a web of natural ecosystems (Zhang, Ricketts, Kremen, Carney, & Swinton, 2007), agro-ecosystem services still provide benefits to human wellbeing. Changes in agricultural land cover can impact the entire urban environment by altering ecosystem services. Ecosystem services are defined as the benefits human populations derive, directly or indirectly, from ecosystem functions (Costanza et al., 1997); they are also defined as the processes and conditions through which natural ecosystems and the species that comprise them, sustain and fulfill human life (Daily, 1997). The UN's Millennium Ecosystem Assessment (2005) followed this broad definition and differentiated between supporting, provisioning, regulating, and cultural services, which are provided by unmanaged natural or human-domesticated agricultural land and that provide services of direct benefit to people. These agro-ecosystem services can be continued within the new patterns of urban spatial development (e.g. concentric rings spreading outward from an adjacent city, growth along exurban transportation corridors, etc.) by maintaining corridors for connectivity (Forman, 1995). Any landscape can be managed to optimize specific ecological functions, as well as the supply and delivery of ecosystem services. For example, in the "Jaws" model, retaining large patches, maintaining corridors for connectivity, increasing boundary length and allocating remnant patches in the center of a landscape contributes to structure an optimal spatial configuration in a land transformation process (Forman, 1995).

Land use and land cover change caused by urban growth negatively affect agro-ecosystem services. These impacts include habitat loss, habitat fragmentation, stormwater management problems, water pollution and impacts on cultural ecosystem services (Kroeger & Casey, 2007; Martínez et al., 2009; Seto & Fragkias, 2005; Weng, 2007). The loss of agro-ecosystem services due to the change from agricultural to urban land use in peri-urban areas is rarely reversed because of contamination and the potential loss of economic investments in buildings and infrastructure.

Cities are inherently vulnerable to extreme weather events because of the concentration of population and industry, physical capital, waste, and high percentages of impervious surface. The farmland within or surrounding urban areas provides agro-ecosystem services that mitigate some of the effects of extreme weather events. The importance of peri-urban agriculture in moderating impacts such as extreme temperatures and enhanced surface runoff has become even more critical under climate change scenarios (Gill, Handley, Ennos, & Pauleit, 2007; Gill et al., 2008). The spatial configuration of farmland in peri-urban regions is also a factor in determining the effect of land use change on agro-ecosystem services. For the climate regulating service, the loss of microclimate regulating services cannot only be reflected by the percentages of green cover, but also be reflected by the location of vegetated surfaces from the viewpoint of landscape configuration. Farmland as a part of urban green infrastructure plays an important role in regulating urban microclimate, especially a reduction in the urban heat island effect. Yokohari, Brown, Kato and Moriyama (1997) suggested that the longer the boundary line between urban areas and paddy fields, the more the urban areas can benefit from the effect, but the less the cooling effect of the paddy fields.

By planning the spatial configuration of remnant peri-urban agricultural land use, specific agro-ecosystem services can be optimized for a given proportion of agricultural land use. Landscape metrics can be applied to inform the development of planning guidelines to help reduce the loss of agro-ecosystem services. Because agro-ecosystem services are increasingly important in the context of urban growth and peri-urban landscape change, managing the spatial configuration of remaining agricultural lands becomes a crucial planning issue.

Paddy rice fields are an important agricultural land use in most of the countries in East Asia and Southeastern Asia where the total harvested area of paddy rice accounts for approximately 20% of the total paddy rice field areas in the world (FAO, 2011). Besides being the most important agricultural product in Taiwan, paddy rice fields also provide numerous environmental, ecological, and cultural functions, known here as agro-ecosystem services. Paddy rice fields provide ground water recharge, prevention of soil erosion, microclimate regulation, habitats for wild animals, and prevention of flood damage (Chang & Ying, 2005). Due to the particular farming practices of paddy rice, paddy rice fields also play a significant role in regional hydrology – for example by providing storage capacity to minimize surface runoff.

This paper focuses on the changes in spatial patterns of agricultural land in the western coastal plain of Taiwan and the effects of this agricultural land use change on agro-ecosystem services, particularly in the peri-urban areas. The research will test the proposition that agricultural and use and its associated agro-ecosystem services can be managed and optimized through spatial planning. In summary, the purposes of this paper are:

- To investigate, characterize, and measure the type and spatial distribution of agricultural landscape change of Taiwan's peri-urban area in western coastal plain based on the two officially published land use survey of 1971 and 2006;
- To discuss the role of spatial configuration of agricultural land in a peri-urban landscape for providing and supporting agro-ecosystem services;
- To offer guidelines to inform planning for future land use change to maintain agro-ecosystem services.

2. Peri-urban land use change in Western Taiwan

Environmental and socio-economic problems associated with increased urbanization of peri-urban areas have already emerged in many developing countries, especially in South-East Asia (Firman, 1996; Hugo, 1996; Tacoli, 1998). Taiwan's rapid economic growth from 1970 to 2000 transformed the island from a predominately rural to an industrialized economy (Huang, Kao, & Lee, 2007). Because of the mountains along the east, most of the population is concentrated on the western coastal plain of Taiwan where peri-urbanization is leading to increased pressure on the environment (Huang et al., 2009). Intensive urban and industrial development with high population density has turned the western plain of Taiwan into a "mega-city" since the 1970s (Lin et al., 2008). Nearly 80% of Taiwan's population currently lives in urban areas, making it a highly urbanized nation. The percentage of total built-up area in the western plain of Taiwan increased from 15 to 21% from 1971 to