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SPECIAL ISSUE

Global changes in terrestrial ecosystems

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Land use change in Asia and the ecological consequences

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Abstract Viewed within a historical context, Asia has experienced dramatic land transformations, and currently more than 50% of Asian land area is under agriculture. The consequences of this transformation are manifold. Southeast Asia has the highest deforestation rate of any major tropical region. Many of the world's large rivers and lakes in Asia have been heavily degraded. About 11 of 19 world megacities with more than 10 million inhabitants are in Asia. These land use activities have resulted in substantial negative ecological consequences, including increased anthropogenic CO_2 emissions, deteriorated air and water quality, alteration of regional climate, an increase of disease and a loss of biodiversity. Although land use occurs at the local level, it has the potential to cause ecological impact across local, regional and global scales. Reducing the negative environmental impacts of land use change while maintaining economic viability and social acceptability is an major challenge for most developing countries in Asia.

Keywords Agricultural intensification · Deforestation · Freshwater habitats degradation · Sustainable land use · Urbanization

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Introduction

Land use change, including land conversion from one type to another and land cover modification through land-use management, has greatly altered a large proportion of the earth's land surface to satisfy mankind's immediate demands for natural resources (Meyer and Turner 1992; Vitousek et al. 1997; Foley et al. 2005). Many land use changes have resulted in substantial negative ecological consequences, such as increased levels of anthropogenic CO_2 emissions and the non-carbon greenhouse gases (GHGs) of methane and nitrous oxide (Houghton 2003; Kaye et al. 2004), modifications in surface fluxes of heat and water vapor and changing regional weather patterns (Houghton et al. 2001; Pielke 2005; Feddema et al. 2005), degradation of air and water quality (Akimoto 2003; Van Metre and Mahler 2005), a lack of renewable fresh water (Postel et al. 1996) and the loss of biodiversity worldwide (Pimm et al. 1995; Sala et al. 2000). Human population growth represents the primary driving force in land use change (Vitousek et al. 1997). Asia is the home to nearly 3.5 billion people among a worldwide population of more than 6 billion, and the world's two most populous countries (China and India), each with more than 1 billion people (Hillstrom and Hillstrom 2003), are found within its boundaries. Therefore, the role of land use change and its ecological consequences have been becoming a critical issue and of great interest in Asia.

The objectives of this paper are to (1) review the most pervasive land use changes in Asia, such as agricultural intensification, deforestation, freshwater habitats degradation and urbanization, and (2) evaluate the role of land use changes and their ecological consequences. We will also illustrate case studies that show how sustainable land use practices can be achieved in Asia.

Expansion of agricultural land and agricultural intensification

Expansion of agricultural land is the most pervasive anthropogenic land conversion process in Asia. From 1700 to 1980, the total area of agricultural land in South and Southeast Asia has increased by 296 and 1275%, respectively (Meyer 1996). Thus, agricultural land has become the dominant landscape in most regions of Asia. About 14 of 48 Asian countries have more than 50% of their land surface area under cultivation (Fig. 1). In South Asia, 73% of the total land area is under agriculture, and almost half of the Southeast Asia's land area is in agricultural use (Wood et al. 2000). Land use management on these agricultural lands, such as maintaining soil fertility by chemical fertilization and irrigation and controlling pests by chemical pesticides, intensified. From 1961 to 2002, fertilizer use in Asia has increased by approximately 1900%, and irrigated agricultural area has increased by approximately 115% (Faostat 2004).

These land use changes associated with agriculture have positively impacted on crop yields in Asia, resulting in a remarkable increase in yield. For example, food production grew faster in Southeast Asia than in any other regions in the world during the 1980s (UN Conference on Trade and Development 1994). In China, grain yields nearly quadrupled from 1952 to 1996 (State Statistical Bureau of China 1997).

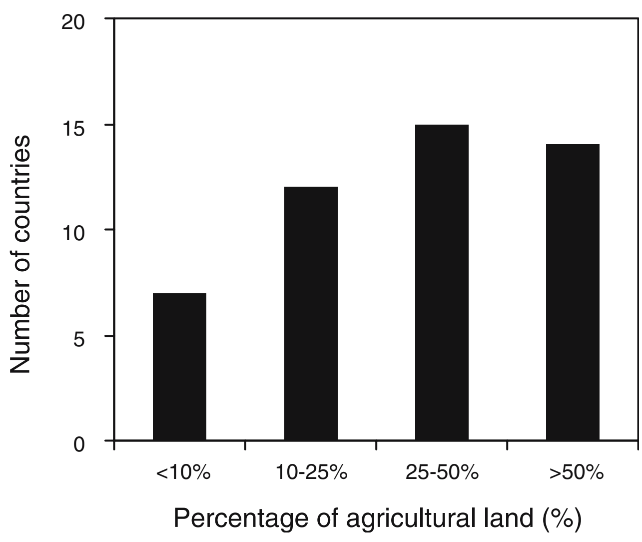

Fig. 1 Frequency distribution of agricultural land percentage for 48 Asian countries in 2002 (based on Faostat 2004)

However, this expansion of agricultural land and agricultural intensification has had serious ecological consequences. Most of the agricultural lands currently in use occupied former primary forests, grasslands and wetlands; this conversion has resulted in the loss of biodiversity associated with these natural habitats (Castelletta et al. 2000; Fang et al. 2005a). Agricultural activities have caused a serious degradation of the soil on 27% of the total land in South and Southeast Asia (Hillstrom and Hillstrom 2003). Asia irrigates a much higher proportion of its cropland than other regions of the world, which not only has led to a lack of freshwater in many Asia countries, but also resulted in extensive salinization of previously fertile land (Postel 1989). Increased use of fertilizers and pesticides has led to the pollution of ground water and eutrophication of rivers and lakes in many Asia countries (Shiklomanov 1997; Bouman et al. 2002; Jalali 2005).

Deforestation and reforestation

Asia is home of many of the world's tropical rain forests and subtropical mountain forests with exceptionally rich and exclusive biodiversity. However, large-scale deforestation has occurred in Asia, primarily as a result of agricultural expansion and timber harvest. From 1850 to 1978, about 1.2 million km^2 of forest was cleared in Asia (Meyer 1996). Consequently, over the period 1850–1995, the clearing of forests in South and Southeast Asia for permanent croplands released 43.5 petagrams of carbon (Pg C) to the atmosphere. The forest biomass and soil carbon in this region has been reduced by 58 and 18%, respectively. The decreased biomass in the remaining forests has contributed to an additional net loss of 11.5 Pg C (Houghton and Hackler 1999). The loss of natural forest has been particularly pervasive in Southeast Asia. Most of Southeast Asia was under forest cover 8000 years ago; however, less than half of the original forests of Southeast Asia are currently standing (Sodhi et al. 2004) (Fig. 2). The rapid deforestation rate has accelerated since the 1990s. From 1990 to 2000, approximately 23,000 km^2 of forest in Southeast Asia was cleared annually, resulting in a net carbon emission of approximately 0.5 Pg C per year to the atmosphere, accounting for 29% of the global net carbon release from deforestation (Phat et al. 2004). In contrast, the carbon emissions from the combustion of fossil fuel in the region only accounted for 3% of global fossil fuel emission (Houghton and Hackler 1999).

Deforestation and forest fragmentation have also caused major threats to the flora and fauna that live therein. The loss and fragmentation of montane evergreen forests in northern Thailand can be closely related to the decline of species richness in mammals and birds and the extinction of large mammals and frugivorous birds (Pattanavibool and Dearden 2002). The conse-

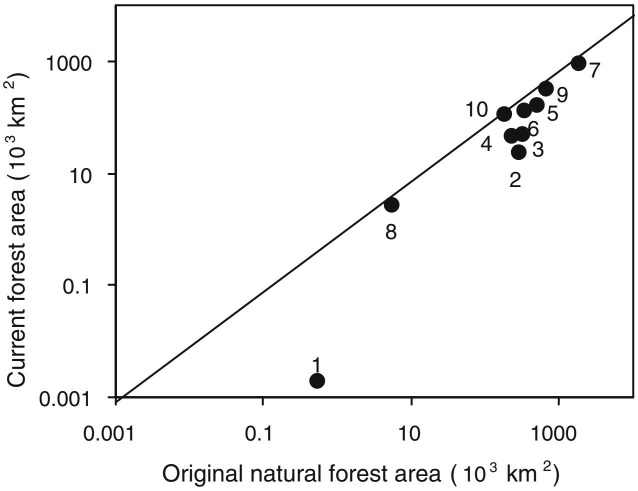

Fig. 2 Comparison of original forest area and current natural forest area of ten countries in Southeast Asia: *1* Singapore, *2* Philippines, *3* Vietnam, *4* Laos, *5* Thailand, *6* Malaysia, *7* Indonesia, *8* Brunei, *9* Myanmar, *10* Cambodia (modified from Sodhi et al. 2004)

quence of a 95% deforestation rate in Singapore over the past 183 years has been that more than 28% of overall biodiversity has disappeared, with the local extinction rate for forest specialists reaching 33%. Butterflies, freshwater fish, birds and mammals have suffered from the greatest extinctions (34–43%) (Brook et al. 2003). Increasing forest disturbance through logging activities, agriculture or urbanization are known to have caused a decline in species richness and population density for a wide range of Southeast Asian taxa, including termites, dung beetles, ants, bees, butterflies, moths, birds and mammals (Sodhi et al. 2004).

This loss of forest cover in Asia has been shown to affect the climate, both locally and globally. Southeast Asian deforestation has caused an increase in the albedo by reducing local net surface radiation and a reduction in Asian precipitation that persists throughout the year (Suh and Lee 2004; Werth and Avissar 2005). The deforestation in Southeast Asia, coupled with deforestation of the Amazon basin and Central Africa, has led to a significant decrease in winter precipitation in California and a cumulative increase of precipitation during the summer in the southern tip of the Arabian Peninsula (Avissar and Werth 2005).

On the other hand, forested land area and associated biomass carbon accumulation has largely increased in East Asia in the past several decades, mainly as a result of the expansion and regrowth of planted forests. For example, between the late 1970s and 1998, the planted forest areas in China have increased from 12.74 to 23.11 million ha; correspondingly, the mean carbon uptake by China's forests is currently estimated to be 0.021 Pg C per year (Fang et al. 2001). Between 1976 and 1995, the surface area of planted forests in Japan expanded from 9.9 to 10.4 million ha, resulting in a sequestering of 0.0185 Pg C per year in the living forest biomass, with about 80% of this contributed by planted forests (Fang et al. 2005b). The carbon sequestration of forests in South Korea significantly increased from 0.001 Pg C per year in the period of 1955–1973 to 0.012 Pg C per year in the late 1990s because of a national reforestation project and forest management that is continuing at the present time (Choi et al. 2002).

Freshwater habitats degradation

It is well known that Asia houses many of the world's large rivers, including the Ganges, Yangtze, Yellow and Mekong, to name a few, as well as major freshwater lakes, including Dongting Lake in China, Tonle Sap in Cambodia, Lake Toba in Indonesia, the Kasumigaura in Japan and Lake Songkhla in Thailand (Hillstrom and Hillstrom 2003). These rivers and lakes are notable not only for their size and volume, but also for providing habitats for aquatic fauna and flora, especially for a number of endemic species. Unfortunately, these bodies of water have been greatly affected by human-induced land use changes. For example, in the past seven decades, the water surface area of Dongting Lake has decreased by 49%, from 4955 km^2 in the 1930s to 2518 km^2 in 1998, with an average decrease rate of 38 km^2/year. The lake has been fragmented, as indicated by a decrease in its mean path size from 4.2 km^2 in the 1930s to 1.7 km^2 in 1998. The degradation of this lake is largely attributed to extensive agricultural reclamation, resulting in negative ecological consequences, such as frequent flooding, a decline in biodiversity and the extinction of a number of endemic species (Zhao et al. 2005) (Fig. 3).

In addition, water quality in most Asian rivers, lakes, streams and wetlands has been heavily degraded, mainly due to agricultural runoff of pesticides and fertilizers, and industrial and municipal wastewater discharges, all of which cause widespread eutrophication (see Karn and Harada 2001; Bouman et al. 2002; Liu and Diamond 2005). Less than 50% of the domestic wastewater in Asia is treated, compared with 80% in the developed world. In major metropolitan areas, more than 95% of wastewater from Asian cities is discharged directly into rivers, lakes and streams without any treatment at all. Consequently, the bacterial level resulting from human waste found Asian rivers is threefold higher than the world average and 50-fold higher than World Health Organization guidelines (UN Environment Programme 1999).

By the end of the twentieth century, about 31,340 large dams (> 33 m in height) had been built in the major river basins across Asia; this is comparison to the approximately1500 dams (more than 15 m in height) in 1950 (WCD 2000). The rapid proliferation of dams in Asia has caused widespread loss and/or fragmentation of freshwater habitats, especially those of riparian floodplains and wetlands, although dams have played a critical role in water supply, flood control, irrigation, and hydroelectric power production. China's ongoing

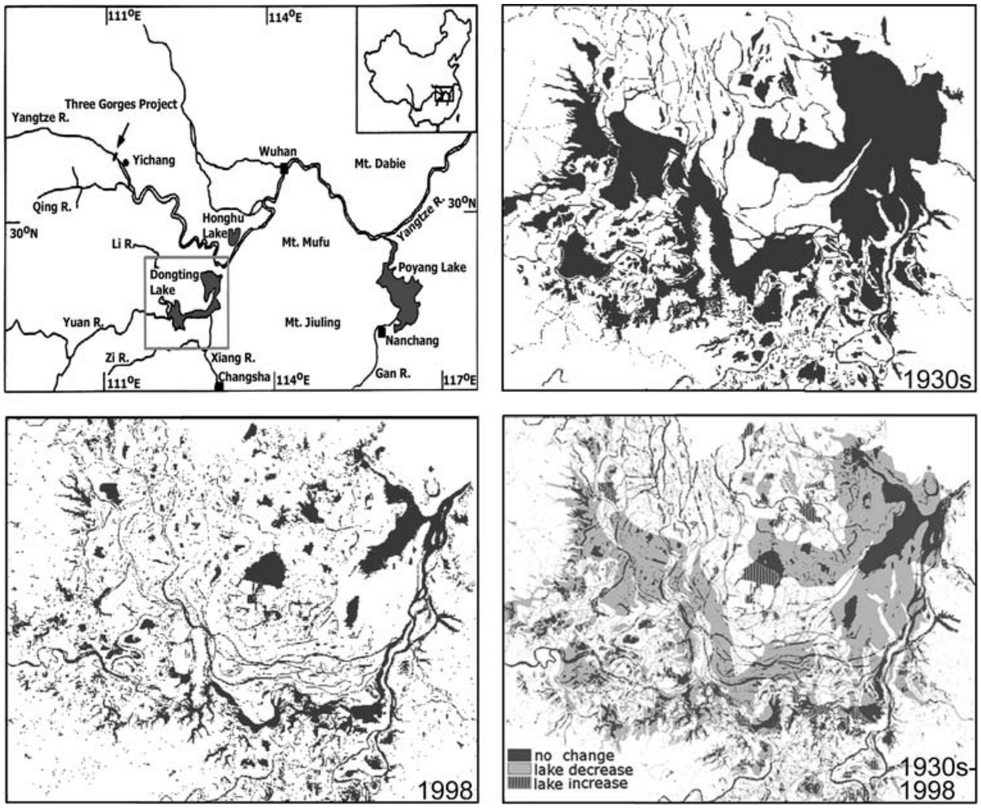

Fig. 3 The seven-decade degradation of Dongting Lake in Central Yangtze River, China. The *solid black areas* indicate water bodies (Based on Zhao et al. 2005)

Three Gorges Dam is the world's most controversial dam project, and many environmentalists and scientists are concerned about its ecological consequences (see Park et al. 2003; Wu et al. 2004).

Moreover, land use activities such as deforestation and wetland reclamation also affect the quality and condition of Asian freshwater bodies. Deforestation has contributed to the siltation of rivers, and wetland reclamation has reduced the ability of river basins to regulate flows and, consequently, extensive flooding has resulted. Both of these activities alter freshwater habitats, causing the decline or disappearance of species therein (Dudgeon 1992; Earle 1994). These land use activities are widespread across the Asian continent and are particularly pervasive in Myanmar, Thailand, Cambodia, Philippines, Vietnam, China and India. For example, in the lakes of Central Yangtze, China, the species richness of aquatic vascular plants, fish and waterfowl, and the population size of Baiji Dolphin, a well-known endemic species of the Yangtze River, have rapidly declined, primarily as a result of reclamation of the lakes and their associated wetlands for agricultural use (Fang et al. 2006).

Urbanization

Asia has been experiencing rapid urbanization. Between 1950 and 2003, the percentage of the population living in urban centers has increased from 16.6 to 38.8% (Population Division of the Unite Nations 2004). Among 19 world megacities with more than 10 million inhabitants in 2000, 11 are found in Asia (The State of World Population 2001) (Table 1). Rapid urbanization has greatly promoted the Asian economic and social development, but it has also created severe environmental damage. Urban expansion generally occurs on arable

Table 1 World and Asian megacities with a population more than 10 million (based on The State of World Population 2001)

Megacities	Population in 2000 (million)	Continent
Tokyo, Japan	26.4	Asia
Mexico City, Mexico	18.1	North America
Bombay, India	18.1	Asia
Sao Paulo, Brazil	17.8	South America
Shanghai, China	17	Asia
New York, USA	16.6	North America
Lagos, Nigeria	13.4	Africa
Los Angeles, USA	13.1	North America
Calcutta, India	12.9	Asia
Buenos Aries, Argentina	12.6	South America
Dhaka, Bangladesh	12.3	Asia
Karachi, Pakistan	11.8	Asia
Delhi, India	11.7	Asia
Jakarta, India	11	Asia
Osaka, Japan	11	Asia
Manila, Philippines	10.9	Asia
Beijing, China	10.8	Asia
Rio de Janeiro, Brazil	10.6	South America
Cairo, Egypt	10.6	Africa

land, which may affect food production. The conversion of agricultural land to urban land has been most pronounced in India. From 1955 to 1985, Indian urban land expanded by about 1.5 million ha, primarily through encroaching on agricultural land, and its urban growth is continuing. For example, the rapid urban expansion in Saharanpur City between 1988 and 1998 came at the cost of the loss of fertile agricultural land (Fazal 2000). A recent study has suggested that urban land expansion of the 145 cities in China between 1990 and 2000 mainly occurred on (former) arable land (Tan et al. 2005). China and India are the world's two most populous countries, thus the loss of agricultural land due to urbanization may cause concerns over their food security in the future.

Urbanization also leads to an alteration in the regional climate. A significant urban heat island effect was recently observed in Southeast China, where rapid urbanization has occurred. It is estimated that the mean surface temperature over Southeast China has increased by 0.05°C per decade under the impact of urbanization (Zhou et al. 2004). Urbanization has also caused increased summer temperatures and nighttime temperatures in South Korea (Chung et al. 2004).

Urbanization places a heavy burden on the urban atmosphere and water quality. Asian megacities contributed approximately 16% of the total anthropogenic sulfur emissions in Asia (Guttikunda et al. 2003). The rivers in Nepal, India and Bangladesh have been severely polluted as a result of pollution discharge from urban activities (Karn and Harada 2001). Urbanization exerts a substantial effect on biodiversity. Rapid urban expansion in Shanghai, China, has led to the loss of native species, and the subsequent remarkable increase in the numbers of nonnative species. For example, the number of wild plant species decreased from 254 in the 1980s to 145 in 2000 on Dajinshan Island of this city as a result of urbanization, while 300 alien plants have been introduced to the urban area between the 1980s and 2005 (Zhao et al. 2006).

In addition, urbanization can affect public health. For example, the increase in coronary heart disease in Asia was found to be associated with the growing urbanization (Khoo et al. 2003). Urbanization has become an extremely serious public health challenge in India (Sarkar et al. 2005).

It is important to point out that different land use changes may affect one another and that most of the ecological consequences of land use change reflect interactive effects under different land use changes. For example, deforestation has led to the degradation of freshwater habitat through contributing to the siltation of rivers. The role of the Asian forest as a carbon sink and source varies from year to year or from place to place as a result of interactive effects between deforestation, afforestation and reforestation. Therefore, the interactions of different land uses along their change trajectories represent a big challenge for a better understanding of the land use change issue.

Concluding remarks

Asia is one of the priority regions with respect to studies related to the global environment, land use and climate change. One of the main reasons for concern is the dramatic transformations in land use that have occurred within – in a historical context – a relatively short period of time. These have resulted in substantial negative ecological consequences, such as increased anthropogenic CO_2 emissions, a degradation of air and water quality, alteration of regional climate, an increase in disease and a decline in biodiversity. Due to the rapid economic growth in many Asian countries and a large population – more than half of the world's population lives in Asian countries – emissions of the principal GHGs from Asia are increasing faster than those from any other continent.

Enhanced public awareness of environmental issues, specifically a growing concern for the consequences of uncontrolled land use change has motivated the establishment of sustainable land use policies in Asian countries. For example, four Asian countries – the Philippines, China, Mongolia and Japan – have established the national strategy towards sustainable development (Boyer 2000), which is aimed at reducing the negative environmental impacts of economic development while maintaining economic and social benefits. Ecological agriculture in Bangladesh, which advocates the use of crop residues, organic fertilizers, cropping diversification, mixed cropping, crop rotation, reduced use of inorganic fertilizers and absence of pesticides, is relatively more sustainable in terms of integrating environment, development and social concerns compared to the conventional agriculture, which is highly dependent on high-yielding varieties of seeds, inorganic fertilizers, pesticides and water (Rasul and Thapa 2003). China has adopted a new forest policy since 1998, entitled the Natural Forest Conservation Program, which is aimed at the expansion of natural forests and an increase in the productivity of forest plantations (Zhang et al. 2000). This program not only creates a new opportunity for restoring and maintaining forest sustainability in China, but also provides an example of how to manage the forest resources sustainably for other countries in Asia. The Chinese government announced a wetland restoration program in 1998 right after the catastrophic flood of that year, and about 9770 km^2 of land nationwide will return to wetland. In the Central Yangtze River, this project was successfully implemented through growing hydrophytes with high economic value, raising livestock on the seasonal grasslands, planting commercial seasonal vegetables, developing aquaculture in the low-lying paddy field and encouraging ecological tourism; as such, economic efficiency has been maintained without any negative effects on wetland ecological functions (Liu et al. 2004). China has established land use management strategies for developing green cities with a healthy environment for humans, vegetation and wildlife, which

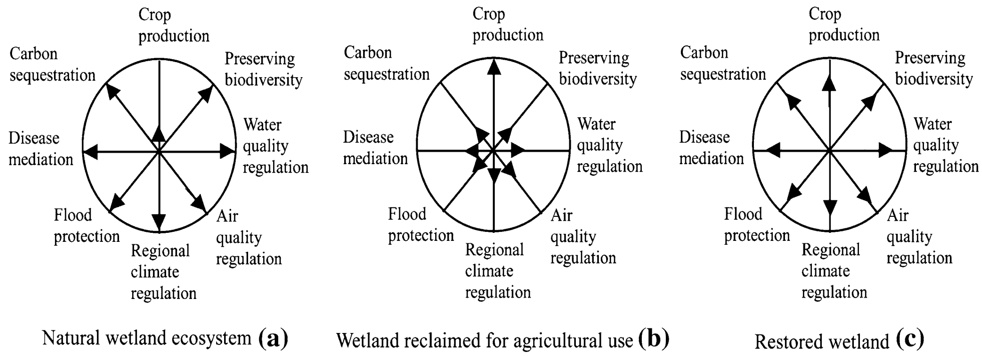

Fig. 4 The conceptual framework for comparing land use practices and trade-offs of the ecosystem services they provide. The ecosystem services provided by different land use practices can be illustrated with these *circles* where the length of the *line* with an *arrow* inside the *circle* qualitatively indicates the condition of each ecosystem service. We compare three hypothetical land use practices for illustration: natural wetland ecosystem (**a**), wetland reclaimed to agricultural use (**b**) and restored wetland (**c**). The natural wetland ecosystem can provide many ecosystem services at high levels, but not crop production. The agricultural land reclaimed from wetland supplies food at a high level, at the expanse of degrading other services offered by the natural wetland. A managed and restored wetland maintains multiple ecosystem services, which may be an example for sustainable land use in Asia (modified from Foley et al. 2005)

are exemplified by Guangzhou and Hong Kong through increasing green spaces in the processes of rapid urbanization (Jim 1999; Jim and Liu 2000).

The challenge of sustainable land use practices is to assess and manage trade-offs of land use between meeting immediate human needs and sustaining the ability of ecosystems in order to provide good and services in the long term. Figure 4 shows the conceptual framework for comparing land use practices and trade-offs of ecosystem services they provide, which may provide some ideas for sustainable land use in Asia. Land use change occurs at the local scale, but its ecological impacts spread across regional and global scales (Foley et al. 2005). Thus, developing innovative sustainable land use strategies in Asia are crucial not only for the environmental soundness, economic viability and social acceptability of the countries in Asia, but also for global sustainable development. The implementation of ecologically sound land use policy and planning requires multi-disciplinary approaches and more collective efforts by research scientists, land use policy makers and land managers of non-governmental organizations worldwide.

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