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Managing tropical wetlands for advancing global rice production: Implications for land-use management

Arun Jyoti Nath[a,b,*], Rattan Lal[b]

[a] Department of Ecology and Environmental Science, Assam University, Silchar 788011, India
[b] Carbon Management and Sequestration Center, The Ohio State University, Columbus, OH 43210, USA

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ABSTRACT

Being fertile lands, wetlands have been managed for traditional agriculture over millennia. However, the integrity and ecosystem services of wetlands are being jeopardized by intensive land-use comprising of drainage and excessive disturbance. An adhoc and intensive use of wetlands, without preserving ecological integrity is causing ecosystem disservices and threatening conversion of a large soil organic carbon (SOC) sink into a net source. Wetlands in the tropical parts of the world are distributed unevenly and represent ∼3% of the total world land area. Due to stagnancy and even reduction in rice (*Oryza sativa*) yield of many agricultural regions, there is a need for additional and alternative land-uses which can raise the global rice production to ∼1 billion Mg (megagram = 10^6g = metric ton) by 2050 from ∼497 million Mg now. Wetlands can be a viable option to advance global food security because of high soil fertility and vast geographical distribution. A '3-tier rice production system' is proposed herein based on specific hydrological niche to advance global food security without degrading the ecosystem services of wetlands. In addition to increasing agronomic yield, the proposed *modus operandi* can also improve the livelihood security of farmers through an additional income streams by: (i) trading of SOC credits generated through adoption of conservation agriculture in littoral zones, and (ii) promoting fish and duckery culture in conjunction with deepwater rice farming. Furthermore, the proposed strategies will also set in motion the process of restoration of wetlands while enhancing C sink capacity of the ecosystems.

1. Introduction

Wetlands are transitional zones between terrestrial and aquatic systems, and remain inundated or saturated due to high groundwater or surface water during a part or all through the year (Junk et al., 2013). Wetlands in the tropical parts of the world represents 3% of total land mass (Junk et al., 2013). Due to natural fertility and water availability, wetlands have been used for agriculture since millennia (MEA, 2005). Traditional way of rice (*Oryza sativa* L.) cultivation has been carried out in wetlands for millennia (Verhoeven and Setter, 2010) in either level or gently undulating slopes. Such traditional practice of rice cultivation might have maintained the wetland ecosystem integrity. Rice is one of the most important cereal crops feeding more than half of world's population (Khush, 2005) and globally it is cultivated on 153 million hectares (M ha) or ∼11% of the world's arable lands (FAO, 2012). Global paddy rice production in 2012 was ∼497 million Mg (megagram = 10^6g = metric ton) and is of a special importance to the nutrition of large population in Asia, Africa and parts of Latin America and the Caribbean (FAO, 2012). Inspite of large cultivated area and increasing yield in some countries, total rice production has lagged behind the global demand (Mosleh et al., 2015). Rice demand can be met either by (i) increasing production from the existing rice area, or (ii) increasing the area under cultivation. However, increasing the area is not a viable option because of the scarcity of prime land, water scarcity and emission of greenhouse gases (GHG) associated with land use conversion (Lal, 2008). Therefore, increasing productivity from the existing rice field is the only viable option to feed the projected population. Wetlands are fertile ecosystems but produce low yields (Balasubramanian et al., 2007) in extensive agriculture systems (i.e. more or less intact ecosystems) without the use of machinery and chemicals (Verhoeven and Setter, 2010). Such extensively managed wetland rice fields were traditionally characterized by a rich aquatic and semi-terrestrial flora and fauna (Verhoeven and Setter, 2010). Fish, amphibians, reptiles and birds were abundant and there were many examples of combined cultures of rice production and fishing (Fernando, 1993). In spite of numerous biodiversity values and other ecosystem services (ESs) of wetland rice farms, 30–90% of wetlands have already been destroyed or strongly modified for meeting the ever-

* Corresponding author at: Department of Ecology and Environmental Science, Assam University, Silchar 788011, Assam, India.
E-mail address: arunjyotinath@gmail.com (A.J. Nath).

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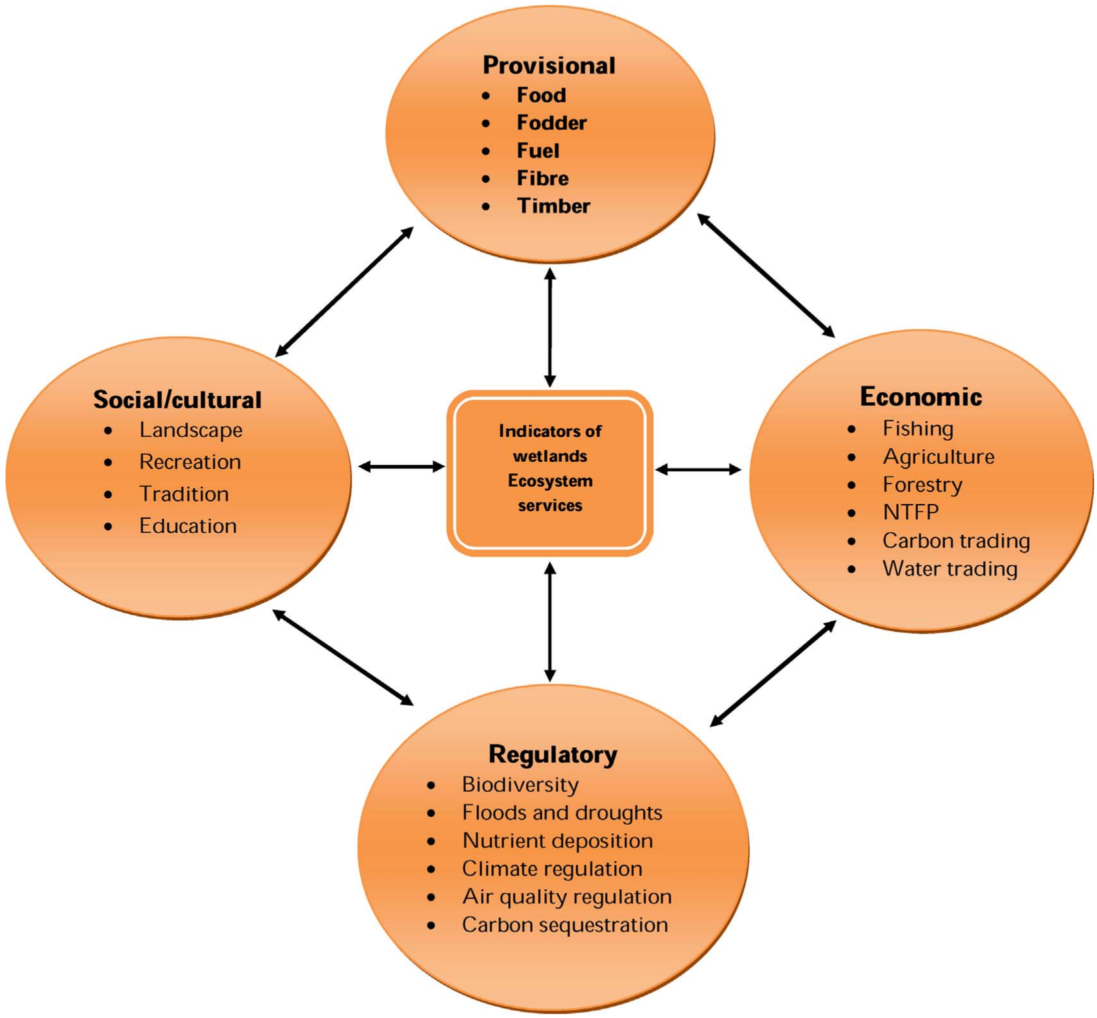

Fig. 1. Indicators of wetland ecosystem services.

increasing food demand (Junk et al., 2013) through intensive agriculture system i.e. high degree of soil amelioration, drainage and fertilizer use. This situation has been further exacerbated through double cropping of rice and crop intensification by growing higher value crops such as mungbean (*Vigna radiate*), peanut (*Arachis hypogaea*) and vegetables (Mitchell et al., 2013) and the conversion of tropical wetlands in to oil palm plantations in South-East Asia (Verhoeven and Setter, 2010). However, prudent intensification of wetland rice cultivation following a holistic approach can enhance rice production, advance global food security and promote ESs through maintaining the integrity of wetlands. Therefore, the objective of this article is to identify viable strategies for advancing global food security from wetland rice cultivation for enhancing productivity while sustaining wetland ESs.

2. Wetlands rice agriculture and production constraints

Floodplains of large river basins globally (South America, Africa and South-East Asia) are mostly managed by local communities following traditional systems (Gopal et al., 2008), but produce range of vital ESs (Fig. 1). Seasonal flooding through water impulse from interconnected streams produces a “moving littoral” which prevents permanent stagnation while allowing rapid recycling of nutrients and organic matter (OM) in the floodplain (Junk et al., 2013). Such water impulse and nutrient cycling strategy promotes higher diversity and productivity in floodplain system than that under either permanently wet or dry conditions (Junk et al., 2013). Therefore soils of floodplains are nutrient-rich and are naturally ‘fertilized’ by seasonal flooding events (Verhoeven and Setter, 2010). The latter enhances the capacity of wetlands to provide their ESs to the users. Hydrological connectivity between floodplain lakes and the river and flood pulses is a key determinant of the ESs (Coops et al., 2006; Junk et al., 2013). Through the practice of natural fertility management, wetland agro-ecosystems of rice production in many countries are environmentally sustainable. Although wetland agriculture is amongst the most sustainable system for its natural soil fertility management and preferential accumulation of soil organic matter (SOM) (Sahrawat, 2006; Nath et al., 2016a), provision of ESs by wetlands (Fig. 2) is threatened because of the adverse effects of management (Junk et al., 2013) and low agronomic yield under traditional systems (George et al., 2002). Similarly, average rice yields of ~ 1.4 Mg ha^{-1} in inland valleys across Africa (Diagne et al., 2013) is lower than 5–6 Mg ha^{-1} achieved under best management practices or BMPs (Wakatsuki and Masunaga, 2005).

3. Viable strategies for enhancing productivity

Some pertinent and viable strategies which are already practiced to improve yield from wetland agriculture include: (i) Flood and drought tolerant rice cultivars, (ii) Pest and disease control, (iii) Riparian vegetation management etc. In conjunction with these, a ‘3-tier rice cultivation system’ is proposed. This is based on specific hydrological niches that can enhance yield, promote socioeconomic conditions of the farmer and improve wetland ESs.