Review Article

GLOBAL IMPORTANCE OF RICE CULTIVATION IN MAINTAINING ECOLOGICAL BALANCE: A FOCUS ON KERALA, INDIA

ABSTRACT

Rice is crucial to over half of the world's population, profoundly shaping history, diet, and economies globally. In Asia, rice is deeply embedded in daily life and cultural traditions, from religious ceremonies to everyday meals. As a major staple, rice is predominantly produced in South and East Asia, with China and India being the leading producers. In India, the state of Kerala exemplifies the integral role of rice in both cultural and ecological contexts. Kerala's paddy fields are essential for flood management, groundwater conservation, and supporting diverse ecosystems. Traditional rice farming practices in Kerala not only improve local geography and ecology but also sustain a range of vital ecological processes. Beyond food production, rice paddies offer critical services including flood control, groundwater recharge, water purification, soil erosion prevention, landslide mitigation, local climate regulation, and landscape formation. They also act as biodiversity reservoirs, provide recreational opportunities, and enhance aesthetic values. To safeguard these benefits and promote sustainable rice farming, it is essential to implement effective management strategies. These strategies must address issues such as paddy land conversion, intensive agriculture, and climate change, aiming to restore and preserve the ecological functions of rice ecosystems. By doing so, they ensure the continued provision of these valuable services and the long-term sustainability of rice paddies for human well-being.

Key words: Rice; Ecosystems; Biodiversity; Climate change; Land conversion

1. INTRODUCTION

Rice is the lifeblood for more than half of humanity, profoundly influencing the history, diet, and economy of billions across the globe. In Asia, rice is so deeply woven into daily life that it forms the very fabric of cultural practices—people rest on rice straw, consume rice-based beverages, and offer rice in religious rituals. The growth cycle of rice crops not only signifies the passage of time and seasons but also reflects the intricate relationship between agriculture and cultural traditions (Scaria *et al.*, 2014). Its significance extends into language, where rice has become synonymous with daily greetings and social interactions. For instance, in countries like Japan and China, the day is traditionally marked by “morning rice” and concluded with “evening rice.” Historically, in Thailand and China, the customary way to greet someone was by asking, "Have you taken your rice today?" rather than simply saying hello. Furthermore, during New Year celebrations, instead of the conventional "Happy New Year," people would wish each other, “May your rice never burn” (Ahuja and Ahuja, 2017). As noted by Gomez (2009), rice transcends its role as a mere grain; it represents the cornerstone of civilization in numerous regions, underpinning both historical development and contemporary life.

2. HISTORY OF RICE CULTIVATION

The genus *Oryza*, part of the Poaceae family, includes 22 wild species (both annual and perennial) and two cultivated species: *Oryza sativa* (primarily grown in Asia, the Americas, and Europe) and *Oryza glaberrima* (cultivated in Africa). The cultivated species of *Oryza sativa* have three main subspecies—*japonica*, *javanica*, and *indica*—each with distinct morphological traits resulting from their separate domestication processes. The subspecies *indica* originated in a region stretching from the Himalayan mountains along the Ganges in India, while *japonica* developed in the southwestern part of China, and *javanica* emerged in Indonesia. The species *Oryza glaberrima* originated in Nigeria. Evidence suggests that rice cultivation has been practiced for over 7,000 years, with historical records indicating rice was cultivated in

India and China around 4000–5000 BC. It was introduced to Japan between 1000 and 300 BC, to Western India and Pakistan around 2300 BC, and to Malaysia and the Philippines by 1400 BC (Joshi, 2015).

3. RICE ECOSYSTEMS

Rice farming is practiced across various agroecological zones (AEZs), with the majority taking place in warm/cool humid subtropics (AEZ 7), warm humid tropics (AEZ 3), and warm sub-humid tropics (AEZ 2). The International Rice Research Institute (IRRI, 1993) categorizes rice land ecosystems into four main types: irrigated rice ecosystems, rainfed lowland rice ecosystems, upland rice ecosystems, and flood-prone rice ecosystems.

Most rice cultivation is wet, except for the upland system. In the irrigated rice ecosystem, fields benefit from a reliable water supply for one or more crops each year. This system covers over half of the world's rice lands and accounts for about 75% of global rice production. The rainfed lowland rice ecosystem, on the other hand, suffers from unpredictable water availability, leading to challenges such as flooding and drought. Approximately one quarter of the world's rice lands fall under this category. Upland rice ecosystems, which include low-lying valleys as well as steep and undulating slopes, experience varied soil textures, water holding capacities, and nutrient levels. These lands range from the heavily leached alfisols of West Africa to the fertile volcanic soils of Southeast Asia, and constitute less than 13% of the world's rice land. The remaining rice lands are classified as flood-prone ecosystems, which make up nearly 8% of the total. These areas face uncontrolled flooding, with water levels reaching 0.5 to 4.0 meters or more, and intermittent brackish water flooding due to tidal fluctuations, particularly in coastal plains.

Rice is a staple for over three billion people globally, contributing to 20% of the world's dietary energy supply. Enhancing food security in developing countries hinges on sustainable rice production, making rice critical to global food security.

The IRRI projects that rice production must increase by 25% over the next 25 years to meet future global demands. The rise in the global population and the effects of climate change in the region influence the need to boost rice production and improve its quality. The recent food crisis has prompted a reassessment of rice self-sufficiency goals. For agricultural sustainability, rice-producing countries have developed policies focusing on productivity and quality growth to ensure adequate food (Mohidem *et al.*, 2022).

4. RICE AREA AND PRODUCTION: WORLD, INDIA, AND KERALA

Rice is one of the most widely consumed grains globally, with South and East Asia being the primary regions for its production. China and India stand out as the leading producers of paddy rice. China, the most populous country in the world, leads in rice consumption, producing 148.87 million tonnes of rice in the 2017-18 period. India follows, with a production of 112.91 million tonnes from an area of 43.79 million hectares during the same period (GOI, 2018). Within India, the states of West Bengal, Punjab, and Uttar Pradesh are the top producers in terms of both production and area.

In Kerala, rice holds a central place in the lives of its people, deeply ingrained in every aspect of daily life. It influences music, art, tradition, folklore, rituals, and even language. For many in Kerala, life without rice is unimaginable (Balachandran, 2007). The state’s rice cultivation covers approximately 0.202 million hectares, producing around 0.578 million tonnes of rice (GOK, 2018). The key rice-producing districts in Kerala are Palakkad, Alappuzha, and Thrissur.

Paddy fields play a crucial role in Kerala's environmental and ecological systems. They function as natural drainage systems for floodwaters, conserve groundwater, and support a diverse range of flora and fauna. In various regions, traditional rice cultivation methods enhance the local geographical and ecological features. For example, in the Kaipad fields of Kattampally in Kannur district, rice is grown in saline water conditions. In the Pokkali fields around Kochi, farmers practice alternating prawn and rice cultivation. Similar practices are found in the Kole fields of Thrissur and Ponnani, as well as in the paddy fields of Kuttanad, Onattukara, Palakkad plains, and the High Range.

5. FUNCTIONS OF RICE FIELDS

Rice fields play a crucial role in various ecological processes that provide significant benefits to humans. These ecosystems offer a range of goods and services that hold considerable value for society. The ecological functions and their associated value of a wetland are influenced by factors such as its location, surrounding environment, water source and quality, biological diversity, and other characteristics (Chopra, 1997). Beyond rice production, rice ecosystems yield numerous outputs with non-market values. These can be broadly classified into five major functions: water cycle regulation, environmental load mitigation, landscape formation, social and cultural enrichment, and recreational and aesthetic benefits (Masumoto, 2003; Matsuno *et al*., 2006; Huang *et al.*, 2006; Kim *et al.*, 2006). The following sections will explore these functions and their sub-functions in detail.

5.1 Ground water recharge and Flood control

Rice fields enhance the water storage capacity of river basins, reduce peak river flows, and serve as buffers for downstream areas during heavy rainfall. In Japan, the flood-storage capacity of rice paddies, calculated by multiplying levee height by field area, ranges from 4.4 billion to 5.2 billion cubic meters (Imaizumi, 2006). In the Kumamoto region, known as the "Groundwater City," nearly one million people rely on groundwater, with approximately 45% of this recharge attributed to paddy fields (Ichikawa, 2002). Research by Tripathi (2016) in Bhubaneswar and Ludhiana demonstrated that bund heights of around 22 cm were effective in reducing runoff and boosting groundwater recharge. Additionally, studies at the Kerala Agricultural University revealed that 85% of the water in paddy fields percolates into the ground, serving as a significant water reservoir (Popular Expert Committee, 1998). Nehru *et al.* (2007) found that sustainable rice farming practices contribute to groundwater recharge, ensuring an adequate water supply for local populations.

5.2 Water purification function

Rice fields can effectively purify water, particularly when incoming irrigation water contains high levels of nitrogen (N) and phosphorus (P) (Maruyama *et al.*, 2008). The average water purification value for both active and fallow paddy fields has been estimated at 1.2 × 10^3 JPY/m^2 (Shiratani *et al.*, 2006). Experiments conducted by the USDA's Natural Resources Conservation Service demonstrated that water leaving rice fields is significantly clearer than the water entering from a nearby river (Moore, 2018). Additionally, a study by Panizzon *et al.* (2013) on the microbiological water quality in the Sinos River basin in Southern Brazil revealed that rice fields effectively filter out coliforms and faecal coliforms from irrigation water as it flows through the agroecosystem (Fig. 1).

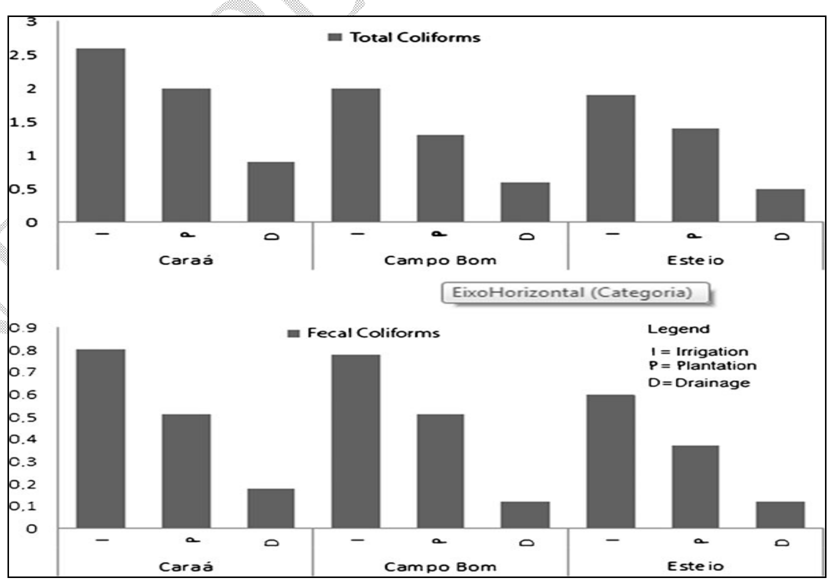

Fig. 1 Average abundance of bacteria in the irrigation water (I), in the rice fields water (P), and in the drainage water (D) (Panizzon *et al.*, 2013)

5.3 Soil erosion and landslide prevention

Agricultural heritage sites, such as terraces, are complex socioecological systems developed by long-term interactions between humans and nature (Chen *et al.*, 2020). Land abandonment, mismanagement and inadequate maintenance are one of the most common problems that can turn into hydrogeological dysfunctions and soil erosion overall (Pijl *et al.* 2019; Tarolli and Straffelini, 2020). In Japan, it is widely acknowledged that paddy fields in mountainous regions, particularly rice terraces, play a crucial role in preventing soil erosion and landslides. Approximately 10% of the country's paddy fields are situated on steep slopes with a gradient steeper than 1:20. The ponding effect created by these fields prevents raindrops from directly impacting the soil, thereby reducing soil susceptibility to erosion from rainfall (Matsuno, 2006). However, it is important to note that while ponding water helps mitigate erosion, it can also lead to increased soil particle dispersibility, which may contribute to soil runoff, especially during land preparation activities such as ploughing (Taniyama, 1999).

5.4 Local climate mitigation

Evapotranspiration from paddy fields plays a significant role in cooling the surrounding environment by absorbing a substantial amount of heat, thereby reducing ambient temperatures, particularly during the summer months. This cooling effect is especially noticeable in peri-urban areas where paddy fields are interspersed with urban lands. Research by Yokohari *et al.* (1998) demonstrated that the temperature reduction effect is more pronounced in areas with extensive paddy cultivation and extends up to 150–200 meters downwind from these fields. Additionally, this cooling effect contributes to mitigating the urban heat island phenomenon, making paddy fields a valuable component in managing local climate conditions. The ability of paddy fields to lower surrounding temperatures can also influence local microclimates, enhance comfort levels for residents, and potentially reduce energy consumption for cooling in nearby urban areas.

5.5 Nature formation: Biodiversity

Rice ecosystem act as a very good habitat for plants, animals, predators and micro-organisms in one or another way like woodlands, irrigation ponds, drainage ditches, river etc and which responsible for food chain or food web system in and around the rice fields (Fig. 2).

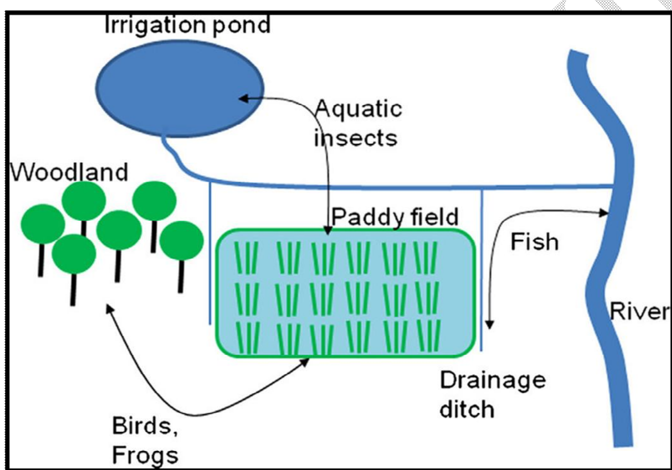

Fig. 2 Water management of paddy field and life cycle of species (Yosihiro, 2013)

The Kaipad system of rice cultivation in North Kerala represents an integrated organic farming approach that combines rice cultivation with aquaculture in coastal brackish water marshes rich in organic matter. This ecosystem is notably diverse, supporting a wide range of flora and fauna, including numerous species of phytoplankton and marine fungi that play crucial roles in the decomposition of organic matter. A distinctive feature of the Kaipad tracts is the presence of mangroves along the fringes of backwaters and estuaries. Mangroves are essential for providing breeding grounds for fish and prawns, as well as for trapping toxic chemicals and pollutants. Additionally, mangrove forests offer various resources such as fish, shellfish, livestock fodder, fuel, building materials, local medicine, honey, beeswax, and timber. The prop roots of mangroves penetrate deep into anaerobic mud flats, facilitating mineral cycling and sustaining the productivity of the Kaipad ecosystem. The mangrove canopy also provides vital resting and nesting sites for birds, while the flowers contribute to local honey production (Vanaja, 2013).

5.6 Landscape formation

Rice-based systems have profoundly shaped the landscapes of rural areas across the globe, and the Kuttanad Below Sea-Level Farming System (KBSFS) in Kerala stands out as particularly unique. This is the only system in India where rice cultivation is practiced below sea level. The KBSFS encompasses about 50,000 hectares of flat, reclaimed delta swamps, characterized by extensive rice fields known locally as "Puncha Vayals." The system includes three distinct landscape elements: Karapadam (upland rice fields), Kayal (wetland rice fields), and Kari (lands covered with black, coal-like materials).

Farmers in Kuttanad have perfected the technique of below-sea-level rice cultivation over the past 150 years. This innovative system not only contributes significantly to the region's agricultural productivity but also plays a crucial role in conserving biodiversity and providing vital ecosystem services. It supports various livelihood activities for local communities, including fishing, duck farming, and the cultivation of other crops. Additionally, the KBSFS helps in maintaining the region's hydrological balance and soil fertility, demonstrating its importance as both an agricultural and ecological asset (FAO, 2012). This system exemplifies how traditional agricultural practices can integrate with natural processes to sustain and enhance local environments and economies.

5.7 Social and cultural formation

Both historically and in contemporary times, the labour-intensive nature of rice cultivation—encompassing land reclamation, the construction and maintenance of terrace systems, and the synchronization of cropping patterns to combat soil erosion, landslides, and flooding—has necessitated collective effort within villages. This communal effort has profoundly shaped both social structures and the cultural significance of rice. The relationship between rice and people has inspired a rich tapestry of artistic and cultural expressions, including songs, paintings, stories, and other forms of communication.

Numerous festivals celebrate rice and rice cultivation, such as the Land Opening Festival in China, which marks the beginning of the rice season. Historically, rice was revered by many Asian emperors and kings, and in Japan, rice is still regarded as the "mother" of their culture, with rice farmers honoured as custodians of both cultural and rural traditions. Over the centuries, rice has deeply influenced the cultures and dietary practices of its cultivators and consumers. The term "rice-fish societies" refers to the integration of rice and fish in the diets of many Asian countries. In Colombia, the dish "rice and beans" is celebrated as a national staple and continues to be a vital source of sustenance for many impoverished communities (FAO, 2004).

In India, rice cultivation is celebrated through various festivals, reflecting its cultural significance. Notable examples include *Baisakhi* in Punjab, the *Puthari* harvest festival in Kodagu, *Nabanna* in West Bengal, the *Agera* harvest festival in Maharashtra, and *Vishu* in Kerala. These festivals not only honour the agricultural cycle but also reinforce the cultural and social fabric surrounding rice cultivation.

5.8 Recreation and aesthetics

Terraced paddy fields are increasingly being recognized for their multifaceted roles beyond mere rice cultivation. *Shiroyone* terraced paddy fields in the Noto Peninsula, Ishikawa Prefecture, Japan, exemplify this broader value. This culturally significant landscape was designated a Globally Important Agricultural Heritage System (GIAHS) pilot site by the FAO in 2011, highlighting its exceptional agricultural and cultural importance (Bixia, 2016). In Tokyo, Japan's most populous city, rice fields are preserved and promoted as a key part of urban and peri-urban agriculture, reflecting their cultural and ecological significance (Agriculture Development Policy Draft, 2013). The *Pasona* Urban Farm in Tokyo represents an innovative approach to rice cultivation, blending urban agriculture with recreational spaces. This initiative not only engages city residents in farming activities but also provides a rural escape from the city's dense environment.

Additionally, the annual "Tanbo Art" event in Inakadate Village, Aomori, transforms rice paddies into large-scale living art installations using colored rice stalks. This artistic technique has also been introduced to India and Kerala, aiming to explore and enhance the recreational potential of rice fields. These initiatives underscore the evolving recognition of rice fields as valuable cultural and recreational assets, in addition to their traditional agricultural roles.

Rejula (2015) conducted a study on farmer’s awareness regarding ecosystem services of paddy land of 12 agro ecological zones of Kerala revealed that majority (65%) of the respondents were aware about the overall ecosystem services of paddy wetlands (Table 1).

Table 1. Farmer’s awareness regarding ecosystem services of paddy land (Rejula, 2015)

Components	Per cent of respondents who are aware
True value of paddy wetland recourses	43.00
Water purification function	47.00
Sediment & nutrient retention function	55.00

Scenario of food deficit in Kerala	56.25
Flood control function	65.00
Groundwater replenishment function	66.25
Consequences of degradation on livelihood conditions	73.75
Basic information about paddy wetlands	74.50
Reservoirs of biodiversity	88.75
Total (overall awareness of ecosystem services of paddy wetlands	65.00

6. ECOSYSTEM SERVICE VALUE (ESV)

Ecosystem service valuation is an economic approach that assigns monetary value to ecosystems and the services they provide. Rice ecosystems are increasingly recognized for their role in promoting sustainability and are receiving growing attention in agricultural policy reforms. Kyun (2002) conducted a study on the social and economic evaluation of the multifaceted roles of paddy farming in Korea, revealing that the estimated value of these ecosystem services ranged from US$9.75 billion to US$11.46 billion (Table 2). Notably, even the lower end of this range exceeds the value of the harvested rice, which is US$8.37 billion. This indicates that the ecosystem services provided by rice cultivation have a significantly higher economic value than the rice itself.

Table 2. ESV of multi-functional roles of paddy farming in Korea (Kyun, 2002)

Ecosystem service	Quantities involved (mt)	Value (million US $)
Flood control	2733	1208
Conserving water resources	5420	1224

Purifying water	704	1651
Preventing soil erosion	1	713
Disposal of organic wastes	N: 23	558
Air purification	CO_2: 14, O_2: 10	1613
Climate mitigation	5171	1175
Landscape		745
Recreation and relaxation		2572
Total		11,458

The Kole wetlands extend to about 18,602 ha in Malappuram and Thrissur district. It is an important rice-growing area that occupies 2.35% of the total rice cultivating area of the state and one of the major ecologically important freshwater wetlands of the state. Nikhil and Azeez (2009) calculated the total value of the Kole wetland was $278 million/ha/yr in terms of ecosystem services (Table 3).

Table 3. ESV of Kole wetlands (Nikhil and Azeez, 2009)

Ecosystem service	**Value ($ million ha^{-1} yr^{-1})**
Wetland area	18,602 ha
Gas regulation	3
Disturbance regulation	85
Water regulation	0.3
Water supply	71
Waste treatment	78

Habitat	6
Food production	5
Raw materials	2
Recreation	11
Cultural	17
Total ecosystem value	278

7. NEGATIVE IMPACT OF RICE CULTIVATION

One of the primary environmental challenges associated with rice cultivation is the emission of methane (CH4), a potent greenhouse gas that significantly contributes to global warming. Flooded rice fields contribute significantly to methane emissions, which account for 48% of agricultural greenhouse gas emissions (Martínez *et al.,* 2021). Methane emission from paddy is primarily influenced by water management practices and soil conditions (Jiang, 2021). Methane emissions from rice fields are a major concern due to their impact on climate change. Globally, rice fields contribute between 31 to 112 teragrams (Tg) of methane annually, which accounts for approximately 5% to 19% of total methane emissions (Smith *et al.,* 2007). These emissions arise from the anaerobic decomposition of organic matter in flooded rice fields, a process that releases methane into the atmosphere.

To address this issue, various mitigation strategies are being explored and implemented. These include adjusting water management practices, such as intermittent flooding, which can reduce methane emissions by promoting aerobic conditions in the soil. Alternate wetting and drying (AWD) have been identified as one of the most promising techniques for reducing methane emissions from rice cultivation. Using the methodologies outlined by the Intergovernmental Panel on

Climate Change, the AWD scenario could reduce annual methane emissions by 32% compared to the continuously flooded scenario (Prangbang *et al.*, 2020). Additionally, research into alternative rice cultivation methods, such as dry-seeding and the use of methane-reducing rice varieties, aims to minimize greenhouse gas emissions. The development and adoption of these technologies are crucial for reducing the environmental footprint of rice cultivation while maintaining its crucial role in global food security.

8. THREATS TO RICE ECOSYSTEM

The major threats which affect rice ecosystem are paddy land conversion, intensive agriculture, and climate change.

8.1 Paddy land conversion

Paddy conversion involves abandoning a highly developed and intricate wetland agro-ecosystem, leading to the irreversible transformation of the landscape. In Kerala, the issue of paddy conversion is multifaceted, encompassing economic, ecological, socio-cultural, and structural dimensions (Agus and Mulyani, 2005).

Over the past 61 years, significant changes have occurred in the rice cultivation patterns in Kerala. Initially, both the area and production of rice increased following the formation of the state and during the period of land reforms. Districts such as Kozhikode, Palakkad, Thrissur, Ernakulam, and Alappuzha experienced positive growth in rice cultivation from 1956–57 to 1975–76. In contrast, the southern districts of Thiruvananthapuram and Kollam exhibited a significantly lower area under rice cultivation, with no notable increase during the same period. This initial growth phase was followed by a decline in rice cultivation across all districts and the state as a whole, a trend that has persisted up to 2016–17 (Johnson, 2018). This shift reflects broader changes in agricultural practices, land use, and regional development dynamics.

8.1.1 Factors involved in paddy land conversion

The conversion of paddy lands is driven by a complex interplay of factors, each contributing to the transformation of these vital agricultural landscapes. Demographic changes and shifting settlement patterns have led to increased pressure on land resources, often resulting in the conversion of paddy fields for housing and urban expansion. Concurrently, infrastructure development—such as roads, industrial zones, and commercial centers—further encroaches upon agricultural land. The growth of land markets has also facilitated the sale and repurposing of paddy fields for higher-value uses. Economic reasons play a significant role, as the profitability of alternative land uses often outweighs the benefits of maintaining rice cultivation. Political factors, including land policies and zoning regulations, can either incentivize or hinder the preservation of paddy fields. Cultural factors and attitudinal changes towards agriculture, particularly among younger generations, contribute to the declining interest in farming. Additionally, a lack of environmental awareness and understanding of the ecological importance of paddy fields exacerbates the issue, as the long-term consequences of land conversion are often overlooked. Together, these factors create a challenging environment for the preservation of paddy lands, impacting both local ecosystems and agricultural sustainability.

8.1.2 Conversion leads to further conversion

The conversion of upland plots impacts the water supply for adjacent downland areas, while the filling and leveling of downland plots can obstruct drainage for uplands. Alterations to plots within a polder, such as filling and leveling, can significantly reduce the water-holding capacity of neighboring plots. This disruption affects the water retention and discharge functions of wetlands, compromising their ecological balance. Additionally, farming on plots adjacent to converted areas becomes increasingly challenging and costly. Table 4 illustrates the comparative costs of rice cultivation in standard plots versus those adjacent to converted plots (Gopikuttan, 2004).

Table 4. Cost of Rice Cultivation in normal plot (NP) and adjacent to converted plots (ACP) of Ullanoor Watershed (Gopikuttan, 2004)

Name of items	Cost per hectare for winter crop (in Rs.)		
	NP	ACP	Difference
Ploughing/tilling	5500	7000	1500
Chemical fertilisers	3750	4500	70
Artificial irrigation	Nil	2500	2500
Weeding	2800	3640	840
Total	12050	17640	5590

8.1.3 Ecological Impacts of Paddy Conversion

A study by Gopikuttan (2004) on the ecological impacts of converting paddy wetlands in the Ullanoor watershed revealed a significant decline in the water table. Converted fields become harder and are often overtaken by amphibious grasses and other weeds due to community succession. The proliferation of mat-like vegetation in dry or fallow fields exacerbates water loss through increased transpiration and capillary action, further drying out the fields.

In these converted areas, water bodies accumulate more silt and sediments compared to those in non-converted regions, leading to increased turbidity. This turbidity obstructs sunlight penetration, disrupting the photosynthetic processes of phytoplankton and algae. These planktonic organisms, which are crucial food sources for fish and frog tadpoles, are severely affected, disrupting local food chains and ecosystems. Species that were once abundant in the 1960s have become rare or disappeared by the end of the 2000s due to extensive wetland conversion.

The costs and benefits of land conversion vary widely among stakeholders. While landowners may repurpose the converted land for their preferred uses, local farm workers may gain limited employment opportunities. However, the broader community suffers as access to common-pool resources (CPR) is restricted when the converted land is enclosed. Residents of the valley lose access to fresh water from springs and side canals of paddy fields, and rural children lose recreational open spaces. The responsibility of ensuring safe drinking water for all increases the financial burden on the government, particularly during the summer months. Consequently, the wider society, excluding the direct beneficiaries such as landowners or legal custodians of the converted lands, bears the negative impacts of such conversions.

A micro-level study conducted by Scaria *et al.* (2014) examined the changes in cropping patterns and the impact of declining paddy fields on floristic diversity in the Karrimpuzha watershed, located in the northwestern part of Palakkad District, Kerala. The study, conducted over a relatively short period, highlighted significant changes in the cropping patterns of paddy fields, which have been increasingly converted to other land use systems. In the year 1970-71, paddy fields constituted 53.16 percent of the total cropped area in the Karrimpuzha watershed. By 1990-91, this area had decreased to 18.38 percent, and it further declined to 12.10 percent by 2010-13. If the trend of large-scale conversion continues, it is projected that rice cultivation could be entirely abandoned in the near future.

The ongoing conversion of paddy fields to non-agricultural uses has emerged as a major challenge contributing to biodiversity loss. The study found that paddy fields support a diverse range of plant species, from algae to angiosperms. The bunds of paddy fields provide habitats for various grasses, marsh plants, creepers, and small trees. In contrast, plantations with dense canopies limit sunlight, suppressing the growth of heliophilic plants such as grasses and marshes, which are common in paddy fields. Consequently, plantations tend to support only shade-tolerant, mesophytic herbaceous plants. Additionally, intensive weeding practices in plantations contribute to further declines in vegetational biodiversity.

Thomas (2016) assessed the impacts of wetland and paddy land conversion in Kollam Corporation, identifying several major issues: changes in soil infiltration and settlement characteristics, increased runoff, reduced water recharge, heightened flooding and waterlogging risks, water scarcity, and foundation settlement in reclaimed lands.

According to The Hindu (2019), the incremental filling of paddy fields and wetlands in areas like Kakkodi and Thannerpanthal has led to significant problems, such as inundated roads and waterlogged homes during recent floods. For instance, approximately 87 hectares of paddy fields in the Kottuli wetland area of Kozhikode have been converted, and about 10 acres of former paddy fields in Ramanattukara are being developed into a Cyber Park. Additionally, surviving wetlands are increasingly threatened by stormwater runoff, urban garbage, and sedimentation.

8.2 Intensive agriculture

Animals and plants in paddy fields are highly susceptible to the impacts of various agricultural practices. Intensive rice cultivation poses significant threats to the ecological functions of these systems. Tillage methods, along with the use of agrochemicals and fertilizers, affect both the abundance and species composition of aquatic life in paddy fields (Wilson et al., 2007). Azuma and Takeuchi (1999) found that converting small, traditional paddies into large, well-drained fields negatively impacts the habitat of the Japanese brown frog.

Modern rice farming often relies heavily on chemical fertilizers and pesticides to boost yields. This overuse of fertilizers can lead to significant runoff, causing eutrophication in downstream water bodies (Peng et al., 2012). In Kerala, the heavy application of fertilizers has resulted in pollution, eutrophication, and harm to local biodiversity. Additionally, intensive rice cultivation can adversely affect human well-being by increasing pesticide residues in food and water supplies (Sruthi et al., 2017).

Land-use changes, such as agricultural intensification and farmland abandonment, further impact biodiversity. Research by Katayama et al. (2015) indicates that both intensification and abandonment negatively influence the richness and abundance of agricultural wetland species during summer. Katano (2000) identified key factors affecting fish abundance and diversity, including blocked migration routes, concrete channel linings, and straightened waterways. The loss of connectivity between waterways and paddy fields, along with seasonal water loss and the simplification of waterways for drainage purposes, has severely diminished fish populations and overall aquatic biodiversity (Fig. 3).

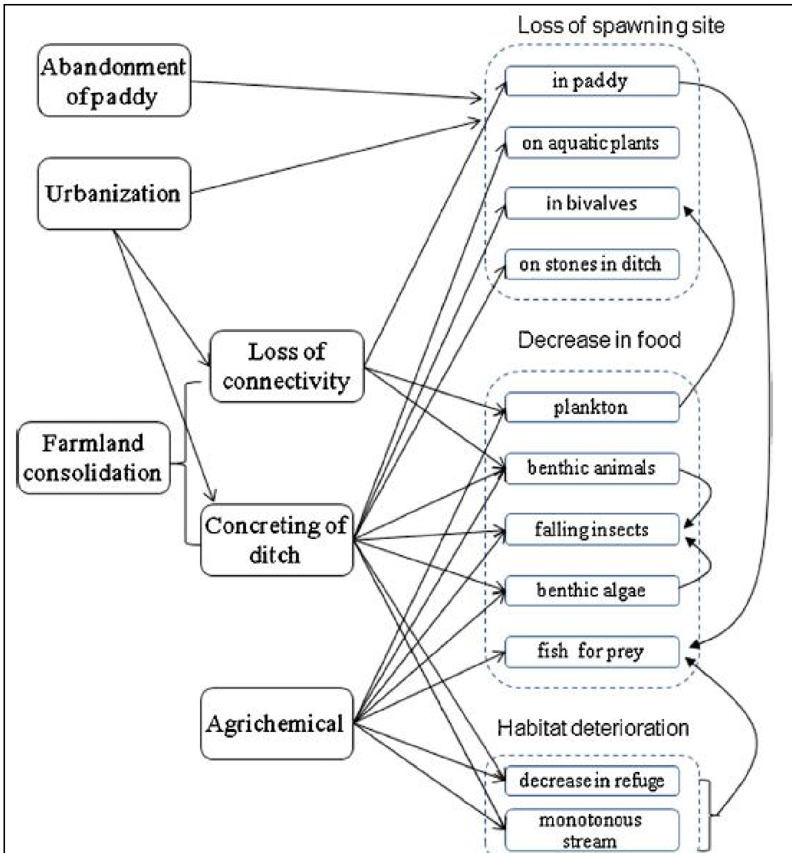

Fig. 3 Impacts of changes in paddy field on fish (Katano, 2000)

Berg *et al.* (2017) investigated farmers' perceptions of ecosystem services provided by rice farming in the Mekong Delta, Vietnam. They found that farmers observed a significant decline in these services over the past 15 years, attributing the reduction to intensive rice farming practices. The decline was linked to factors such as excessive use of agrochemicals, illegal fishing gear, environmental pollution, and soil acidification. Similarly, Smitha and Anilkumar (2015) reported a notable decrease in both faunal and floral diversity in the rice fields of the Palakkad plains. Farmers attributed these changes to several factors, including the overuse of inorganic inputs and poaching activities (Table 5).

Table 5. Farmers' perception on variation in the floral and faunal diversity in rice fields of Palakkad district

Flora	Fauna
Hydrilla	Spiders
Penny wort (Mal. Brahmi)	Damsel fly
Nymphaea (Mal. Ambal))	Dragon fly
Wedelia (Mal. Manjakkayonni)	Lady bird beetle
Glenwood grass (Mal. Pollakala)	Grass hoppers
Blood grass (Mal.Changali/ Naringa)	Crickets
Puncture vine (Mal. Njerinhil)	Butterfly
	Rove beetles
	Water striders
	Frogs
	Water snakes
	Small weed fish (Paral)
	Local Muzhi / nadan muzhi
	Crabs
	Garden lizard / chamaleon
	Grey herons
	Mynah

8.3 Climate change

Global climate change poses serious threats to rice production and, by extension, global food security. Land-use systems in many developing countries are particularly vulnerable and poorly equipped to handle these impacts. Predictions indicate that rice farming conditions will worsen in numerous regions due to factors such as water shortages, declining water quality, thermal stress, rising sea levels, flooding, salinity, increased carbon dioxide levels, and more severe tropical cyclones. According to a study by the International Food Policy Research Institute (IFPRI), climate change is expected to reduce irrigated rice yields in developing countries by 15% and increase rice prices by 12% by 2050. The impact on rice productivity will be particularly severe, with reductions of 14% in South Asia, 10% in East Asia and the Pacific, and 15% in Sub-Saharan Africa.

9. STRATEGIES TO ADDRESS THREATS

9.1 Strategies to address paddy land conversion

Since the 1960s, Kerala has undergone significant social transformation. In instances where economic interests conflict with environmental concerns, the state's high literacy rate often leads to decisions favoring economic benefits. Private owners of paddy fields, driven by economic rationale, frequently opt to convert these lands for non-agricultural uses. However, the long-term ecological and environmental consequences of such conversions are not always fully understood. The decline of paddy lands and wetlands has become a pressing issue for residents, prompting the state to implement stringent protective measures. In response, the Kerala legislature enacted the Kerala Conservation of Paddy Land and Wetland Act in 2008. This comprehensive legislation aims to conserve paddy lands and wetlands, restrict their conversion or reclamation, and promote agricultural growth while sustaining the state's ecological balance. Pillai (2018) has proposed renaming the act to the "Kerala Conservation of Paddy Land and Wetland and Restoration Act," suggesting that it should include more robust enabling and enforcement provisions to better address these concerns.

9.1.1 Making rice cultivation profitable

To address the issues surrounding paddy land conversion, several management strategies can be implemented to make rice cultivation more economically viable and appealing to farmers. One approach is group farming, which effectively pools labor resources and better utilizes family labor, thus alleviating labor shortages in rice cultivation (Binth *et al.,* 2019). Another strategy is biodiversity certification, which promotes environmentally conscious farming by encouraging farmers to protect charismatic and culturally significant species, such as birds, fish, plants, and aquatic insects. In Takashima City, Japan, farmers are required to identify and declare three species they are proud to find in their paddies as part of the certification process. This approach not only helps in maintaining biodiversity but also enables farmers to sell their certified rice at a premium price (Natuhara, 2013). Additionally, ecological compensation or Payment for Ecosystem Services (PES) is a policy arrangement that uses economic incentives to balance stakeholder benefits and ensure sustainable use of ecosystem services. This can include direct subsidies or increased product prices, which help offset the environmental impact of farming while increasing farmer income (Li *et al.*, 2011; Ying *et al.*, 2017). Value addition in rice cultivation, such as producing rice flakes or coffee rice, can also make farming more profitable by creating additional income streams. Finally, farm tourism offers a way to leverage the ecological benefits of rice ecosystems for stable income. For instance, the Navara Organic Eco Farm in Chittur, Palakkad, provides a successful model of farm tourism, offering visitors the chance to explore its 18 acres of diverse crops and enjoy locally sourced dishes.

9.2 Strategies to address intensive agriculture

Sustainable agriculture aims to reduce the environmental impacts of farming by implementing practices that enhance biodiversity and ecological balance. Dermiyati and Niswati (2014) found that using organic fertilizers, such as "*bokashi,*" in Indonesian paddy fields significantly boosts soil and water biodiversity.

Continuous application of organic fertilizers, use of biofertilizers, and crop rotation can further enhance biodiversity and pest control. Constructing paddy systems that integrate animals and plants is another effective strategy. The FAO (2004) suggests that sustainable management measures for aquatic resources should be integrated into broader development programs. Introducing species like fish, ducks, and Azolla can improve biodiversity and ecosystem functionality. For instance, Letourneau *et al.* (2011) found that such integrated paddy systems increased natural enemy populations and reduced pest mortality. Quan *et al.* (2005) reported that raising ducks in paddy fields can delay and reduce the severity of rice-sheath blight, while Yang *et al.* (2004) observed that crabs help reduce incidences of rice diseases. Azolla can also suppress weeds, mitigating crop damage in integrated systems (Su *et al.*, 2004).

Protecting the ecological environment around paddy fields involves combining ecological principles with practical production methods to benefit both human society and the natural environment. Paddy ecological engineering can restore connectivity between water and fields, providing habitats and increasing biodiversity. Modern techniques, such as fish ladders, allow fish to navigate drainage ditches, while escape paths along canal slopes help reptiles and amphibians survive (Serra *et al.,* 2007; Wu *et al.,* 2006). Drainage control gates can also raise water levels to support diverse habitats (You and Wu, 1989). Heong *et al.* (2014) noted that bund flora offers essential resources for natural predators, aiding in pest control and biodiversity conservation. The National Institute of Plant Health Management (NIPHM) in India is promoting these ecological practices among farmers to maintain biodiversity and manage pests effectively.

Promoting ecological education and public awareness is crucial for encouraging the adoption of sustainable practices. The challenge lies in motivating farmers to move away from chemical sprays towards ecological methods. Raising awareness about the benefits of enriching bunds with nectar-rich plants can foster eco-friendly rice farming practices. Utilizing paddy field ecology as a tool for environmental education can empower farmers with knowledge and skills for sustainable agriculture.

9.3 Strategies to address climate change

In modern agriculture, balancing rice yields with environmental impacts is crucial for sustainable soil management. Environmentally friendly systems, like integrated rice-duck farming (IRDF), have shown promising results. Xu *et al.* (2017) found that IRDF significantly reduced methane emissions by 8.80-16.68% and lowered the global warming potential (GWP) compared to conventional farming, while increasing rice yields by 0.76-2.43%. Other ecological models, such as rice-duck and rice-fish systems, also help mitigate GWP (Yuan *et al*., 2009; Fang *et al.*, 2019).

To address climate change, the International Rice Research Institute (IRRI) is developing management strategies. Efficient irrigation and water-saving techniques can optimize water use. Modified cropping patterns, improved nutrient management, and soil improvements help manage droughts, while proper seed and seedbed practices, along with optimal fertilizer use, support flood resilience. Water-saving technologies like alternate wetting and drying can cut methane emissions by 60-90%. Additionally, using biochar from charred rice residues can reduce methane emissions by up to 80%. IRRI is also exploring gene modifications for lower gelatinization temperatures to save energy and reduce greenhouse gas emissions. Marker-assisted breeding is used to develop "climate change-ready rice," benefiting poor farmers through improved crop management and technology.

10. KERALA’S REVIVAL OF RICE CULTIVATION

Rice is a staple food in Kerala and holds a central place in the state's agrarian economy. The vibrant green of the paddy fields is a defining feature of Kerala’s landscape. In recent years, both state and local governments have launched various initiatives to support agriculture, especially rice cultivation. In the late 1980s, the state government introduced the Group Approach for Locally Adapted and Sustainable Agriculture (GALASA) program to overcome technological, management, and marketing challenges through empowerment, thus enhancing sustainable agricultural development. As part of this effort, *Padasekhara* Samitis, or collectives of paddy farmers, were established to facilitate group farming. These collectives receive seeds and fertilizers at subsidized rates from Krishi Bhavans, which also organize training camps to form *Thozhil Senas* (labour armies) in various panchayats to address the shortage of trained agricultural workers. Volunteers for the *Thozhil Sena* undergo five to seven days of training and receive free uniforms, identity cards, insurance, and a daily stipend of Rs 160–200. Additionally, farmers in Palakkad have set up a cooperative rice-procuring and processing unit called Paddyco in Elappully. Paddyco, with 353 farmers as shareholders, aims to ensure a steady income for its members and produce high-quality rice at reasonable prices.

The Kerala Conservation of Paddy Land and Wetland Act of 2008 aims to protect paddy lands and wetlands by restricting their conversion or reclamation, thereby promoting agricultural growth, and maintaining ecological balance in Kerala. To advance organic farming, the Kerala State Biodiversity Board introduced a policy in 2008 with a goal to transition 20 percent of the state's agriculture to organic practices annually over five years (Shinogi, 2011). Integrated rice cultivation methods, such as the *"Oru Nellu Oru Meenu"* approach, are also gaining traction among farmers.

In 2018-19, key initiatives included providing input assistance of ₹ 5,500 per hectare, establishing a 'Rice Innovation Fund' for eco-friendly and sustainable technologies, and implementing focused interventions in seven special agriculture zones—Kuttanad, Onattukara, Pokkali, Kole, Palakkad, Wayanad, and Kaipad—to boost rice production and farmer incomes (GOK, 2018). Additionally, the state plans to offer financial assistance under the 'Royalty for Ecosystem Service' program to paddy landowners, recognizing the ecological value of these lands. With approximately two lakh cultivable paddy fields and around six lakh paddy farmers, this program aims to curb land reclamation and promote conservation.

11. CONCLUSION

The rice ecosystem plays a crucial role in delivering numerous ecological processes that benefit human societies. Beyond its primary function of food production, it offers essential services such as flood control, groundwater recharge, water purification, soil erosion prevention, landslide mitigation, local climate regulation, and landscape formation. Additionally, rice paddies serve as biodiversity reservoirs, support recreational activities, and contribute aesthetic value to the landscape. These ecological functions generate significant value by providing goods and services vital to human well-being. To safeguard these benefits and promote sustainable rice farming, it is imperative to implement effective management strategies. These strategies are designed to address threats such as paddy land conversion, intensive agriculture, and climate change, thereby restoring and preserving the ecological functions of rice ecosystems and ensuring their long-term viability.

12. DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of manuscripts.

14. REFERENCES

Agus, F. 2005. Judicious use of land resources for sustaining Indonesian rice self-sufficiency. In: *Proceedings of International Rice Conference, Denpasar, Bali, Indonesia*, pp. 152-155.

Ahuja, S. C. and Ahuja, U. 2006. Rice in religion and tradition. In: *Proceedings of the Second International Rice Congress*, pp. 9-12.

Azuma, A. and Takeuchi, K. 1999. Relationships between population density of frogs and environmental conditions in Yatsu-habitat. *J. Jpn. Inst. Landsc. Archit*. 62(5): 573-576.

Balachandran, P. V. 2007. Rice scenario of Kerala and the future strategies. In: *Proceedings of XIX Kerala Science Congress*, pp. 22-32.

Berg, H., Söderholm, A. E., Söderström, A. S., and Tam, N. T. 2017. Recognizing wetland ecosystem services for sustainable rice farming in the Mekong Delta, Vietnam. *Sustainability Sci.* 12(1): 137-154.

Binth. S., Hulagur. B., and Goudappa. S. B. 2019. Labour management and benefit sharing practices in collective farming: A study in Palakkad district of Kerala state. *J. Pharmacognosy Phytochem.* 8(6): 1376-1379.

Bixia, C., Qiu, Z., and Nakamura, K. 2016. Tourist preferences for agricultural landscapes: A case study of terraced paddy fields in Noto Peninsula, Japan. *J. Mountain Sci.* 13(10): 1880-1892.

Chen D., Wei W., Daryanto S., and Tarolli, P. 2020. Does terracing enhance soil organic carbon sequestration? A national-scale data analysis in China. Science of The Total Environment 721:137751

Dermiyati and Ainin, N. 2014. Improving biodiversity in rice paddy fields to promote land sustainability [on-line]. Available: https:// link. springer. com/ content/ pdf/ 10. 1007%2F978-4-431-54804-1.pdf. [24 Dec. 2019].

FAO [Food and Agriculture Organization]. 2004. Rice and culture [on-line]. Available: http:// www.fao.org/rice2004/en/rice8.htm [12 Jan 2020].

FAO [Food and Agriculture Organization]. 2012. Kuttanad Below Sea Level Farming System [on-line]. Available: http: //www. Fao .org /family-farming/ detail/ en/ c/ 283069/ [15 Jan 2020].

Feng, X., Jiang, C. S., Peng, X. L., Li, Y. P., and Hao, Q. J. 2019. Effects of the crop rotation on greenhouse gases from flooded paddy fields. *Huan jing ke xue Huanjing kexue* 40(1): 392-400.

FIB [Farm Information Bureau]. 2013. Agriculture development policy draft, Government of Kerala [on-line]. Available: https: //www.fibkerala. gov. in /images/ agri/ agrifp.pdf [12 Jan 2020].

GOI [Government of India]. 2018. Agricultural statistics at a glance 2018. Directorate of Economics & Statistics [on-line]. Available: https://eands.dacnet.nic.in/[15 Jan 2020].

GOK [Government of Kerala]. 2018. Area and production of major crops. Department of Economics and Statistics [on-line]. Available: http://ecostat.kerala.gov.in/index. php/agriculture [10 Jan 2020].

Gomez, K. A. 2001. *Rice, The Grain of Culture.* The Siam Society, Thailand, 252p.

Gopikuttan, G. and Kurup, K. N. P. 2004. Paddy Land Conversion in Kerala. In: *An Inquiry Into Ecological and Economic Aspects in a Midland Watershed Region, Final Report,* Kerala Research Program on Local Level Development, Centre for Development Studies, Thiruvananthapuram, India, 125p.

Heong, K. L., Escalada, M. M., Chien H. V., and Cuong, L. Q. 2014. Restoration of rice landscape biodiversity by farmers in Vietnam through education and motivation using media [on-line]. Available http://sapiens.revues.org/1578 [16 Jan 2020].

Huang, C. C., Tsai, M. H., Lin, W. T., Ho, Y. F., Tan, C. H., and Sung, Y. L. 2006. Experiences of water transfer from the agricultural to the non-agricultural sector in Taiwan. *Paddy Water Environ.* 5(4): 271-277.

Ichikawa, T. 2002. Assessment of groundwater recharge from paddy field in the middle of Shirakawa Basin, Kumamoto. In: *Proceedings for 6th symposium on water resources, 2002*, pp. 87-92.

Imaizumi, M., Ishida, S., and Tuchihara, T. 2006. Long-term evaluation of the groundwater recharge function of paddy fields accompanying urbanization in the Nobi Plain, Japan. *Paddy Water Environ.* 4(4): 251-263.

IRRI [International Rice Research Institute]. 1993. The rice field ecosystem. [on-line]. Available: http:// pubs. iclarm.net/ Pubs/ Culture of Fish/ section1.pdf [20 Dec 2019].

Jiang, Y., Zhang, H., He, J., and Huan, P. 2021. Study on Methane Emission Factor of Paddy Fields in Hubei Province. IOP Conf. Ser. Earth Environ. Sci., 651, 042031.

Johnson, D. 2018. Cropping Pattern Changes in Kerala, 1956–57 to 2016–17. *J. Foundation Agrarian Stud*. 8(1): 256-258.

Joshi, M. 2015. *Textbook of Field Crops.* PHI Learning Private Limited, New Delhi, pp. 5-6.

Kanchan, C. 1997. *Economic Valuation of Biodiversity*. Study Report, IEG, New Delhi, 54p.

Katano, O. 2000. Ecosystems of rice fields from the perspective of fish conservation. LBRI Bulletin 19, pp. 72–76.

Katayama, N., Osawa, T., Amano, T., and Kusumoto, Y. 2015. Are both agricultural intensification and farmland abandonment threats to biodiversity? A test with bird communities in paddy-dominated landscapes. *Agric. Ecosyst. Environ.* 214: 21-30.

Kim, T. C., Gim, U. S., Kim, J. S., and Kim, D. S. 2006. The multi-functionality of paddy farming in Korea. *Paddy Water Environ.* 4(4): 169-179.

Kyun, S. and Suwon-si, K. D. 2002. *Social and Economic Evaluation of the Multi-functional Roles of Paddy Farming*. Food and Fertilizer Technology Center, 252p.

Letourneau, D. K., Armbrecht, I., Rivera, B. S., Lerma, J. M., Carmona, E. J., Daza, M. C., Escobar, S., Galindo, V., Gutiérrez, C., López, S. D., and Mejía, J. L. 2011. Does plant diversity benefit agroecosystems? A synthetic review. *Ecol. Appl.* 21(1): 9-21.

Li, W. H., Liu, M. C., and Min, Q. W. 2011. China's ecological agriculture: Progress and perspectives. *J. Resours. Ecol.* 2(1): 289–299.

Martínez, E, M., Alcaraz, C., Viñas, M., Noguerol, J., Aranda, X., Prenafeta-Boldú, F.X., Català-Forner, M., Fennessy, M.S., and Ibáñez, C. 2021. The main drivers of methane emissions differ in the growing and flooded fallow seasons in Mediterranean rice fields. Plant Soil, 460, 211–227.

Maruyama, T., Hashimoto, I., Murashima, K., and Takimoto, H. 2008. Evaluation of N and P mass balance in paddy rice culture along Kahokugata Lake, Japan, to assess potential lake pollution. *Paddy Water Environ.* 6(4): 355-362.

Masumoto, Y., Gerlovin, I., Ikezawa, M., Ignatiev, I., Okuno, T., Verbin, S., and Yugova, I. 2003. Spin relaxation in InP quantum dots. *Physica Sstatus Solidi* 4: 1368-1371.

Matsuno, Y., Nakamura, K., Masumoto, T., Matsui, H., Kato, T., and Sato, Y. 2006. Prospects for multi functionality of paddy rice cultivation in Japan and other countries in monsoon Asia. *Paddy Water Environ.* 4(4): 189-197.

Mohidem, N. A., Hashim, N., Shamsudin, R., and Che Man, H. 2022. Rice for Food Security: Revisiting Its Production, Diversity, Rice Milling Process and Nutrient Content. Agriculture 2022, 12, 741. https://doi.org/10.3390/agriculture12060741

Moore. M. T. 2018. Expanding wetland mitigation: Can rice fields remediate pesticides in agricultural runoff? *J. Environ. Quality* 12(3): 124-128.

Natuhara, Y. 2013. Ecosystem services by paddy fields as substitutes of natural wetlands in Japan. *Ecol. Eng.* 56: 97-106.

Nehru, M. S., Anilkumar, A., and Job, E. 2007. Wetland eco-system conservation through sustainable rice farming- The case of Kalatharakkal ela in Thiruvananthapuram district. *Kerala Environment Congress,* pp. 142-146.

Nikhil and Azeez, P. A. 2009. Real estate and agricultural wetlands in Kerala. *Econ. Political Weekly* 44(5): 63-66.

Panizzon, J. P., Macedo, V. R. M., Machado, V., and Fiuza, L. M. 2013. Microbiological and physical–chemical water quality of the rice fields in Sinos River's basin, Southern Brazil. *Environ. Monitoring Assess.* 185(3): 2767-2775.

Peng, S., Luo, Y., Xu, J., Khan, S., Jiao, X., and Wang, W. 2012. Integrated irrigation and drainage practices to enhance water productivity and reduce pollution in a rice production system. *Irrigation Drainage* 61(3): 285-293.

Pijl, A., Tosoni, M., Roder, G., Sofia, G., and Tarolli P. 2019. Design of terrace drainage networks using UAV–based high–resolution topographic data. Water 11:814

Pillai, G. M. 2018. Coming to terms with Kerala's ecological imbalance. *The Hindu* [on-line]. Available: https://www.thehindubusinessline.com/opinion/coming-to-terms-with-kerala s-ecological-imbalance/article25478397.ece [9 Jan 2020].

Popular Expert Committee. 1998. *Study Report - Paddy Field Protection Movement*. Government of Kerala, Thiruvananthapuram, 69p.

Prangbang, P., Yagi, K., Aunario, J. K. S., Sander, B., O., Wassmann, R., Jäkel, T., Buddaboon, C., Chidthaisong, A., and Towprayoon, S. 2020. Climate-Based Suitability Assessment for Methane Mitigation by Water Saving Technology in Paddy Fields of the Central Plain of Thailand. Front. Sustain. Food Syst. 4, 575823.

Quan, G. M., Zhang, J. E., Xu, R. B., Liu, J. L., and Huang, Z. X. 2005. Effects of biological control of pests and diseases of rice by raising ducks in the paddy fields. *Ecol. Sci*. 4: 336-338.

Rejula. K. 2015. A multidimensional analysis of rice farming and related agro ecosystems in Kerala. Ph.D thesis, Kerala Agricultural University, Thrissur, 215p.

Scaria, R., Kumar, S., and Vijayan, P. K. 2014. Paddy land conversion as a threat to floristic biodiversity–a study on Karrimpuzha watershed, Kerala state, South India. *Int. J. Environ. Sci*. 5(1): 123-134.

Serra, P., Moré, G., and Pons, X. 2007. Monitoring winter flooding of rice fields on the coastal wetland of Ebre delta with multitemporal remote sensing images.

In: *Proceedings of IEEE International Geoscience and Remote Sensing Symposium,* 2007, pp. 2495-2498.

Shinogi, K. C. 2011. Organic Farming In Kerala: An Assessment of Adoption, Sustainability And Constraints. Unpublished M.Sc.(Ag) thesis. Indian Agricultural Research Institute, New Delhi, 125p.

Shiratani, E., Yoshinaga, I., and Miura, A. 2006. Contingent valuation approach in measuring the multi functionality of agriculture and rural areas in Japan. *Paddy Water Environ.* 4: 211–215.

Smith, J. B., Suarez, A., and Yamin, F. 2007. Assessing Key Vulnerabilities and the Risk from Climate Change. In: Parry, M. L., Canzini, O. F., Palutikof, J. P., Van der Linden, P. J., and Hanson, C. E. (eds), *Climate Change* 2007: *Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, pp. 52-56.

Smitha and Anilkumar. 2015. Documentation and farmer perception on biodiversity in rice fields of Palakkad district. In: Laladhas, K. P., Oomen, V., and Sudhakaran, P. R (Eds), *Biodiversity Conservation, Challenges for Future.* Bentham science publishers, United Arab Emirates, pp. 78-81.

Sruthi, S. N., Shyleshchandran, M. S., Mathew, S. P., and Ramasamy, E. V. 2017. Contamination from organochlorine pesticides (OCPs) in agricultural soils of Kuttanad agroecosystem in India and related potential health risk. *Environ. Sci. Pollution Res.* 24(1): 969-978.

Su, Z., Chu, G., Miao, K., Ji, M., Fu, F., Liu, Y., and Shen, X. 2004. Effects of biological control of pests diseases and weeds and increasing production by rice-duck-*Azolla* farming in paddy fields. *Jiangsu Agric. Sci.* 6: 72–75.

Taniyama, I. 1999. Soil erosion prevention function of agricultural land and forest. *Agric. Hortic*. 74(4): 11-17.

Tarolli, P., and Straffelini, E. 2020. Agriculture in Hilly and Mountainous Landscapes: Threats, Monitoring and Sustainable Management. Geography and Sustainability. https://doi.org/10.1016/j.geosus.2020.03.003

The Hindu. 2019. Vanishing act of paddy fields, wetlands in Kozhikode [on-line]. Available: https://www.thehindu.com /news /cities /kozhikode/the-vanishing-act-of-paddy-fields-wetlands-in-kozhikode/article28628864.ece [12 Jan 2020].

Thomas, U. 2010. Environmental impacts on natural and physical resources due to the conversion of wetlands and paddy fields. Ph.D theses. Kerala Agricultural University, Thrissur, 212p.

Tripathi, K. P. 2016. Field bunding: Foremost rain water management measure. In: Singh, N. and Kumar, A. (Eds.), Water Conservation and Management in India, The institute of Engineers (India), Annual Technical. Vol II, pp.34–40

Vanaja, T. 2013. KAIPAD–A unique, naturally organic, saline prone rice ecosystem of Kerala, India. *Am. J. Environ. Prot.* 2(2): 42-46.

Vandermeer, J. and Perfecto, I. 1995. Breakfast of Biodiversity: The Truth About Rain Forest Destruction. *Food First* 5: 152-156.

Wilson, A. L., Watts, R. J., and Stevens, M. M. 2008. Effects of different management regimes on aquatic macro invertebrate diversity in Australian rice fields. *Ecol. Res.* 23(3): 565-572.

Wu, J., Li, Y., Wang, Y., and Liu, L. 2006. Effect of different herbicides on shift of weed community in paddy fields. *J. Plant Prot.* 33: 202–206.

Xu, X. Y., Zhang, M. M., Peng, C. L., Si, G. H., Zhou, J. X., Xie, Y. Y., and Yuan, J. F. 2017. Effect of rice-cray fish co-culture on greenhouse gases emission in straw-puddled paddy fields. *Chin. J. Eco Agric*. 25: 1591-1603.

Yang, Y., Hu, X., Zhang, H., Xu, K., Ge, Y., and Wang, B. 2004. Study on high quality and efficient cultivation of rice in a rice-raising fish (crab) system: Occurrence of diseases, pests and weeds and non-polluted prevention. *Jiangsu Agric. Sci.* 6: 21–26.

Ying, X., Moucheng, L., Shiming, P., and Yehong, S. 2017. Study of ecological compensation for paddy fields: Oriented towards eco-environmental restoration. *J. Resour. Ecol.* 8(6): 613-619.

Yokohari, M., Kato, Y., and Yamamoto, S. 1998. Temperature reduction effect of peri-urban paddy on surrounding urban area. *J. Jpn. Inst. Landscape. Architect* 61(5): 731-736.

Yosihiro, N. 2013. Ecosystem services by paddy fields as substitutes of natural wetlands in Japan. Ecological Engineering. 56. 97-106. 10.1016/j.ecoleng.2012.04.026.

You, M. and Wu, Z. 1989. The diversity of the arthropod communities in paddy fields. *J. Fujian Agric. For. Univ. (Nat. Sci. Ed.)* 18: 532–538.

Yuan, W., Cao, C., Li, C., Zhan, M., Cai, M., and Wang, J. 2009. Methane and nitrous oxide emissions from rice-fish and rice-duck complex ecosystems and the evaluation of their economic significance. *Sci. Agric. Sinica* 42(6): 2052-2060.