In 4th World Water Forum, Joint Session, INWEPF and ICID, Mexico, 16 – 22 March 2006.

Draft

Managing Paddy Fields for Ecosystem Services: Some Insights from the Comprehensive Assessment of Water Management in Agriculture

Authors: David Molden, Naoya Fujimoto, Rebecca Tharme, Priyanie Amerasinghe[1]

Abstract

A key to poverty reduction and maintaining or enhancing ecosystem services lies in recognizing and building on multiple benefits beyond crop production, and minimizing negative effects. A convergence of concepts from different disciplinary backgrounds is occurring – multiple use, multifunctionality, ecosystem services - with a plurality of institutions engaged and water productivity increasingly focused on the explicit inclusion of the range of values involved. Understanding the relation between concepts helps in communicating and in finding solutions. A field example from Sri Lanka is presented to demonstrate the ideas. In this case eco-agricultural approaches have shown promise to minimize negative externalities and generate value for human well-being.

Introduction

A key to poverty reduction and safeguarding ecosystem resilience and services lies in recognizing and building on the multiple benefits of agricultural water use beyond crop production, as well as minimizing negative effects. Managing water and ecosystems to enhance benefits such as water for domestic use, home gardens, fisheries, livestock, groundwater recharge and biodiversity can help to increase the productivity of water, broadly defined as increasing the value per unit of water used in agriculture. To do so will require an institutional setup that embraces different stakeholders and provides the linkages between various parties for informed decisions.

This outcome is derived from the ***Comprehensive Assessment of Water for Agriculture*** (CA). The program, co-sponsored by the Consultative Group on International Agricultural Research (CGIAR), the Convention on Biological Diversity, Food and Agriculture Organization of the United Nations (FAO), and the Ramsar Convention on Wetlands, engages a diverse group of some 500 leading scientists and practitioners to answer the question: how can water for food be developed and managed to reduce poverty, ensure environmentally sustainable water-agriculture practices, and find a balance between food and environmental security? More results can be found on www.iwmi.org/assessment.

The CA attempts to bring people closer to consensus in an area where there is considerable debate about best bet investment. Instead of divergence, there was considerable convergence of ideas around the broad concept of system multifunctionality, coming from people of different backgrounds – wetland ecology, paddy rice, institutions, irrigation management, and conservation agriculture. This paper:

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[1] The authors are researchers at the International Water Management Institute (IWMI), Colombo, Sri Lanka. The authors gratefully acknowledge the support received from the Japanese Institute of Irrigation and Drainage (JIID).

- Provides a brief discussion to link of multifunctionality with other similar concepts
- Argues that enhancing multiple benefits while reducing costs of agricultural water management is a key to balance food and environmental security, and
- Presents an example from Sri Lanka on an eco-agricultural approach to manage water for food production and maintenance of wild biodiversity.

A Convergence of Ideas

During the assessment process, people from an irrigation background made a case for for the multiple uses of irrigation water. Others contended that food was one of the many ecosystem services provided by agro-ecosystems. The International Network on Water and Ecosystem in Paddy Fields (INWEPF) have argued the importance of multifunctionality. Those working in the area of water productivity stated that the term includes the values derived from agricultural water use. The group working on policies and institutions noted the plurality of institutions at play in water management.

Multifunctionality. According to an extensive review by Matsuno *et al.* (2005), the multiple roles of agriculture include food security, maintaining and ensuring the viability of rural communities and environmental protection, such as land conservation, sustainable management of renewable natural resources, preservation of biodiversity, landscape, and so on. (OECD, 1998). The benefits of paddy cultivation include: flood control, groundwater recharge, soil erosion and landslide prevention, water purification (through the system acting as a constructed wetland), climate mitigation, biodiversity conservation, and social and cultural values. To illustrate the importance of multifunctionality, a Korean study estimated the economic value of Korean paddy at between US$ 9.75 and 11.46 billion, higher than the rice producer price of US$ 8.37 billion (Seo *et al.*, 2003).

Ecosystem Services are the benefits people obtain from ecosystems (Millennium Ecosystem Assessment, MA, 2003). These include provisioning services such as food and timber; regulating services such as flood and disease control, and ground water recharge; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth (as outlined in the MA Framework). Although we use the definitions from the MA, we do not regard water as a provisioning service, since all water comes from precipitation, mainly governed by solar energy and not ecosystems. In MA (2005) it is noted that while fresh water was treated as a provisioning service in the MA, it is also regarded as a regulating service by various sectors. While irrigation produces several ecosystem services, there is high variability in their delivery amongst different kinds of systems. Some systems generate food as a primary ecosystem service, while others generate numerous high-valued services. Paddy cultivation can be quite remarkable in the number/quantity and quality of services provided (box on ecosystem services provided by paddy cultivation).

Multiple Uses are the use of water delivered for irrigation for drinking, washing, homestead gardens, and trees, livestock, replenishment of aquifers, urban water supply, rural industry, artisanal fishing, aquaculture, etc. (Bakker et al, 1999) It has been recognized that even though not intended, irrigation systems generate value by meeting these multiple needs. This can be particularly relevant for the poor and landless who can gain health benefits from nutrition supplied by home gardens, by bathing, and a supply of drinking water. Additional production benefits include fisheries, small scale industries such as brick making and support of livestock.

Through multiple uses women and the landless have a chance to benefit more from irrigation water.

Water Productivity is broadly defined as the value generated per unit of water use in agriculture (Kijne *et al.*, CA chapter on water productivity, 2003). Included in the values are the various ecosystem services generated by water, and in fact a definition of water productivity can be ecosystem services per unit of water depleted. This extends the definition beyond crop per drop, defined as kg/evapotranspiration (ET). The crop per drop concept remains important, and is critical in evaluating the central function of irrigation as crop production.. A focus on crop per drop alone, however, underestimates the total benefits, and indeed the costs, derived from irrigation.

Plurality of Institutions and Polycentric Governance. As there are many stakeholder groups with multiple objectives, it is not surprising that a plurality of institutions has evolved to manage water (CA policy and institutions chapter, Merrey *et al.*, 2006). Our key message calls for managing water to enhance the multiple benefits derived from water, but there are many possible institutional setups for such management. One approach is a polycentric governance arrangement that would recognize the various institutions at play and link these together (CA basin chapter, Molle *et al.*, 2006). Another approach is to form a single multi-purpose organization. While it is worthwhile looking into polycentric arrangements, the key point is to build on existing institutional structures even though many may not have been formalized. In Japan for example, a triangle structure for supporting farmers is active throughout Japan, consisting of (1) Land Improvement Districts (LIDs), legally backed water user's association, (2) Farmers Organization (JA), and (3) governments of each administrative level. The horizontal structure of the triangles are piled up from city level, prefecture (district) level and state level, and frequent communication is done among levels (Ogino, 2000).

All of these concepts are related. While we do not argue for the use of one term over the others, we argue that it is important that we clearly understand different concepts so that we can better communicate. Multifunctionality and ecosystem services overlap considerably, and the notion of ecosystem services is becoming broadly accepted. While the multiple uses of water focuses on productive and domestic uses of water for humans, these multiple uses can be readily thought of as multiple services provided by water. The broad definition of water productivity recognizes the benefits and costs per unit of water of the many uses of water. Moreover, the recognition of the plurality of formal and informal institutions provides insights on how to govern for multifunctionality.

Ecosystem Services of Paddy Rice (from CA chapter on Rice, Bouman et al, 2006)

Provisioning services: The production of rice primarily. Fish, ducks, frogs and snails are grown for consumption in some areas.

Regulating Services: Bunded rice fields may increase the water storage capacity of catchments and river basins, lower the peak flow of rivers, and increase groundwater flow, trapping of sediments and nutrients, and prevent or mitigate of land subsidence, soil erosion and landslides. Percolation from rice fields, canals and storage reservoirs recharges groundwater systems. Such recharge may also provide a means of sharing water equitably among farmers who can pump from shallow aquifers at relatively low cost rather than suffer from inequitably shared or poorly managed surface irrigation systems. The moderation of air temperature by rice fields has been recognized as a function in peri-urban areas where paddy and urban land are intermingled. Despite its salt sensitivity, rice can be used as a desalinization crop because of its ability to grow well under flooded conditions where continuously percolating water leaches salts from the topsoil.

Supporting services: A complex mosaic of landscapes that support biodiversity. The Surveys show that such landscapes sustain a rich biodiversity, including unique as well as threatened species (Fernando et al., 2005), and species that threaten the rice crop. Ramsar Convention on wetlands classified irrigated rice land as a human-made wetland (Ramsar, 2004).

Cultural Services: For centuries, rice has been the main staple food and the single most important source of employment and income for many rural people. Rice affects daily life in many ways and the social concept of *rice culture* gives meaning to rice beyond its role as an item of production and consumption (Hamilton, 2003). There are many traditional festivals and religious practices associated with rice cultivation and rice fields are valued for their scenic beauty. Rice is also an integral part of the history and culture of Africa, where it has been grown for over 3000 years.

Managing for Multiple Ecosystem Services

Enhancing the multiple benefits and reducing costs, including environmental costs, is important to meet the multiple objectives of poverty reduction and environmental sustainability as embraced in the Millennium Development Goals. Agriculture has been one of the main drivers of ecosystem change, degradation, and loss of ecosystem services according to the Millennium Ecosystem Assessment (e.g. MA 2005). Much ecosystem change has been unavoidable, if we accept the need to feed the world. On the other hand, there are ways to reverse trends of degradation, and build ecosystem resilience if agriculture is managed as an ecosystem, including its multiple services, and in an integrated manner in relation to other ecosystems within the landscape. Modern irrigation has focused primarily on crop production, and has been a successful contributor to economic growth and poverty alleviation (Faures *et al*, 2006) But now, modern irrigation is called on to do even more, including the reduction of associated negative social and environmental impacts.

There is much to learn in terms of system management for multiple purposes from traditional, age-old paddy cultivation for example. The collective action required to build paddy systems and maintain canals, reservoirs has been the glue of communities. Many great kingdoms of South-East Asia have been based on irrigated rice production (Piper, 1993). The foundation of old kingdoms was formulated during the centralization of political power through co-working for constructing irrigation facilities to stabilize rice production. So, rice cultivation was considered symbol of safety of the kingdom. In fact, all existing kingdoms in Asia still possess the ceremony of rice where the monarch implements several activities by himself/herself. For example, the current Japanese Emperor personally sets out rice in the grounds of his palace in May each year.

In general, individual names are given to similar but different items in particular language which has close relation and long history to the items. There are different expression in Japanese, Chinese, and other Asian languages related to rice (Table 1). Also, 'to eat' and 'to eat rice' are often synonymous, in East and South-East Asian languages, such as *Tarn kao* in Thai, *Ngajenga ng* in Balinese (Piper, *op. cit*), *Chi fan* in Chinese and *Gohan o taberu* in Japanese show us importance of rice in daily life.

Table 1 Different expressions for the English word "Rice" in Asian languages (source Fujimoto, 2005)

Table 1 Different Expressions of "Rice" in Daily-use Term in Asian Languages.

English	Urdu	Hindi	Tamil	Vietnamese	Tagalog	Chinese	Japanese	Sinhala
Paddy (Paddy field)	*khaat*	*dhan khet*	*kazhani, nel vayal*	*Ruong lua*	*palayan*	*dao tian,*	*tambo, sui den*	*kumbura*
Rice (Rice plant)	*dahan*	*bali*	*nel seli*	*Cay lua*	*palay*	*dao zi*	*ine*	*Goyam gaha*
Paddy, Rough rice (Un-hulled rice)	*munji*	*dhan, munji*	*nel*	*thoc*	*palay*	*dao gu*	*momi*	vee
Rice, Brown rice, (Unpolished rice)	-	*dhan, munji*	*nel*	*Gao luc*	-	*cao mi*	*geng mai*	*Nivudu haal*
Rice, White rice, (Polished rice)	*chawal*	*chawal*	*arisi*	*gao*	*butil, bigas*	*bai mi*	*haku mai*	*Sudu haal/ kekulu haal*
Rice (Cooked rice)	*ubla chawal*	*chawal*	*soru*	*com*	*kaning*	*mi fan*	*go han*	*Bath*

The paddy field is a man-made wetland where *Oryza sativa* (rice) grows. Examining the paddy field with a biologist's eye, one can recognize that the paddy field is an ecosystem comprising soil, water, air, solar energy, and the wetland flora and faunas (NACF, 2001; Bambaradiniya and Amerasinghe, 2003). Birds, frogs, snakes, and various other fauna are high in the paddy field's food chain (NACF, 2001). Aquatic invertbrates such as pond snails, pond skaters, diving beetles, and various microorganisms also inhabit the system. Insects such as grasshoppers, oriental longheaded locusts, spiders, butterflies and dragonflies coexist with vegetation such as Decan grass and *Monochoria raginalis*. In Japan, the rice grains that fall on the field after harvest become feed for millions of migratory birds that come to the country every year. This dynamic ecosystem of the rice paddy has existed for thousands of years (NACF, 2001).

Two studies carried out in Sri Lanka captured the biodiversity associated with ricefileds documenting 77 species of invertebrates, 45 species of vertebrates and 34 species of plants (Bambaradeniya *et al,* 1998); 494 species of invertebrates belonging to 10 phyla, 103 species of vertebrates, 89 species of macrophytes, 39 genera of microphytes and 3 species of macrofungi from an irrigated rice field ecosystem in the Kurunegala District (Intermediate Zone) of Sri Lanka (Bambaradeniya, 2000a). The majority of the invertebrates are arthropods (82%, 405 species), dominated by insects (78%, 317 species). The higher number of animal and plant species documented in the above survey indicates that the irrigated rice field is an agroecosystem with a high gamma (γ) diversity.

A very important side-benefit of traditional systems of rice cultivation in Cambodia is their role in helping to conserve the Mekong/Tonle Sap freshwater fishery. This fishery is one of the most productive in the world, and is dependent for its productivity on the seasonal flooding that provides fish with extensive areas of nutrient-rich water for breeding, feeding and maturing. The agricultural systems of recession rice (with supplementary irrigation from natural and artificial ponds) and *colmatage* farming extend the areas of water that provide fish habitat, by creating additional impoundment and increasing the flow of water into the back-swamp areas (Tara *et al.*, 2003).

Aquaculture is an important aspect of irrigated agriculture in many villages in Cambodia, producing about 15,000 ton of fish nationally in 2000. In addition to pond culture, in which fish are raised in special-purpose ponds, fish also can be raised in the rice fields. This happens naturally as fish enter the seasonally inundated areas of paddy. Production can be increased to 30-40 kg/ha of fish by stocking fish into the fields, digging ditches around the fields to provide water for fish at all stages of crop growth, and by providing artificial feed (Tara et al., *op. cit.*).

Rice needs water to grow and apart from the tiny percentage of dryland hill rice, almost all of it is grown in flooded fields. Such fields may be a picturesque series of paddies stepping down a hillside in Bali, China or the Philippines, with the water carefully organized to flow from field to field down the hill, or a flat field on the plains of Australia, Burma or India's Punjab where the water is pumped to the fields from irrigation channels and canals (Wheeler, 2004).

Organizing the irrigation water for rice fields is often a politically charged situation. In Bali the *subak* organization is effectively a rice growers' local government with responsibilities not only to ensure that the irrigation channels and waterways are maintained, but also to make sure that everybody gets their fair share of the precious fluid. It is often said that the best person to be in charge of the *subak* is the farmer at the bottom of the hill; he has a considerable incentive to ensure the water flows all the way down! (Wheeler, 2004).

Multifunctional benefits, combined with productivity gains, have potential to be an important tool to fight poverty. Reducing poverty by these means requires special care, because gains do not necessarily reach the hands of the poor. The overall idea is that by improving the value derived from agriculture, without increasing the amount of water (a water productivity gain), can generate opportunities. These opportunities must be carefully targeted to the poor. Managing for improved fish production provides opportunity for another group of stakeholders. Livestock and the grazing lands they require are commonly forgotten in the design of irrigation, to the detriment of herders, and the canal systems and small dams that get damaged or polluted by thirsty animals. Home gardens and drinking supplies can benefit women, and be extremely important for household food security and nutrition. A healthy agricultural ecosystem, including one with reasonable levels of biodiversity, is a key to long-term sustenance.

Ecoagriculture Approaches to Enhance Ecosystem Services and Mitigate Environmental Damage

***On-Site alternatives for mitigation of impacts*:**
As discussed at length in Molden *et al.* (2004), within irrigation systems there are a number of options that will have the potential to enhance ecosystem services including biodiversity. Many of these are not necessarily expensive or difficult to implement.

Maintain habitat integrity and connectivity for biodiversity
The strategy is to minimize habitat fragmentation by maintaining appropriately sized patches of natural or desired vegetation or waterbodies within the irrigated landscape to provide habitat for plants and animals, then connect them providing a larger habitat area with opportunities for movement and dispersal.

In large irrigated areas, canals and roads often lined with trees are dominant features of landscapes, and can serve as important passages for biotic movement and as habitats. Hydraulic structures often block water pathways. While these cannot always be prevented, they can be managed to enhance habitat connectivity and biodiversity. At critical times, canals should have water, and gates or sluices should not necessarily be closed. Trees and other vegetation along canals are often targeted to be removed. Keep in mind their value as providing habitat and connectivity, as well as other ecosystem services such as fruits and fiber, before taking such actions. Hedgerows and corridors of natural vegetation interconnect parcels of irrigated land (McNeely and Scherr, 2003 provide numerous case examples).

Promote Landscape Mosaics
One reason that traditional tank cascades in Sri Lanka support biodiversity is that they provide mixed, heterogeneous landscapes – small tanks, irrigated paddy fields, forests, and villages in small areas. In many larger irrigated landscapes, it is important to break up large mono-cropped areas by identifying, and creating diverse landscape mosaics. These protect and link natural habitat patches and provide for elevated biodiversity (Case 1 and 2).

Choose the right infrastructure and operation to support multiple uses
Most infrastructure considerations are based on functions of delivering water to crops – flexibility in delivery and storage so that water can be used when crops need it. Much more attention is required up front to infrastructure design and operation to support in an optimal fashion the multiple uses of water. For example, canal designs that allow for movement of fish may not require so many weirs and gates. Unlined canals may better support flora and fauna, as well as promoting local groundwater recharge. Integrating livestock into the design can enhance the value of crop-livestock production systems.

For example, the extension of the Walawe Left Bank irrigation canal system currently under construction in southern Sri Lanka is intended to provide for different water delivery regimes for paddy and banana crops. Modification of larger-scale hydraulic infrastructure, for example, through the provision of dam multiple release outlets rather than single near-bottom releases, as well through changes in the operation of dam releases to generate downstream flow regimes that better mimic natural flow patterns, can result in enormous reductions in ecological impacts on-site, as well as off-site.

Social mobilization
Engaging local communities dependent on irrigation, including farmers, domestic users, fishers, and livestock users into the process of management is a critical element of managing water sustainably for meeting food and environmental needs. Discussion and decision making forums on the implications of alternative regimes of water use and the tradeoffs involved are essential.

Promote institutions to support multiple uses
Local organizations and supporting laws and regulations, both formal and informal, play a key role in ensuring effective, sustainable and equitable management of water for agriculture. Participatory irrigation management involving communities is an effective way of dealing with local problems. Typically efforts have been placed on mobilizing communities and strengthening organizations to manage irrigation delivery and maintenance, with less emphasis on overall natural resource management. More needs to be done to bring in other stakeholders to promote the multiple uses of water.

***Off-site alternatives for mitigation of negative environmental impacts*:**
Irrigation alters hydrologic flow paths to deliver water to crops and drain it away, thus impacting both the quality and quantity of river and other wetland flows, affecting the ecological character of systems. Managing irrigation systems, from the storage dam through to the canal network, so as to maintain environmental water requirements for wetlands can serve to greatly minimize the impacts of irrigation. These off-site effects are not often the direct concern of irrigation managers serving farmers, but they are of major concern to water, wetland and overall resource managers.

Environmental Flows
For wetlands and rivers to be able to retain their character and a level of services accepted by society, both their water quantity and quality requirements must be understood and provided for - the science of environmental flow assessment (Tharme, 2003; Dyson *et al.*, 2003). Water needs to be managed to make sure that natural flow patterns are mimicked to the extent possible or agreed in terms of the desired future condition of the ecosystem (Richter *et al.,* 1997). There has been considerable work on approaches for determining such ecosystem water requirements (environmental flows), to support biodiverse, healthy ecosystems both in their role as users of water and as the base of the freshwater resource - Tharme (2003) describes a range of methodologies in use globally at present and highlights their relative merits and limitations. Irrigation tends to drastically modify hydrologic regimes, because of the need for storage and the process of crop evapotranspiration. This makes the problem of achieving the multiple objectives of irrigation, including its multiple benefits, and maintaining wetlands, at the best, difficult.

Even if the required environmental flow to maintain a certain level of ecosystem functioning is known, getting that water to the right place at the right time is another matter. Two additional procedures are required – first a formal, negotiated allocation of water to the ecosystem within the basin allocation and tradeoff process, and second an actual distribution of supplies (i.e. the implementation and follow-up monitoring phase). Water allocation rules are put in place to ensure that various parties receive a portion of developed water supplies. These are important for irrigation at two levels: within the irrigated area, and within a river basin. While allocation of water to farmers is the norm for irrigated areas, it is uncommon to find allocations to environmental uses. Similarly within river basins, allocations to cities, industries and agriculture commonly have been in place, but now more and more there is at least recognition of the need to allocate some water to the environment - increasingly, this is being based on observed direct linkages between changes in ecosystem character and the delivery of important ecological services to people (e.g. fish as food, high quality drinking water, riparian trees for house construction, and so on). Furthermore, it is recognized that the water needs of the ecosystem need to be considered explicitly alongside those of other users early on, at the planning and design stages of water resource development projects for irrigation and other purposes.

River Basin Management (IWRM)
As impacts occur at larger scale than the irrigation system, or outside of the irrigation, institutional arrangements need to incorporate means to deal with both on-site and off-site effects. Nested institutional structures can help deal with the problem. Irrigation organizations that have the responsibility of delivering water service to farmers may not by themselves be responsive to downstream problems they cause, unless there is another authority to deal with the problem. River basin organizations in theory should be able to manage these larger scale upstream-downstream issues, while not having to manage the details of irrigation service delivery.

Managing for Multiple Uses
Irrigation managers typically deliver services to crop-based farmers. Yet activities such as livestock and fisheries production are integral components of agriculture that seem to be neglected in the development and management of irrigation (for example the Walawe Left Bank project – Case 2). In this sense, fishers, herders, use of water for drinking and small industrial activities, and people dependent on other ecosystem services are 'off-site', external to their management regime. An action then is to internalize these non-crop irrigation uses of water into management, and include these stakeholders in water allocation and overall management decisions.

Conclusions
It is possible to design, construct, and manage irrigation systems to support a diversity of ecosystem services and thus enhance the productivity of water. Many of these solutions are not necessarily high cost, complex or difficult to implement. The problem is that they are not integral to accepted design and operation processes and procedures for irrigation, or included in most training programs for engineers and agriculturalists.

This conclusion is important because of the need for paddy cultivation, and in fact all of irrigation, to do better in the areas of poverty reduction and mitigation of negative environmental and social impacts. By recognizing and managing for the multiple uses of water, there is an opportunity for the poor to benefit from gains in health, nutrition and production. Irrigation systems which are designed without enough consideration of the ecological consequences are liable to seriously alter environmental balance and resilience to human and natural disturbances. As a consequence, biodiversity, livelihoods, and even long-term productivity are threatened. Dealing with the negative effects of irrigation development and management is a priority issue.

The challenge in the very near future is to bring about some fundamental changes about how we think about, design, and manage irrigation. There are ways to do irrigation much better, but it is necessary to spread this knowledge, and get the incentives right so that practices that support multiple ecosystem services in irrigation are implemented. Several actions are required for this to happen including gaining a better understanding of positive and negative impacts and why they occur, developing practical solutions, spreading the knowledge, and getting the incentives and institutions in place to support the multiple benefits that can be provided in irrigated landscapes.

Case 1: Positive impacts of agriculture on wetlands: small tank systems of Sri Lanka (adapted from Vidanage & Kallesøe 2004).

Sri Lanka has one of the oldest traditions of agriculture in the world, dating back to 500 BC. A hydraulic civilization has evolved since that time of localized irrigation schemes, predominantly for rice cultivation, centered on cascades of small tanks (water storage reservoirs). Within the country's dry zone, there are thousands of such ancient, man-made wetlands of varying sizes and forms, some operational and others abandoned. During the rainy season they provide water for local cultivation and domestic supply, while their frequent drying-out in the dry season allows for livestock grazing. They are also recognized as constituting one of the richest sources of biodiversity in the country. Many such traditional tank systems are under increasing threat, largely from their marginalization in favour of the seemingly more productive uses of 'modern' large-scale irrigation and hydropower, as well as accelerated siltation and eutrophication, endangering both livelihoods and environmental security.

Some 600 small tanks in the Kala Oya Basin, northwestern dry zone, occur in conjunction with a large-scale irrigation scheme, the Mahaweli Irrigation Expansion Project, with the latter the recipient of 65% of basin water. Some 400 000 rural people are engaged in farming as their principally livelihood source, half of whom are poor (monthly income below US$ 15). A socio-economic assessment of 429 tanks revealed that they are used for cultivation of rice and other crops (with values per total inundated tank area of 216-39 US$/ha/year for individual crops), as well as domestic uses (1469 US$/ha/year) such as bathing, clothes washing and household water supplies, and water for livestock (335 US$/ha/year). They also provide many other ecological services (in US$/ha/year): fish (351), lotus flowers for use in Buddhist temples and ceremonies (72), lotus roots and other edible plants as food (107), as well as reeds and wild animals. Other services not addressed in economic terms include hydrological functions (mitigation of downstream flooding, replenishment of groundwater reserves), nutrient retention and purification. These uses amount to an average value of US$ 425 per household per year, and almost US$ 3000 per hectare of inundated area. Benefits were greatest for the poorer families for whom alternative sources of income and domestic water supply were limited.

Case 2: Expansion without extinction: biodiversity conservation in irrigation systems, southern Sri Lanka (Tharme and others, unpubl. data).

The agricultural sector plays a major role in Sri Lanka's economy, and irrigation has received a high priority in development initiatives, contributing to greater agricultural productivity and improved livelihoods for the rural poor. It also has resulted in widespread loss and degradation of the island's ecosystems, in addition to knock-on socioeconomic effects due to declines in the provision of valuable ecological services to people. Biodiversity in Sri Lanka is especially vulnerable to large-scale developments because of the island's small size, and increasing population pressure on its already highly fragmented natural landscape - an estimated 560 animal and 690 plant species are presently threatened with extinction.

An existing irrigation system in the Walawe Catchment of southern Sri Lanka (in area over half of a final proposed total of 15 000 ha) is currently undergoing expansion under Walawe Left Bank Irrigation Upgrading and Extension Project Phase-2 SL-P48 (Figure 1). The water resource agency, Mahaweli Authority of Sri Lanka (MASL), and consulting engineers, Nippon Koei Japan (NK), are establishing 5152 ha under new irrigation, with an associated human resettlement programme. According to a Mahaweli Economic Agency 1992 study, an estimated 6018 households (26 685 people) whose main livelihood is agriculture (primarily paddy, upland crops and chena cultivation), are located within the proposed extension area. The construction area comprises mostly semi-degraded dry zone forest with an ancient system of some 17 seasonally water-filled small tanks, traditionally used for crop cultivation, domestic, livestock and other services, and now being rehabilitated for routine irrigation.

The International Water Management Institute (IWMI) and the World Conservation Union (IUCN) Sri Lanka, are collaborating with MASL and NK, through a pre- to post-development assessment of the extent to which both biodiversity and people's reliance on natural resources, linked to their socio-economic status, are altered by the progressive establishment of the scheme and shift towards a landscape mosaic of natural and agroecosystems. Preliminary results revealed a high baseline biodiversity in natural rock outcrop forests, as well as tank wetlands, than in existing farmlands such as rice fields and chena habitats. Overall, a total of some 223 floral species, including alien invasive plants (e.g. *Prosopis juliflora, Opuntia dillenii, Eichhornia crassipes*), and 307 vertebrates (15 endemic and 34 nationally threatened species, IUCN Sri Lanka 2000) were recorded from the area prior to the first steps in extension of the irrigation scheme. The composition of different groups of vertebrates in the project area, and their conservation status, is shown in Figure 2. The comparatively high number of birds, inhabiting both terrestrial and wetland ecosystems is highlighted. Also a variety of natural resources, including non-timber forest products and fish, were found to be of direct livelihoods importance for local communities, especially the rural poor. Of the 15 fish recorded from freshwater habitats, the tilapia *Oreochromis mossambicus* is dominant, with the local fishery almost entirely dependent on this species.

A number of ecoagriculture strategies (Scherr & McNeely 2003) aimed at managing the system for both agricultural production and the protection of (wild) biodiversity have been initiated, through collaboration among project partners and increasing mobilisation of local communities. These strategies, some of which are only in the early stages of implementation, included first the delimitation and agreed protection of priority tank catchments as biodiversity refuges. Selection of biodiversity refuges was based on ensuring the presence of representative habitat mosaics for each of the three different strata of the project area, the degree of naturalness of vegetation/habitat types, any key habitat patches, as well as species richness of fauna and flora (Figure 3). It is envisaged that the refuges will be connected in future with a retained/created corridor network of natural/near-natural vegetation within the project area (hedgerow concept), to minimise local species extinction, facilitate natural patterns of faunal movement and plant dispersal, and foster integrated pest management (IPM). A Biodiversity Park for storage of genetic material and community use has been delimited and its main features designed. Other strategies under implementation include the planting of appropriate indigenous trees along roadsides and within fuelwood plantations; habitat enrichment through multi-tiered home gardens that mimic the structure of natural forest; translocation of large mammals to protected areas (notably, Asian elephants); and a social mobilisation programme to foster community awareness and, more critically, to ensure long-term biodiversity conservation with agriculture through active participation of local people in appropriate biodiversity-agriculture initiatives.

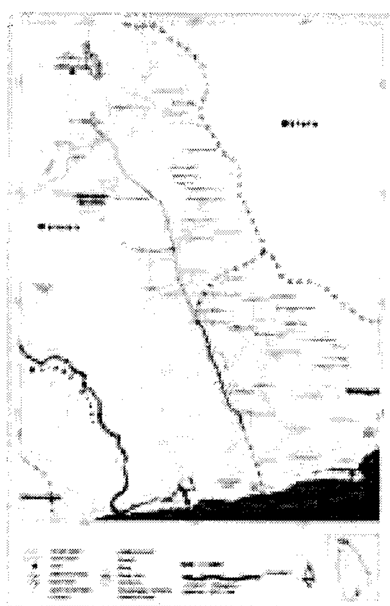

Figure 1: Location of project area.

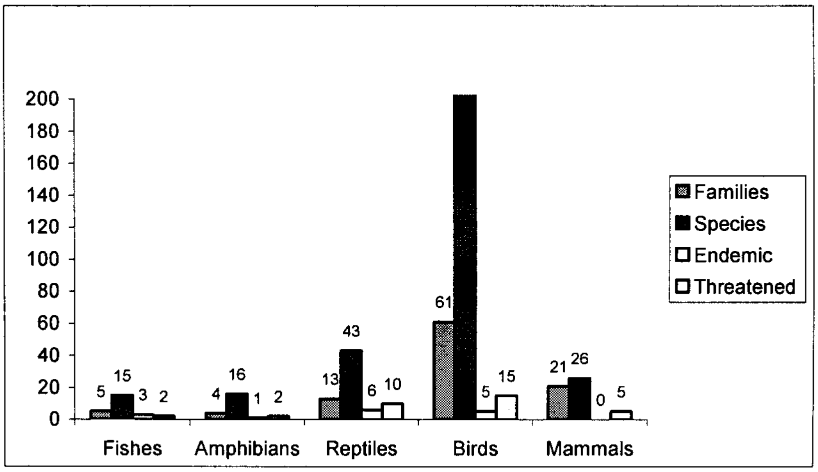

Figure 2: Faunal composition in the project area.

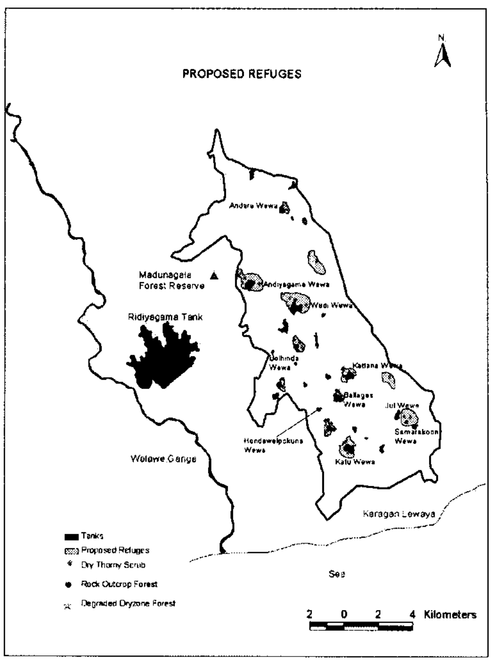

Figure 3: Location of biodiversity refuges within the project area.

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