Trade-offs between ecosystem services and opportunity costs of ES maintaining in the Tonle Sap Lake agro-ecosystem (Cambodia)

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Abstract

The usefulness of Ecosystem Services Framework (ESF) to emphasize relationships between agriculture and ecosystems has received much less attention. In addition, studies applying ESF to understand links between ecosystem services and rice production systems are still missing. The objective of this paper is to try to fill this gap by adopting the ES and EDS (ecosystem dis-services) approach suggested by Zhang, Ricketts, Kremen, Carney, and Swinton (2007), and combine with Agrarian System Analysis and Diagnosis methodology (H. Cochet, 2012; Hubert Cochet, Devienne, & Dufumier, 2007; Hubert Cochet & Devienne, 2006; Dufumier, 2006) in order to identify ES and EDS provided by rice production systems adopted by peasants on the agro-ecosystem of Tonle Sap Lake (TSL) flood plain. Our finding shows that organic rice production system is not economically and ecologically performance in ES provision. Contrary, rainy season rice, floating in particular, is the most performance for ES provision. As recommendation, the study proposes 3 choices to reconcile economic and ecologic performance as following: (1) Promote production system with medium performance for ES but low opportunity cost is to promote adoption of rainy season rice excluding floating rice in combination with short-term rice. (2) Promote production system with medium performance for ES with medium opportunity cost is to promote adoption of rainy season rice including floating rice in combination with short-term rice. And (3) Promote production system with high performance for ES with high opportunity cost is to promote adoption of floating rice alone in production system.

Key word: Ecosystem Services, Ecosystem Disservices, Rice Cropping System, Trade-off, Tonle Sap Lake, production cost, Opportunity Cost.

1. Introduction

The Millennium Ecosystem Assessment (2005) has provided a new framework based on the ecosystem services concept in order to stress the need for ecosystem conservation. In tropical literature, this Ecosystem Services Framework (ESF) has been used mainly to provide economic and ecological arguments for protected areas, mainly in forest ecosystems (e.g. regulation services through hydrological function or carbon sequestration).

However, as explained by some authors Zhang et al. (2007), the usefulness of ESF to emphasize relationships between agriculture and ecosystems has received much less attention, except for specific value chains such as coffee or cocoa (Rapidel, DeClerck, Le Coq, & Beer, 2011). Yet, in tropical developing countries, this issue is particularly relevant. Agriculture is the main form of land management in these countries, in which food security and food sovereignty are key matters for farmers and policymakers. Several recent publications have shown the importance of agro-ecosystems in terms of sustainable development in rural areas. Most of these papers discuss the links between ecosystem services and agricultural activities, and as a feedback loop the links between these activities and ecosystem services (Dale & Polasky, 2007; Power, 2010; S. M. Swinton, Lupi, Robertson, & Hamilton, 2007; Scott M Swinton, Lupi, Robertson, & Landis, 2006; Zhang et al., 2007). Based on a study case of rice production on the flood plain of the Tonle Sap Lake (TSL) in Cambodia, this paper tries to look further into that issue.

Cambodia provides a good illustration of this topic for several reasons. This country, which is ranked in the medium human development UNDP category in 2014 (137th among 187 countries), is mainly a poor and rural country. According to Mund (2010), about 80% of Cambodian people are living in rural areas and 85% them are rice producers. More over, 90% of the poor are coming from these rural areas. The main drivers of rural development are dedicated to the agricultural system of lowland rice production. (Mund, 2010). According to the World Bank, the drivers of poverty reduction between 2004 and 2011 are the increase of rice production (23%) and rice price (24%), far ahead of other factors (farm wages (16%), non-farm business (19%), urban salaries (4%) and unexplained reasons (14%) (World Bank, 2013). In this context, the government tries to increase rice productivity through different way such as machinery and agricultural technology (new varieties, fertilizer, cultivation techniques). Whatever the policy promoted, the key point of the adoption of any rice production systems by these small farmers is the availability and controllability of water of rice terrace agro-ecosystem of The TSL. This flood plain is the most suitable for rice production thanks to increased soil fertility through sedimentation and abundant water for this crop. But the agro-ecosystem also increases the risk of yield loss caused by flood. Besides, rice production terraces also serve as a flood control solution through dykes built between rice fields (Dan, Gordon, & Sok, 2005; Ly, Jensen, Bruun, Rutz, & de Neergaard, 2012; Masumoto, Hai, & Shimizu, 2008; Someth, Kubo, Tanji, & Ly, 2009; Tsubo, Fukai, Tuong, & Ouk, 2007). Thus, farmers face both positive and negative interactions with the TSL ecosystem. The implementation of rural development policies based on rice productivity in this critical ecosystem provides a good illustration of trade-offs between provisioning services and regulation services.

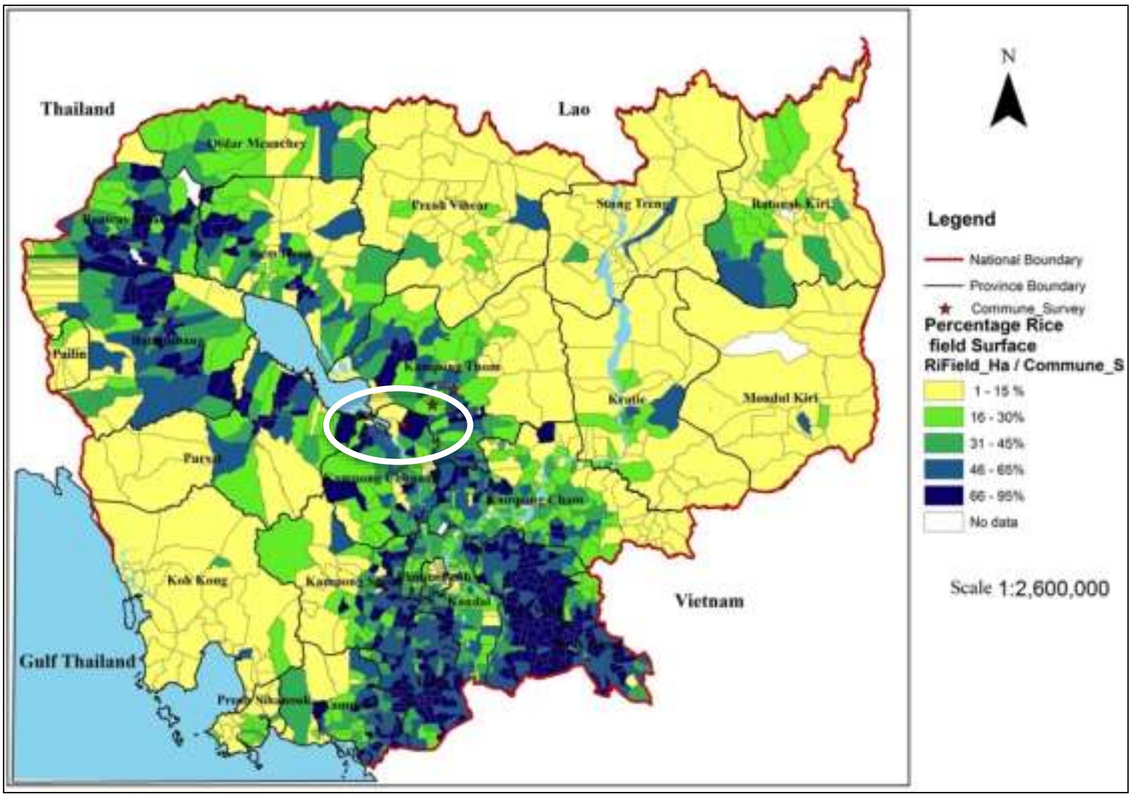
Little research has been conducted on this issue. On the one hand, literature related to the rice sector is abundant and the functioning of the TSL is well known. On the other hand, studies applying ESF to understand links between ecosystem services and rice production systems are still missing. The objective of this paper is to try to fill this gap.

To do so, the first section describes the study case and the functioning of the TSL ecosystem. We present our methodology, based on the general structure of ES (Ecosystem Services) and EDS (ecosystem dis-services) suggested by Zhang et al. (2007). To study interrelations between agricultural activities and the ecosystem, we adopt the Agrarian System Analysis and Diagnosis. In the second section, we present our results, focused on ES and EDS provided by the agro-ecosystem in the different rice cropping systems and rice production systems adopted by farmers. In doing so, we are able to show the different trade-offs and opportunity costs between rice production systems. A general discussion about the usefulness of ESF based on this work is conducted in the last section.

2. Material and methods

2.1. Study site

The Tonle Sap Lake (TSL) is the largest fresh water lake in Southeast Asia and of the Mekong River Basin. In rainy season (May to October), this great lake receives and stores the water flowing back from the Mekong river, rainfall, as well as its tributaries and expands until it covers up to 15,000 km^2. Contrarily in dry season (November to April), from late October or early November water reverses into the Mekong river downstream and the lake shrinks down to 2,500 km^2 (Arias et al., 2012; Brooks, Allison, & Reynolds, 2007; Varis & Keskinen, 2006). This natural mechanism ensures the flow of the Mekong river, protects the agricultural land of the Mekong delta in Vietnam from saltwater (Pham, Takao, & Katsuyuki, 2008) and ensures water availability for dry season and receding rice irrigation in Cambodia and Vietnam (Dan et al., 2005).



Map 1: Rice field in Cambodia
Source: Open development Cambodia

Being the first Biosphere Reserve of Cambodia, this lake is also classified as one of the world's most productive wetland ecosystems (UNESCO, 2012; Varis et al., 2006). Different researches confirm a high productivity of fish catch in the TSL. Van Zalinge, Nao, Touch, and Deap (2000) mentioned 289,000t to 431,000t per year but (TKK, Baran, & Myschowoda, 2008) mention only between 179,500t and 246,000t. The lake is the fourth most productive captive fishery in the world, representing 16% of the Mekong river fish capture. It provides 60% of the protein intake of the entire Cambodian population, who consumes 20kg to 60kg of fresh water fish per capita per year (TKK et al., 2008; Van Zalinge et al., 2000).

The flood pulse creates vast areas of seasonal floodplain habitats for birds and fishes as well as a rich plain for agriculture, which ensures local livelihood with rice (see Map 1), fish and non-fish aquatic species, timber and non-timber products (Lamberts, 2006; MacAlister & Mahaxay, 2006). Thus, this is the world's highest biodiversity and the most productive ecosystem for inland fish in Southeast Asia (Brooks et al., 2007; Yen, Sunda, Oishi, & Ikejima, 2007). The whole ecosystem of the lake, floodplain and riparian flooded forest and shrublands provide an ideal wetland habitat for the Mekong fish species (feeding, breeding and rearing their young) (Matti Kummu, Sarkkula, Koponen, & Nikula, 2006). Varis and Keskinen (2006) show that the TSL ecosystem plays an important role of flood regulation by preventing and mitigating floods in the lower floodplains. This floodplain provides a large seasonal reproductive grassland habitat to two-thirds of the world's bird populations, particularly the threatened Bengal Florican (Houbaropsis Bengalensis).

On the other hand, this entire ecosystem supports since more than 1,000 years the livelihood of the local population, with grazing and traditional land use of wet season rice growing and dry season fallowing. These ecosystems are in many places used for floating and flood recession rice cultivation, which has low productivities. These paddies play an important role in regulating floods and fostering groundwater. Their dike systems use water harmoniously by storing it for irrigation and help to reduce the risk of flooding for the local cities. The excess water is stored and discharged slowly into the lake then down the Mekong (Masumoto et al., 2008; Pham et al., 2008). Every year, 1.6 million tons of sediment are stored in the lake and floodplain, making the soil naturally fertile with young alluvial deposits (Gray, Chamnan, Borey, Collar, & Dolman, 2007; M. Kummu & Sarkkula, 2008) with long term sedimentation rate of 0.75mm/a^{-1} (Dan et al., 2005).

In summary, this ecosystem provides huge ES for local peoples such as Supporting Services, Provisioning Services, Regulating Services and Cultural Services (Millennium Ecosystem Assessment, 2005, 2007). Before going into the details, we present basically the different components of ES provided by TSL through the ESF proposed by Millennium Ecosystem Assessment (see Table 1).

Table 1: ES provided by TSL ecosystem

<table>
<tr><td rowspan="3">Supporting Services
- Soil formation and fertility (Sedimentation, Biomass from forest)
- Nutrient cycling
- Primary production</td><td>Provisioning Services
- Fish and other aquatic species, including plants
- Non timber forest products (wild foods, honey)
- Rice
- Grass for grazing
- Timber for firewood, house construction, equipment for agriculture and fisheries</td></tr>
<tr><td>Regulating Services
- Carbon sequestration by flooded forests
- Regional and local water regulation
- Natural habitat/biodiversity
- Nursery
- Waterways for transportation</td></tr>
<tr><td>Cultural Services
- Ecotourism (floating villages, birds, Tonle Sap trips)
- Cultural heritage (floating villages)
- Sense of place in cultural practices (Water festival)
- Spiritual services (Arak Teuk “Water Guardian”)
- Cambodian culture</td></tr>
</table>

Adapted from Millennium Ecosystem Assessment (2005)

2.2. Methodology

Following Zhang et al. (2007), ecosystems and agriculture are embedded in a complex relationship based on positive and negative interrelations and feedback loops. Ecosystems provide supporting services (soil structure and fertility, nutrient cycling, water provision…), regulating services (soil retention, pollination…) and also dis-services (pest damage, flood disaster etc). Thus, these marketed and non-marketed services are the two main outputs of agro-ecosystems (see Figure 1).

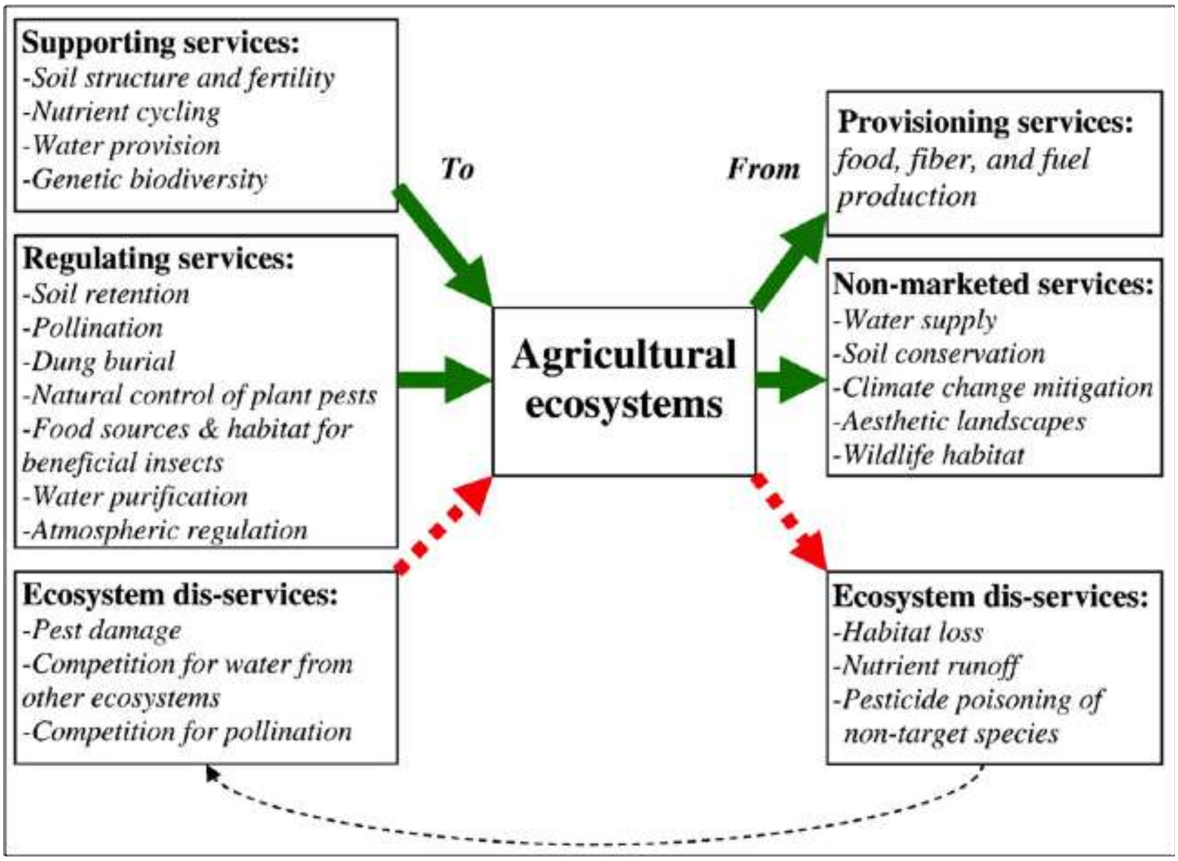


Figure 1: ES and EDS framework suggested by Zhang et al. (2007)

In order to analyze these different flows of services and disservices, we adopt field methodology from Agrarian System Analysis and Diagnosis (H. Cochet, 2012; Hubert Cochet et al., 2007; Hubert Cochet & Devienne, 2006; Dufumier, 2006). The survey has been conducted in 3 stages in order to understand farmers' choices under socio-econo-political conditions: *(1) Landscape reading:* understanding the agro-ecosystem and zoning. Started by observation the agro-ecosystem and vegetation, the question "why" guide us to meet the elder and local people for better understanding of land use change in study zone. *(2) Historical study:* The current agricultural situation is the fruit of a long or medium term evolution. This study is trying to identify the key factors of change, which create the actual agricultural practices. *(3) Production system modeling and performance economic calculation:* This stage leads us straight into economics field. The comparison of performance economic (Value-Added "VA") and Agricultural Revenue per active) of production system will clarify and explain why in the same region farmers practices different production system (Neang, Meral, Aznar, & Déprés, 2017).

Table 2: Economics calculation formula Neang et al. (2017)

(1) $$GO_i/ha = Q_i/ha \times P_i$$

GO_i/ha = gross output per hectare; Q_i = rice yield (auto consumption + sold production); P_i = average selling price on the local market

(2) $$\mathrm{II_i/ha} = \sum \mathrm{Q_{inputs\ used/ha}} \times \mathrm{P_{inputs}} + \sum \mathrm{Q_{services\ used/ha}} \times \mathrm{P_{services}}$$

II_i/ha = monetary value inputs such as seeds, chemical inputs and services used (plowing, transplanting, weeding, harvest, transport) during one year of production for each cropping system (i) in one unit of land (ha)

(3) $$\mathrm{GVA_i/ha = GO_i/ha - II_i\ /\ ha}$$

GVA_i/ha = gross value added.

(4) $$\mathrm{GR_j} = \sum \mathrm{GVA_i} \times \frac{\mathrm{S_i}}{\mathrm{fl}}$$

GR_j/fl = gross remuneration of family labor in their production system ($j = 1 - \infty$)). S_i = total surface of production system

In summary, agrarian system analysis and diagnosis allow us get specific field data on agro-ecosystem management and agricultural practices. Our approach can be divided into 4 steps as following see Figure 3.2 as below.

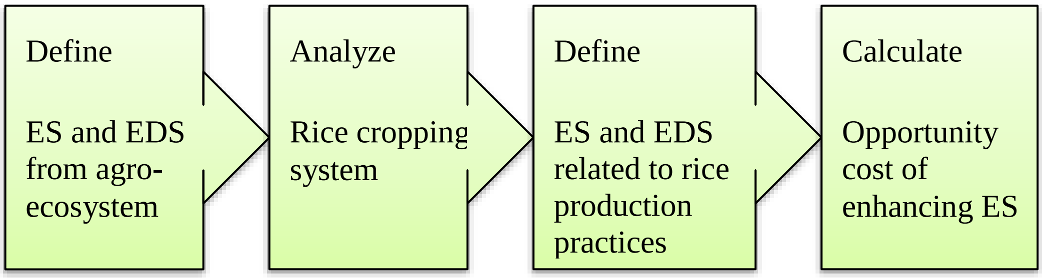


Figure 2: ES and ED's identification step

Combining Agrarian Systems Analysis and Diagnosis with the ES and EDS framework allows to link the economic performance of production systems contribute to farmers livelihood on one hand, and the ecological efficiency of ES provision for sustainable agro-ecosystem use, on the other hand. The comparison of Value-added and ES provided across different production systems typology will show the trade-offs between them. Our purpose is to identify production systems that are most effective and efficient, while being operational, productive and feasible for farmers. In others word, we are looking for production systems that allow to maintain ES with low opportunity costs.

We interviewed 208 farmers living in 2 districts, Steung Sen (Srayove commune: Srayov Tbong, Roka and Rolous villages) and Santuk (TbPhanhagy, Ompus and Porkhav villages). We chose our samples randomly in those different villages along the floodplain of the TSL (flooded grassland, flooded shrub land and clear flooded forest).

Data collection has to be done with an understanding of the agrarian system and economic calculations in order to explain diverse situations and trajectories of a production system. For this study, 208 farmers and key informant was interviewed during 2010 and 2012. Qualitative data helped to delimit the study zone and to understand the history and change in agriculture of that zone. To obtain qualitative data, 36 individual interviews was carried out and one group discussion of 12 elderly farmers. For quantitative data, 172 farmers were interviewed. Sample selection was based on a reasonable sample choice to ensure heterogeneity of farmers in the region. Twenty organic farmers were included in the 172 farmers in order to obtain details from these production systems. After data clearing, only 167 farmers remained for analysis. We decided to choose 50% of them (87 farmers) for deep interviews on their thinking about impact of agricultural inputs and agro-ecosystem change on their health, rice field ecosystem and on the fishery sector.

3. Results

3.1. Services and dis-services provided by the TSL Ecosystem to agriculture

This lacustrine active floodplain has brown or gray clayey or loamy topsoil, which is classified in the Toul Somroung soil type by CARDI. It is characterized by slow drainage and cracks into hard blocks when dry. The soil is well suited to irrigation. This soil is classified by Crocker (1962) in the Brown, Gray, or Cultural Hydromorphic soil units. It would be Luvisol or Vertisol using the FAO/UNESCO soil classification system (P., A., T., & C., 2000; Shimizu, Masumoto, & Pham, 2006; White, Oberthür, & Sovuthy, 1997). Based on the recommendation made by White et al. (1997), irrigation systems are needed to increase its potentiality for rice production. In order to maintain the field, this soil needs 62 to 100 kg of N and 40 to 52 kg of P_2O_5 per hectare.

Even though this soil is naturally fertile thanks to alluvial deposits, the sedimentation doesn't reach the middle and upper terraces due to low speeds caused by vegetation (flooded forest, flooded shrub and flooded grassland) (Dan et al., 2005; Matti Kummu, Dan, J, & Koponen, 2008). Rice yield is still low because of poor soil as well as floods and droughts without proper water management systems (Fujisaka, 1991; Mitchell et al., 2013; Nguyen, Kamoshita, Araki, & Ouk, 2011). Local farmers call their agricultural situation "Tveu Sre Rompeung Mak", which means "Producing rice by counting on the sky". This local saying illustrates their vulnerability to floods and droughts during production season. Their harvest is hazardous.

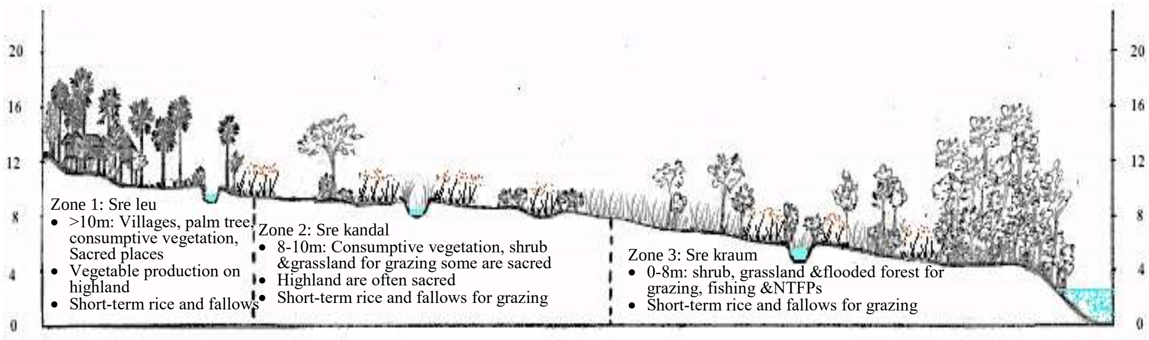


Figure 1 : Current land use in dry season and early rainy season (Dec-Jun)

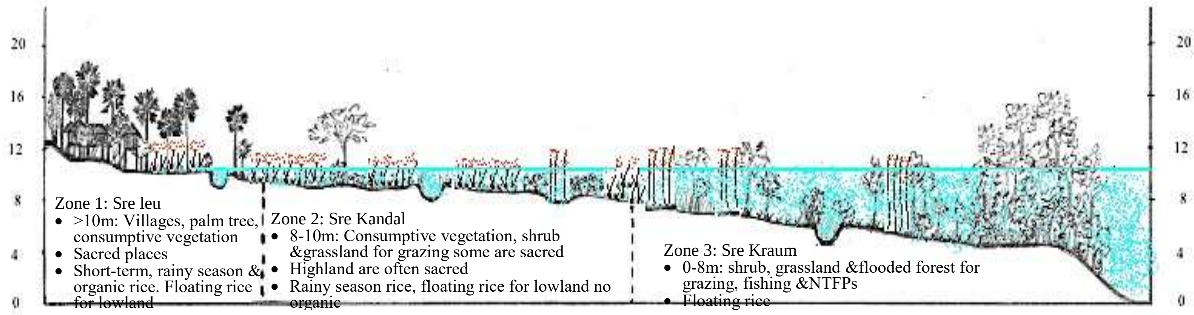


Figure 2: Current land use in middle of rainy season (Jul-Nov)

Following Keske and Huon (2002), this agro-ecosystem landscape can be divided into 3 different zones based on different elevations which receive different effects of the flood pulse. ES and EDS from each zone are different (see Figure 5). We use the local term to refer to those zones, corresponding to the elevation measures by Keske and Huon Keske and Huon (2002).

Zone 1 “Sre Leu”, which means “Upper rice terraces” (approximately 10 m of elevation (Keske & Huon, 2002)). This agro-ecosystem, including the villages, often has ring dikes up to 30 cm high in order to keep water as long as possible after the rain. This zone is flooded last by the flood pulse with 10 to 30 cm of water during August and September. This zone provides several provisioning services. Firstly, water provision enables rice production in rainy season (rainy season rice and floating rice on lowland as well as short-term rice - only one cycle). Secondly, the flood plain absorbs water in rainy season, which prevents floods in the villages. Thirdly, the ecosystem is a source of food (fish and other aquatic species, both animals and plants) in the rice fields. Additionally, palm trees (Borassus Flabellofer) and other trees on ring dikes complete the provisioning services (fruits, leaf, wood). The particularities of palm trees make them important in Khmer society by ensuring different ES. They provide habitat for bats that generate the most fertile excrement to the soil, ensuring a supporting service, as well as regulating services because bats eat insects. These trees represent Khmer identity ensuring cultural services. They also provide sweet juice for producing sugar. There are also a lot of termite nests that local people believe to host guardian spirits. In terms of EDS, the risk of lack of water for rainy season rice and floating rice in the beginning of rainy season is a real problem for farmers. Conversely, flood pulses of the TSL can cause label loss for organic rice and decrease the possibility to produce short-term rice from August to October because of high risks of floods.

Zone 2 “Sre Kandal”, which means “Middle rice terraces” (8 to 10 m of elevation (Keske & Huon, 2002)), the agro-ecosystem is characterized by rice fields with low ring dikes are around 10 cm high. There is less domestic perennial trees because of long and high inundation from the natural flood pulse. Farmers graze their animals in dry season and fish in natural ponds as well as waterways surrounded by flooded shrub. This zone is flooded before zone 1, with 15 to 40 cm of water from mid-July until end of November. Water provision is the main ES. It enables rice production, except organic rice due to flood. Floating rice on lowland is more important than in Zone 1. In contrast, this zone also provides different sources of aquatic food in rice fields and natural ponds or small rivers, and firewood from flooded shrub. This zone provides ideal conditions for animal grazing, particularly buffaloes who like ponds, with highly nutritious grass. In some places, there are highlands with big trees, which local people believe to host the guardian spirits that protect them from natural hazardous. They usually graze their animals on those places in rainy season. In case of flood disaster, those highlands become the safe places to keep their animals. On the other hand, rat hunting during dry season, at the beginning and at the end of rainy season, is an important source of income for farmers by selling them to Vietnam. In terms of EDS, flooding from natural flood pulse of the TSL causes impossibility to produce organic rice. And every year, farmers face a low risk of yield loss because of rats, for rice fields close to flooded shrub areas.

Zone 3 "Sre Kraum", which means "Lower rice terraces" (0 to 8 m of elevation (Keske & Huon, 2002)): In this agro-ecosystem, rice fields are associated with clear flooded forest, which is called "Prey Kraum or Roneam". This ecosystem is the richest one, made up of flooded forest, shrub and grassland. It is permanently flooded in rainy season, starting in June until end of November, with more than 1.5 m of water. This ecosystem provides enormous ES to agriculture and farmers livelihood. Despite the high fertility of the soil thanks to alluvial sedimentation this zone face to high flood, which lead farmers to adopt floating rice. Nowadays majority of farmers convert those floating rice fields in order to d produce two cycles of short-term rice. This zone is also an important source of firewood, some strong wood usable for agricultural tools and for house construction, NTFP (honey and medicinal plants), fishing for family consumption and sale, and animal feed (grazing during the dry season and grass collecting during rainy season) with nutritious grass. Farmers have traditional practices of grazing associated with fishing by organizing work sharing between farmers to graze their animals in that zone (2 persons in charge of 15 to 30 animals for 10 days to 1 month). That zone lies 20 to 40 km from their village. They do also fishing and NTFP collecting. These activities give them financial revenues for their family. Rat hunting is also an important occupation during dry season, at the beginning and the end of rainy season, for sale to Vietnam. These rats are called rice rats and are the most demanded because consumers believe that they are healthy and clean by eating only rice in the purified ecosystem. Anyways, risks of flood and rat damage are still high for floating rice because it is grown during a period of high water level. As a consequence there is no possibility to use rodenticide. Rats climb on trees and eat rice panicle.

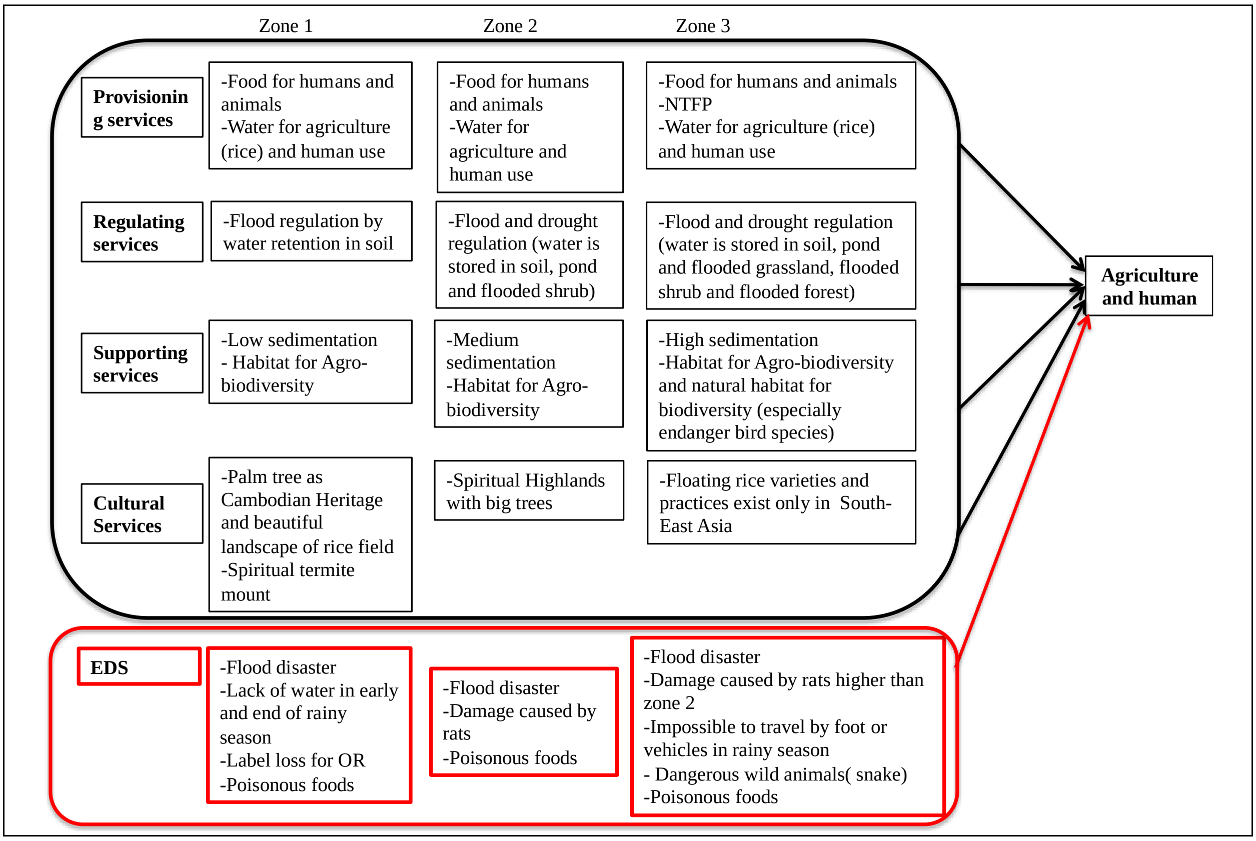


Figure 3: ES and DES related to the three zones of TSL flood plain agro-ecosystem, Adapted from Zhang et al. (2007)

3.2. Services and Dis-services provided by rice cropping system

In our study case, we classify rice cropping systems into 3 main categories composed by 9 cropping systems based on varieties and practices that farmers use in one plot located on different agro-ecosystem of flood pulse of the TSL (Neang et al., 2017).

The first main cropping system is called "short-term rice". These systems have been recently adopted (2000-2002) in order to better adapt to flood disasters during the rainy season that happens often. Short-term rice cropping systems are called dry season rice by farmers. These non-seasonal and non-photosensitive varieties enable farmers to produce outside of the flood period by adopting 3 different cropping calendars. (1) **Early season rice,** which they can start end of Feb and harvest in May or start in May and harvest in August with a productivity around 4.9t/ha. (2) **receding rice**, for which they wait until the water recedes to start in December and harvest in January for 4.57 t/ha. They get lower yield for RR because of drainage from flood is difficult. (3) Some farmers combine them on the same rice field, which enable them to double their productivity to almost 10t/ha. Water management is important Early Season need irrigation while Receding Rice needs drainage most importantly. All kinds of short-term rice require agro-chemical inputs such as fertilizer and pesticides. Our short-term rice respondents assert that, based on sellers' advices, they use chemical pesticides preventively and mix 2 to 3 pesticides together as a cocktail in case of pest attacks. In addition, herbicide use is becoming common practice for short-term rice to reduce plowing. Anyways, farmers percieve that technical practices of these rice cropping systems could lead to agro-ecosystem and agro-biodiversity degradation, as well as poisonous food for local farmers. 75% of respondents believe that fish and other aquatic species from their rice fields are poisonous because of chemicals used and they don't consume them anymore for fear of chemical residues. Regrettably, poorest farmers still continue to eat this food for lack of an alternative. The relation between rice techniques practices, and EDS are detailed in **Erreur ! Source du renvoi introuvable.**.

The second main cropping system is Rainy season rice, these cropping systems are farmers' traditional practices, with seeds selected naturally and locally by them and their ancestors. Medium term rice, with 120 to 150 days to maturity, starts in May. It can be transplanted if water is too high or direct seeded if they start early enough, when water isn't there yet. It is often fragrant rice, with which farmers produce Ambok (rice grilled and flattened by crushing) to sell to Phnom Penh at a national event (Water Festival) in November. This rice is called medium duration of maturity and its flowering time is between 10^{th} and 15^{th} October (CARDI, 2007). This rice is mostly cultivated in zone 1 (90%) because it cannot survive deep and long floods. Sometimes, this rice can also be found in zone 2 where land is not flooded and unsuitable for long-term rice. Long term rice direct seedling is predominantly cultivated in zone 1 and in some high lands in zone 2, where there is less water in early rainy season, enabling farmers to sow on muddy land. On the other hand, transplanting practice is adopted in zone 2 and some low lands in zone 1 where the water is 20 to 30 cm high. Because labor has become rare in the region, farmers prefer direct seedling. According to farmers, long term rice can survive very well in floodwater until 60 to 70 cm. These varieties have 6 months of life cycle, starting in April and ending in December. For rainy season rice, farmers who have money will use pesticides against crabs and rats, and some low amounts of fertilizer (50 to 100 kg of DAP per hectare). On average they get from 1.3t/ha for direct seedling to 2.2t/ha for transplanting. **Organic rice** is cultivated only in zone 1, particularly on high land, to avoid floods even from the natural flood pulse. It has the same life cycle as other medium term rice systems. This rice is transplanted with only one stem at a time, because farmers received trainings from some NGOs about SRI practices (System of Rice Intensification) that transferred to farmers in order to improve their productivity by increasing organic fertilizer use (Ly et al., 2012). Unfortunately, it was adopted by a small number of farmers because in that region, it is very hard to manage water in order to transplant in muddy soil with single young stems and lack of organic matters for compost. The organic label came later, in 2003, to improve farmers' practices and increase their revenues. 55% of farmers in Raksmey Steung Sen Association (RSSA) produce organic rice on 100% of their land, with an average of 0.77 ha per household. Because of the ecological risk of flood, others use only the suitable part of their land for Organic Rice and still continue to produce floating rice associated with long term or medium term rice on the rest of their land. Farmers said OR needs from 2 to 3t of compost per ha but they can find only 1 to 2 oxcarts (around 35kg/oxcart) per year. This is the main constraint and factor limiting their yield, to 2.2t/ha on average.

The third cropping system is **Floating rice (FL)** is normally a cropping system of rainy season rice but this study keeps it separate because of its particularity that it can grow very tall in case of flood, and thus represents a good protection against the risk of flooding. Since 2002, many floating rice fields were converted to short-term rice in zone 3. This is why only 36% is found in zone 3 and 64% in low lands of zone 2. In rainy season, predominantly in September and October, overflow from the lake floods the paddy fields, with up to 4 meters of water, creating conditions that only floating rice can survive. These rice varieties can elongate their stem up to 30 centimeters per day, keep their leaves above the surface of the water and escape drowning (Cummings, 1978). In our study zone, farmers argue that these rice varieties can grow up to 50 centimeters per day in case of flood disaster. This rice cropping system is the most extensive, requiring few labor and capital. As soon as the first rains fall, farmers start ploughing and they did twice, if needed, in order to incorporate weeds into the soil and get them to decompose. After harrowing, they sow in April or May and wait until December to harvest. Since 2010, some farmers start using herbicide instead of ploughing twice. In this case they use Roundup to kill all weeds before incorporating them into the soil. This rice cropping system is the most resistant to flood but it is also the most risky, because when the water is still high at maturity stage, rats can climb on trees and eat rice panicle. This rice cropping system is almost chemical free. It has a low yield, 1.57 tons on average but still more than direct seedling of rainy season rice, which yields 1.2 to 1.4t/ha. This is because lands used for rainy season rice receive less alluvium from the floods compared to floating rice fields. Some farmers growing floating rice in zone 2 tried to use some fertilizer, 50kg/ha of Urea, but the yield was not different because of the run-off of N by water. The ES and EDS provided by this rice cropping system are well define in **Erreur ! Source du renvoi introuvable.**.

Rice cropping systems (i)			Practices and Land Use	Ecosystem services (non-marketed) FROM Agro-ecosystem	Ecosystem dis-services FROM Agro-ecosystem
Early Season Rice	Z1: 21% Z2: 34% Z3: 45%	Short-term rice	Using the existent rice field in zone 1	Cultural Services: Preserve spiritual practices and beauty of agricultural landscape, such as rice fields with palm trees. Provisioning Services: high yield rice, leaves, trunks, fruit and juice from palm trees for farmers' basic needs	
Receding Rice	Z1: 17% Z2: 36% Z3: 47%		Ring dike, canal and reservoir construction for irrigation and drainage or for preventing water from flowing into rice fields	Ensure flood regulation for short-term rice	Disturb water regime, alluvial deposits and flood regulation capacity of ecosystem
			Chemical use (cocktails of pesticides and fertilizer) in all zones with the same practices		Degrade soil and agro-biodiversity and pollute water
Double cycle of Early + Receding Rice	Z1: 24% Z2: 40% Z3: 36%		New variety « High Yield Variety »		Reduce the genetic resources in daily food consumption
			Deforestation of flooded clear forest, shrub and grassland in zone 3		Degrade habitat, biodiversity and flood regulation capacity of this ecosystem
Medium Term rice Direct-seedling	Z1: 90% Z2: 10%	Rainy season rice	Dependence on water regime from flood pulse of TSL with less than 30 cm height of ring dikes	Regulating Services: Respect water regime and alluvial deposit	
Medium Term rice Transplanted			Maintenance of existing high lands, spiritual places and palm trees. Furthermore palm trees are replanted every year in zone 1.	Cultural Services: Preserve spiritual practices and beauty of agricultural landscape, such as rice fields with palm trees. Provisioning Services: Rice, Leaves, trunks, fruit and juice from palm trees for farmers' basic needs.	
Long Term rice Direct-seedling	Z1: 38% Z2: 62%		Absence of chemical use or small amounts of fertilizer and pesticides used if needed	Regulating Services: Preserve Agro-biodiversity fauna, flora and amphibians of rice fields. and Water quality	
Long Term rice Transplanted			Use of natural and local varieties (Fragrant and Non-Fragrant rice)	Regulating Services: Preserve natural varieties for the genetic bank	
			Use of hybrid Medium Term rice fragrant varieties in case of flood or drought.		Degrade natural varieties in genetic bank

Organic Rice	Z1: 100%		Use of only existing rice fields, thus absence of new deforestation of flooded forest, shrub or grassland	Regulating Services: preserve indirectly flooded clear forest for Habitat and Biodiversity	
			High land and spiritual place, Palm tree are kept. Palm tree are replanted every year in zone 1.	Cultural Services: Preserve spiritual practices and beauty of agricultural landscape (Rice field with palm tree). Provisioning Services: Organic rice, leaf, trunk, fruits and juice for farmers' basic need.	
			Restrain from use of chemicals	Regulating Services: Preserve Agro-biodiversity (fauna, flora and amphibians of rice fields) and Water quality	
			Use new varieties « Fragrant Rice »		Reduce the genetic resources in daily food consumption
			Rice field are protected from flood by ring dikes around 40cm high to avoid chemical contamination for preserving label		Degrade regulating services: soil formation from deposit*
Floating Rice	Z2: 64% Z3: 36%	Floating rice	Use of only existing rice fields with many trees (flooded clear forest in zone 3) on it	Conserve directly flooded clear forest Regulating service: Flood regulation, Habitat and Biodiversity Provisioning services : firewood, NTFPs and inland fish	
			Dependence on water regime from flood pulse of TSL	Respect water regime and alluvial deposit. Regulating services: soil formation from deposit*	
			Existed High land for spiritual place and Palm tree are kept	Cultural Services: Preserve indirectly spiritual places and beauty of agricultural landscape (Rice field with palm tree). Provisioning services: leaves, trunk, fruits and juice for farmers' basic need. Provisioning services: Materiel and food from palm trees	
			Absence of chemical use or use of small amount of fertilizer and pesticide if needed	Preserve fauna, flora and amphibians of rice fields. No chemical residue leaching into water. Regulating service: soil biodiversity and water quality	
			Use natural and local varieties	Preserve natural varieties for genetic bank and daily consumption. Regulating Service: Natural variety conservation	

* *Soil deposit (sedimentation) on flood plain is very low because of the low speed of water flow from flood pulse (Dan et al., 2005; Matti Kummu et al., 2008)*

3.3. Trade-offs and opportunity cost analysis

3.3.1. Trade-offs between provisioning services and other ES in each production system

The key interest of ESF is to focus on trade-offs. For farmers and policy makers, the main output of ES is rice provision. As we quoted, the TSL ecosystem is the main zone of rice production in Cambodia, due to the flood pulse process. The previous analysis showed the opportunities and risks to produce in the different area. Our fieldwork led us to identify different strategies developed by peasants to manage these opportunities and risks. These strategies are combinations of different cropping systems (i) into a specific production system (j). Based on several criteria (surface, labor, capital), we distinguish 21 different combinations of rice production systems and calculate the value-added for each (Table 1). The value-added/fl corresponds to the capacity of one family labor to produce on their land. It is then possible to gather these different groups into 7 main categories as **production system models** taken into account relations with regulating and cultural services. Because it is not possible to evaluate a monetary value for all these ES or EDS in this study for each category, we adopt a qualitative valuation (+ for positive effect "ES"; - for negative effects "EDS") based on our expertise in the field and interviews with peasants. Only the provisioning services, which we are able to calculate in monetary terms, are represented as value-added/fl per year.

Production system model A is a combination of different types of short-term rice systems, some of them produce only double cycle of short-term rice. In this production system, farmers can increase significantly their yearly revenue. Model A only provides a low level of cultural services, by maintaining the existing spiritual places. Farmers in model A try as much as possible to convert all their rice fields to adopt short-term rice and they buy water from private rice companies[1]. This model provides only low level of cultural services related to the fact that they maintain the existing spiritual places. On the contrary in term of EDS it degrades a lot of regulating services as detail in (Table 1). System A is a clear trade-off between maintaining others ES and provisioning services correspond to productivity of land and labor (Value-add/fl). To bring the value-added from of 478.28$/fl to 1004.67$/fl, farmers get the score of -9 for EDS.

Model B is a combination of short-term rice systems (double or single cycle) with other rainy season rice cropping systems. Farmers manage their system to convert their land to an agro-ecosystem of short-term rice as much as possible. On the rice fields where they cannot produce short-term rice, they continue to cultivate rainy season rice, including floating rice. Because of its high price, Medium term rice, both transplanting and direct seedling, is their best way to get high land productivity and value-added per family labor. Model B shows a possibility to increase land and labor productivity while still staying in harmony with the ecosystem of the TSL flood plain. In model B, provisioning services from different groups vary significantly (from 260.92$/fl to 1077.81$/fl) but with regards to other ES, they have almost the same score of about +3 on average.

Production model C represents organic production systems, with some being in combination with rainy season rice cropping systems in order to also produce on land where flood cannot be controlled. Organic rice production model is not the most effective in terms of ES because it degrades natural varieties and increases risk face to flood. This is due to organic rice cropping system needing to avoid any contamination by flood to keep its organic label. During the seasonal

[1] There are a few private companies producing short-term rice in zone 3 (Sre kraum). They own 150 to 200 ha of rice field. They invest in irrigation systems by making high dikes around them, with reservoirs inside, to prevent floods and drought.

flood period, farmers generally drain water from their rice field by letting water flow through neighboring rice fields by gravity. Organic rice fields forbidding this, they increase flood risks for other fields. They also disrupt alluvial deposit for nutrient renewal. In model C, one farmer can make a value-added between $106.87 and $235.86 by generating a +6 score of ES on average.

Model D represents the short-term rice production system of farmers with small production areas. Farmers in this model did not have capital to invest in converting their rice field to short-term rice. Thus they only take advantage of the opportunity to get water from private companies and pay back after harvest. They cannot get high labor productivity because of their small area, less than 1 ha per farmer. This system offers small value-added for farmers and comes with a high cost for society and the environment, like production model A. In this model, one farmer can only make 54.30$ to 127.63$ by generating EDS of -9 on average.

Number of farmers	**Rice production system (j)**	**Surface (ha/fl)**	**Provisioning Services**		**Regulating Services**			**Cultural Services**
			Value-added ($/fl)	**Natural Variety**	**Agro-biodiversity**	**Habitat/ biodiversity/ water quality**	**Flood regulation**	**Spiritual / Scenic**
11	**A. System intensive providing high provisioning services and high EDS (-9 in average)**							
3	A1. (Early season rice + Receding rice)	1.35	1004.67	---	---	---	--	+
3	A2. (Early season rice +Receding rice) + Receding rice	1.43	785.54	---	---	---	--	+
5	A3. Receding rice	1.47	478.28	---	--	--	--	+
38	**B. System intensive providing medium to high provisioning services and low regulating + cultural ES (+3 in average)**							
5	B1.(Early season rice + Receding rice) + Receding rice + Floating rice	2.24	1077.81	-	+	-	-	++
5	B2. Receding rice + Medium-term transplanting + Long-term direct seedling	2.55	994.43	+	+	+	-	++
3	B3. Early season rice + Receding rice + Long-term transplanting	2.24	908.2	+	+	+	-	++
3	B4. Receding rice + Medium-term direct seedling + Floating rice	1.41	456.41	++	+	++	-	++
2	B5. (Early season rice + receding rice) + Medium-term direct seedling	0.59	344.61	---	+	-	-	++
2	B6.(Early season rice+Receding rice) + Medium-term direct seedling + Floating rice	0.88	316.19	-	+	-	-	++
7	B7. Early season rice + Floating rice	0.61	261.45	+	+	++		++
11	B8. Receding rice + Floating rice	1.00	260.92	+	+	++	-	++
22	**C. System organic rice providing medium provisioning services and medium regulating + cultural ES (+6 in average)**							
6	C1. Organic rice + Long-term direct seedling	0.75	235.86	-	++	++	-	+++

11	C2. Organic rice	0.29	132.1	---	+++	++	-	+++
5	C3. Organic rice + Floating rice	0.48	106.87	-	+++	++	+	+++
6	**D. System intensive providing low provisioning services and high EDS (-9 in average)**							
3	D1. (Early season rice + Receding rice)	0.37	127.63	---	---	---	--	+
3	D2. Early season rice	0.15	54.3	---	--	--	--	+
37	**E. System traditional providing low provisioning services and high regulating + cultural ES (+11 in average)**							
14	E1. Long-term direct seedling + Floating rice	0.63	129.37	+++	++	+++	+	+++
6	E2. Long-term direct seedling	0.46	117.4	+++	++	++	-	+++
11	E3. Medium-term transplanting + Medium-term direct seedling	0.41	113.64	+++	++	++	-	+++
6	E4. Long term direct-seedling +Floating Rice	0.32	69.13	+++	++	+++	+	+++
42	**F. Floating rice system providing low provisioning services and high regulating + cultural ES (+15 in average)**							
42	F1. Floating Rice	0.78	151.08	+++	+++	+++	+++	+++

Table 1: Rice production system typology with ES (+) and EDS score (-)

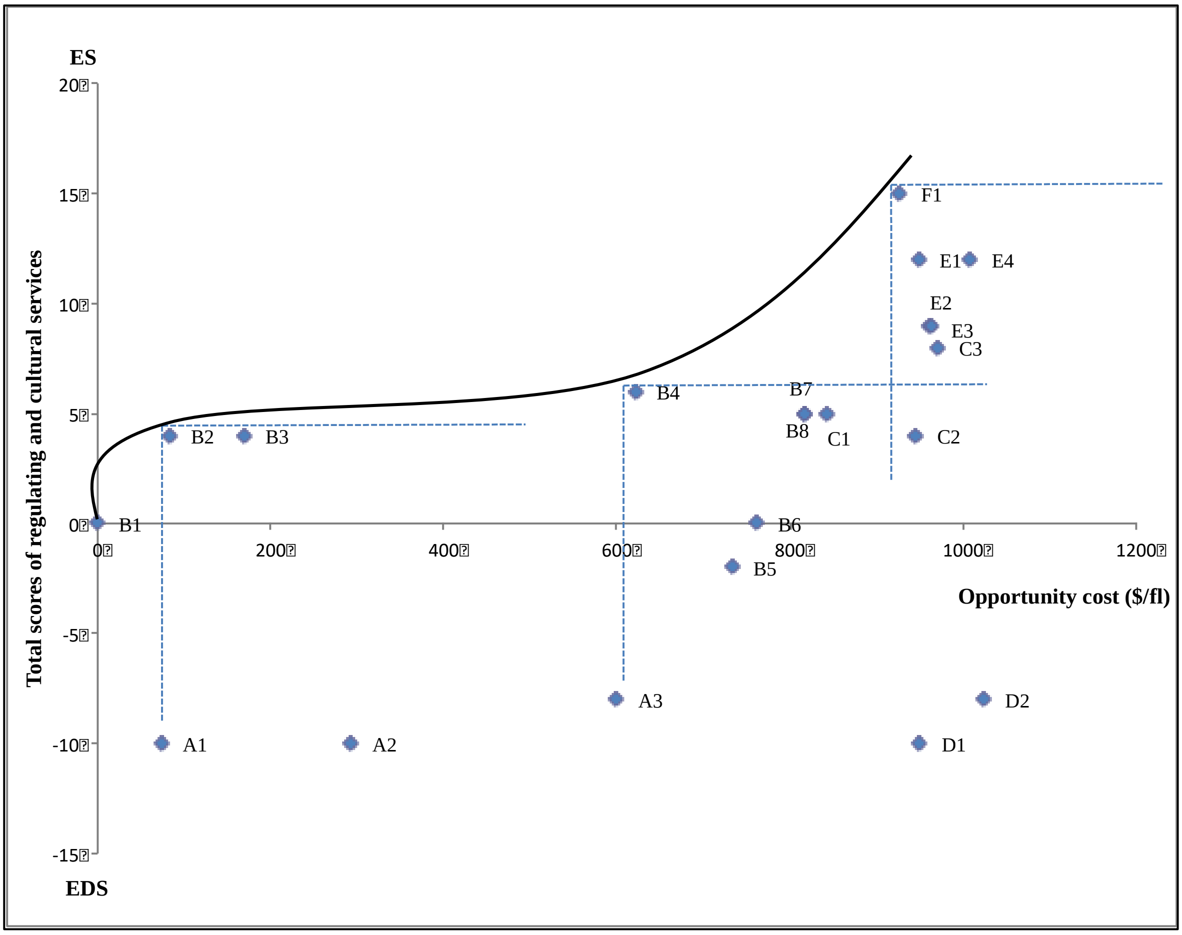
Model E, called “traditional system” by farmers, refers to combinations of different rainy season rice cropping systems. This model represents the way farmers try to adapt to the flood plain ecosystem by creating rice field terraces, which let them adopt rainy season rice cropping systems in all 3 zones of Sre Leu, Sre Kandal and Sre Kraum. It symbolizes a complex manmade agro-ecosystem in harmony with an ecosystem of high risk of seasonal flood. Floating rice is a perfect component of harmony between man and the Roneam (flooded forest) ecosystem because instead of changing this ecosystem, farmers cultivate rice varieties that can adapt to flood. Farmers can get from 69.13$/fl to 129.63$/fl and accumulate a high score of ES of +11 on average.

The last production model, F, corresponds to poor farmers who own around 1 ha per labor, only in the low land area called Sre Kraum, on grassland, in the flooded forest ecosystem or along the waterway, with high risks of flood. These farmers do not have enough financial capital to invest in conversion to short-term rice. Therefore they continue to produce floating rice, which provides low provisioning services but very high regulating and cultural services. Farmers in this model produce on average 151$/fl while they provide the highest score of ES, +15 on average.

3.3.2. The most efficient production system model

The Table 1 clearly shows the impossibility to promote a specific production system that would be able to conserve all ES provided by the agro-ecosystem. The more we promote quantity of rice provision, the more we destroy regulating and cultural services. Moreover, for political decisions it would be useful to calculate the opportunity cost that farmers would have to face if policymakers would decide to promote pro-ES rice production systems. To pursuit this argument, we calculated the opportunity cost of each production systems compared to the adoption of the most productive rice production system, B1 (double cycle of short-term rice + Receding Rice +Floating Rice). This system provides high productivity per one family labor along with a balance between ES and EDS provided. In other words B1 provides high provisioning services (rice) at zero cost for the ecosystem. The Graphic 1 presents a spatial distribution (cloud of points). Each production system is located on the graph with its opportunity cost (in US$) on the horizontal axis, and on the vertical axis the sum of its regulating and cultural services scores (1 plus increase the total score by 1, 1 minus decreases the total score by 1). As we can see, some of the production systems provide the same (regulating and cultural) ES score but with more or less opportunity cost compares to B1. Thus, it is then possible to define an optimal frontier of ES production systems (black curve), composed by the different efficient production system.

- Systems with low opportunity cost, less than 300$/fl: B1, B2, B3, A1 and A2. The system B1 is a control system, with zero opportunity cost and zero balance of ES and EDS. At the same opportunity cost, systems A1 and A2 have negative scores for ES, as opposed to B2 and B3 which have positive scores for ES. In this group, **B2** is efficient in terms of opportunity cost to preserve ES.
- Systems with medium opportunity cost, between 600$/fl and 850$/fl: B4, B7, B8, C1, B5, B6 and A3. At almost the same opportunity cost, A3 and B5 have negative scores for ES, while B4, B7, B8, C1 and B5 have positive scores for ES. Thus, among these production systems, only **B4** is efficient in ES preservation.
- Systems with high opportunity cost, more than 900$/fl: F1, E4, E3, E2, C2, D1, D2. With equal opportunity cost, model D (D1 and D2) has negative scores for ES. On the contrary, others have very positive scores for ES. Among them, **F1** is the most efficient for ES preservation.



Graphic 1: Comparison of opportunity cost with the score of ES provided

When comparing production models A, B, C, D, E and F, model A and model D appear to be the most dangerous for ES. Both systems have -9 as score of EDS. However model D has a much higher opportunity cost, of 986$/fl on average, than model A, with only 321.65$/fl on average. All production systems in model B are reasonable for ES and can also provide high provisioning services. They are thus able to ensure ES with low opportunity cost. Interestingly, models A and D are not productive compared to model B. Another way to say it, is that producing only short-term rice with high chemical pollution and ecosystem conversion is less productive than combining short-term rice with rainy season rice as well as floating rice. The latter also helps to increase positive externalities on the environment, with low chemical pollution and low ecosystem conversion, which are good for ES preservation. Models E and F are the most effective and efficient for ES preservation but they represent the highest opportunity cost for farmers. Organic rice systems (C1, C2 and C3) are not efficient for ES provision, while still coming with a high opportunity cost for farmers, around 919$/fl, despite a price premium for organic label.

4. Conclusion

In most of these production systems, farmers achieve economic efficiency thanks to short-term rice, with this performance being even better if they can adopt a double cycle schedule, to have two harvests per year on the same land. On the other hand, rainy season rice and floating rice enable farmers to achieve ecological performance by ES provision. Thus production systems that are most efficient economically for famers and also ecological in terms of ES provision are systems in which farmers combine short-term rice cropping systems with rainy season rice cropping systems, especially floating rice.

More precisely, compared to B1, which is the most profitable production system, only 3 production systems provide an efficient trade-off between provisioning services on one hand and regulation or cultural services on the other hand: B2 (Receding Rice + MediumTerm Transplanting + Long-Term Direct seedling); B4 (Receding Rice + Mid-Term Direct seedling + Floating Rice); and F1 (Floating Rice). In terms of number of farmers in these production systems, F1 includes the majority of farmers (B1 = 5 farmers, B2 = 5 farmers, B4 = 3 farmers and F1 = 42 farmers). In spite of this, Floating Rice production systems are practiced by the poorest farmers in the region and are on a path to disappear. This is due to their low productivity, together with the high risk of yield loss caused by climate uncertainty and rats. The trend in the region is to convert floating rice field into short-term rice, which requires irrigation and drainage as well as chemical inputs in order to provide high yield.

Consequently, for public policies aiming at promoting pro-ES production models, we recommend to encourage the re-adoption of rainy season rice, especially Floating Rice, or increase its surface in production in order to be both economically efficient for farmers and operationally effective for the agro-ecosystem. Producing only Floating Rice generates the highest ES with very high opportunity cost for farmers. However this cost could be reduced by diversifying towards high value-added rice cropping (Short-term rice, Mid-Term Rice, or Organic rice). Conversely, producing only short-term rice engenders high value-added for farmers with the highest DES. However, DES could be reduced by diversifying towards rice cropping systems providing high ES, such as Floating Rice. Hence promoting this production will contribute to poverty reduction in Cambodia. Despite high ES provision, this production system also generates high opportunity cost, which will make it expensive for public policies to maintain.

Based on our results, organic rice production systems are not economically and ecologically efficient in ES provision. Thus, we propose 3 different choices (1) In order to promote production systems with medium efficiency for ES but low opportunity cost, promote adoption of rainy season rice, excluding floating rice, in combination with short-term rice. (2) To promote production systems with medium performance for ES and medium opportunity cost, promote adoption of rainy season rice, including floating rice, in combination with short-term rice. And (3) To promote production systems with high performance for ES and high opportunity cost, promote adoption of floating rice alone in a production system.

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