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# Land cover-based ecosystem service assessment of irrigated rice cropping systems in southeast Asia—An explorative study

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ABSTRACT

Continuing global population growth requires an increase in food production, but also new strategies to reduce negative effects of intensive land use on the environment. Rice as key staple food for a majority of the human population is of crucial importance for global and particularly Southeast Asian food supply. As food provision is one key ecosystem service (ES), it is important to know which ESs are provided at which places. Therefore, an ES scoring exercise harnessing local experts' knowledge in a 'rapid assessment' was conducted in seven rice cropping regions in Vietnam and the Philippines. The expert-based scoring values were linked in an 'ES-matrix' to the different land use/land cover (LULC) classes abundant in the study areas. The LULC classifications were based on SPOT satellite image interpretation. The matrices were used to compile ES supply maps that give first indications about ES in regions with different intensive agriculture. The outcomes provide a first 'screening' of ES supply related to different LULC types in rice-dominated regions enabling the communication of the relevance of specific ecosystems for local communities and decision makers. Uncertainties inherent in expert- and land cover-based ES assessments are discussed and recommendations for improvements of future studies are given.


## 1. Introduction

Facing a projected world population of more than 10 billion by the end of this century (UN, 2013), but having 868 million people suffering severe food scarcity in the year 2012 (FAO, 2013), explains why intensive research is conducted to enhance food security (Ericksen et al., 2009). Rice (*Oryza sativa* L.) is the major staple food for 2.5 billion people worldwide, whereof 557 million people live in Southeast Asia (Manzanilla et al., 2011). Southeast Asia provides ideal production conditions for rice regarding climate and water supply (Willenbrink, 2003) and therefore the crop has been traditionally cultivated for centuries. However, the face of rice cultivation has changed extremely in most Southeast Asian rice cropping regions since the 'green revolution' in the 1960ies (Greenland 2006).

Achievements like the implementation of new varieties, synthetic fertilisers and the intensive use of pesticides contributed to a significant rise in yields per hectare (Bottrell and Schoenly, 2012). Today, yield increases are slowing down (Laborte et al., 2012; Dobermann et al., 2002), which brings up questions about future food security. Moreover, in many cases ecosystem structures

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(including biodiversity) and functions have suffered from a food production approach that is only focused on maximising yields (Gagic et al., 2012; Olhan and Alaseven, 2010). Exemplary effects are chronic pest infestations and epidemic outbreaks (Hossain, 2007; Heong and Hardy, 2009), unsteady water supplies, biodiversity loss and constantly rising costs of additionally inputs needed to safeguard the agro-ecosystems' functionalities (Singh, 2013). Approaches that enable a sustainable management of rice cropping systems and the surrounding landscapes are urgently needed. It is obvious that instead of technical approaches, more nature-based solutions are required to optimise food production (Ericksen et al., 2009) and to mitigate risks of lacking food supply.

Ecosystem services (ES) offer promising ways to communicate the relevance of biodiversity and functioning ecosystems to decision makers (de Groot et al., 2010). Spatially explicit ES mapping can visualise the consequences of land use/land cover (LULC) changes like conversion of forest to agricultural land (Crossman et al., 2012). Related case studies are an important step towards the further development, acceptance and policy implementation of the ES concept (Maes et al., 2012; Burkhard et al., 2012a, 2013; Daily and Matson, 2008). Expert surveys have become a recognized tool for acquiring and screening complex ES-related information which otherwise would be too resource-consuming to be obtained (Jacobs et al., 2015; Palomo et al., 2013). The combination of expert scores with LULC-data are common within ES mapping studies (Kienast et al., 2009; Maes et al., 2011; Burkhard et al., 2012b). The rather rapid creation of results, especially on the landscape scale, is one main advantage of LULC-based studies (Jacobs et al., 2014). Based on the assessed information, their analysis and the subsequent compilation of ES supply maps, differently managed rice-dominated landscapes in the Philippines and Vietnam were compared referring to their capacities to supply ES.

Such ES-based information can help providing alternative management options for decision-making in agricultural systems (Swinton et al., 2007). Assessing the supply of ES and illustrating it in a way that is easily understandable in order to reach a broad audience also outside the field of ecological sciences, is considered an auspicious approach, to which this work wants to contribute. Therefore, this study aims to identify service providing units (SPUs) for different ESs relevant in the study regions and to detect differences in ES supply between different cropping systems. ES trade-offs between maximised capacities to supply food (rice) ES and areas with multiple ES supply were expected in regions where rice cultivation is practiced more intensively or more traditionally.

The following research questions were used to guide the study:

- Which ES are relevant in the study areas and in which LULC types are they supplied to what extent?
- Are there differences in ES supply between different cropping systems and related production intensities?

## 2. Materials and methods

The study has been part of the research project LEGATO[1] with partners from Europe and Southeast Asia (Settele et al., 2013). The project's core objective is to investigate the interactions between irrigated rice cropping systems, the landscapes in which they are embedded and the human perception and valuation of relevant ESs. The project aims to quantify in what degree ecosystem functions and services relevant in rice cropping systems depend on local and regional land use practices, biodiversity, climate as well as socio-economic and cultural drivers and constraints. Seven research regions of 15 × 15 km² in Vietnam and in the Philippines have been defined (Fig. 1).

### 2.1. Research regions

The research regions (Fig. 1) were selected to enable a comparison of rice cultivation systems in tropic/subtropical climatic conditions with partly different agricultural intensities, structural patterns and socio-cultural settings. Vietnamese as well as Philippine rice cropping is in large parts characterized by intensive cultivation techniques and use of herbicide and fertiliser inputs, especially in lowlands and river deltas (see Klotzbücher et al. (2014)). This development is increasingly affecting the landscapes' natural capacities to maintain biodiversity, ecosystem functions and to supply ES (Spangenberg et al., 2015). In contrast to the majority of sites, the chemical inputs in Philippine rice terraces are extremely low. Also, the yields obtained in such systems are smaller, while simultaneously the landscape is well diversified and high quality local rice varieties are grown (Settele et al., 2013; Settele, 1998).

#### 2.1.1. Research regions in Vietnam

The first region (VN_1) is located in the Red River Delta in the Hai Duong province about 20 km east of Hanoi. In this area, most rice varieties used are highly productive hybrids with two harvests per year. Fast industrialisation in the Hai Duong province has recently led to LULC changes from agricultural land to settlements and industrial areas. The second region (VN_2) is also situated in the Red River Delta about 50 km north of Hanoi in the Vinh Phuc province. In contrast to the Hai Duong province, the area suffers from a general lack of water, mainly caused by sandy soils and a decrease in forest cover (Jadin et al., 2013). Agriculture has a smaller relevance in this region compared to Hai Duong. On most of the rice fields, traditional varieties with higher genetic diversity are planted. Rice is harvested 1-2 times each year, and instead of chemical, mostly organic fertilisers and less pesticides are used.

The third region (VN_3) is located in the mountainous Lao Cai province around 1200 m a.s.l. 300 km northwest of Hanoi, bordering China. The relief is engraved by terraces and the climate is more temperate than in the first two regions. The area faces high population density and growth, leading to periods of food deficiency (Jadin et al., 2013). The growing tourism targeting for the rice terraces is the main source of income here. Rice is grown only in the form of subsistence farming and no market exists within the grasp of local people. Rice is normally planted once a year, due to climatic constraints and water scarcity (Lò Dieu Phu, pers. comm. 2012). New terraces are constantly created, while others have been abandoned. Landslides are visible at numerous slopes.

The fourth region (VN_4) is situated in the Tien Giang province, about 60 km southwest of Ho-Chi-Minh City in the Mekong River Delta in southern Vietnam. Thanks to its plain relief and favourable climatic conditions, this region is presumed to be the most productive rice cropping area of the whole country. The rainy season here lasts from May to November, enabling three major cropping seasons (Bambaradeniya and Amerasinghe, 2004). Insecticides, pesticides and fungicides are commonly used several times per cropping season. The cultivation intensity has been increased considerably in the region with the introduction of the high-yield variety IR8 in 1966 (Tran and Kajisa, 2006). The ancient forests that covered the area of the Mekong Delta prior to the American war have completely disappeared. At some places, small spots of secondary forest have developed and the trees growing there are intensely used for construction.

[1] Land-use intensity and ecological EnGineering-Assessment Tools for risks and Opportunities in irrigated rice based production systems: http://www.legato-project.net

**Table 1**
Overview of research landscapes (based on Settele et al. (2013), adjusted).

| | LEGATO study regions | Intensity of cultivation | | | Landscape structural diversity | | | Cultural identity | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low | Med | High | Low | Med | High | Low | Med | High |
| VN_1 | Hai Duong (Northern Vietnam) | | X | X | X | X | | X | X | |
| VN_2 | Vinh Phuc (Northern Vietnam) | X | X | | | X | | X | | |
| VN_3 | Sapa (Northern Vietnam) | X | | | | | X | | | X |
| VN_4 | Tien Giang (Southern Vietnam) | | | X | X | X | | X | | |
| PH_1 | Laguna (Philippines) | | X | X | | X | | X | | |
| PH_2 | Nueva Ecija (Philippines) | | X | X | X | X | | X | | |
| PH_3 | Ifugao (Philippines) | X | | | | | X | | | X |

*2.1.2. Research regions in the Philippines*

All research regions are located on the island of Luzon. The most southern region (PH_1) is situated in the Laguna Province (south of Manila) and borders the southeastern shore of Laguna de Bay, the biggest freshwater lake of the Philippines. In this province, irrigated rice is mainly cultivated on comparably big fields along the river tributaries as well as on smaller terraced fields on mountain slopes. Mostly modern high-yielding varieties are grown during two cropping seasons per year. The area used for rice planting has clearly declined in the last decades due to real estate and industrial parks' development (Vergara et al., 2005). No natural forests exist anymore in the region but various fruit trees are prevailing in few spacious orchards and in hilly areas.

The second region (PH_2) is situated about 120 km north of Manila, in the Nueva Ecija province of Central Luzon. The relief is mostly plain and rice fields are located on the irrigated lowlands with a comparably high level of mechanisation. The average field size is 2-3 ha and normally two harvests per year are yielded. As in Laguna, mainly high yield hybrid varieties are planted, which often are accompanied by high inputs of pesticides and (mainly inorganic) fertilizers.

The third region (PH_3) is located near the municipality of Banaue in the Ifugao province, ca. 250 km north of Manila at an average altitude of 1000 m a.s.l.. The area is very mountainous and small rivers are used as natural irrigation sources for the characteristic rice terraces. Remnants of primary forests can only be found in higher elevations, whereas in most of the region secondary forests often with fast growing, non-native tree species occur. Most of the local people are farmers, many of them also working in the tourism industry. The rice terraces in the region are said to have been built more than 2000 years ago by the indigenous Ifugao people and since then have been used to cultivate traditional rice varieties (Settele and Martin, 1998). The special topographic and environmental conditions require a strict water management, strong cooperation and organization of community labour (Acabado, 2012).

Table 1 gives an overview of the seven regions' differences in land use intensities, landscape structural diversity and cultural identity (for a more detailed description see Settele et al., 2013).

## 2.2. Land use/land cover (LULC) classification

Altogether 14 relevant LULC types were initially identified in the seven study regions. These LULC types were used for the expert surveys (see Section 2.5). Table 2 gives an overview of the different LULC types and the ecosystem types included.

The remote sensing image interpretation was carried out after the interviews took place using SPOT5[2]-satellite images. These images were the base for the supervised LULC classification of the $15 \times 15\ km^2$ study regions with Erdas Imagine 2011[3] based on previously defined training areas (after Grescho, 2008). Additional refinements with eCognition (Definiens, version Developer XD) were done for the rice areas in the study regions PH_3, VN_3 and VN_4 to make sure that complicated surroundings do not distort the LULC classification. The satellite images are a blend of SPOT5 panchromatic and SPOT5 multispectral data with a ground resolution of $2.5 \times 2.5\ m^2$. The classification of specific vegetation types has been difficult and not always been possible. Therefore, some of the initially identified LULC types (which have been used for the expert interviews) had to be combined afterwards, resulting in ES maps based on fewer LULC classes. The results were different in the seven study regions. Table S1 (Supplementary material) gives an overview of the classified LULC types and corresponding LULC types as evaluated in the expert group evaluations. The general accuracy of the classification was rather high, which was proven by succeeding ground-truthing activities. Fig. 2 shows the LULC map for the Hai Duong region in Northern Vietnam (VN_1).

**Table 2**
Relevant land use/land cover classes and descriptions.

| No. | LULC type | Ecosystem types included |
|---|---|---|
| 1 | Water bodies | Lakes, rivers, and ponds. |
| 2 | Ancient forest | Old-growth forest (not reforested). |
| 3 | Forest | Principally trees, also shrubs, bushes and storey. |
| 4 | Meadow/grassland | Grass cover mainly for grazing. |
| 5 | Highly sealed surface | Houses and other buildings, streets, etc. |
| 6 | Low sealed surface | Unpaved roads, partially sealed surfaces, etc. |
| 7 | Fruit plantations | Fruit trees, banana plantations, coconut trees, etc. |
| 8 | Irrigated rice | Permanently irrigated rice fields. |
| 9 | Vegetable plantation | Potato, eggplant, pepper, pumpkin, etc. plantations. |
| 10 | Other agricultural land | Agricultural areas not covered by classes 7–9. |
| 11 | Leisure facilities | Parks, camping and sports ground, golf courses, etc. |
| 12 | Mineral extraction sites | Mines, and gravel pits. |
| 13 | Wetland | Bogs, and marshes. |
| 14 | Bare areas | Bare rock, sand, etc. |

## 2.3. Ecosystem structures, functions and services

In order not to 'overload' the interviews, altogether 10 items were selected to be assessed by the experts. *Biodiversity* was chosen to represent structural ecosystem features referring to the presence or absence of important species or the appearance of functional groups of species, including all living habitat

[2] http://www.astrium-geo.com/en/143-spot-satellite-imagery

[3] http://geospatial.intergraph.com/products/ERDASIMAGINE/ERDASIMAGINE/Details.aspx


**Fig. 1.** Location of the research regions in Vietnam and the Philippines.

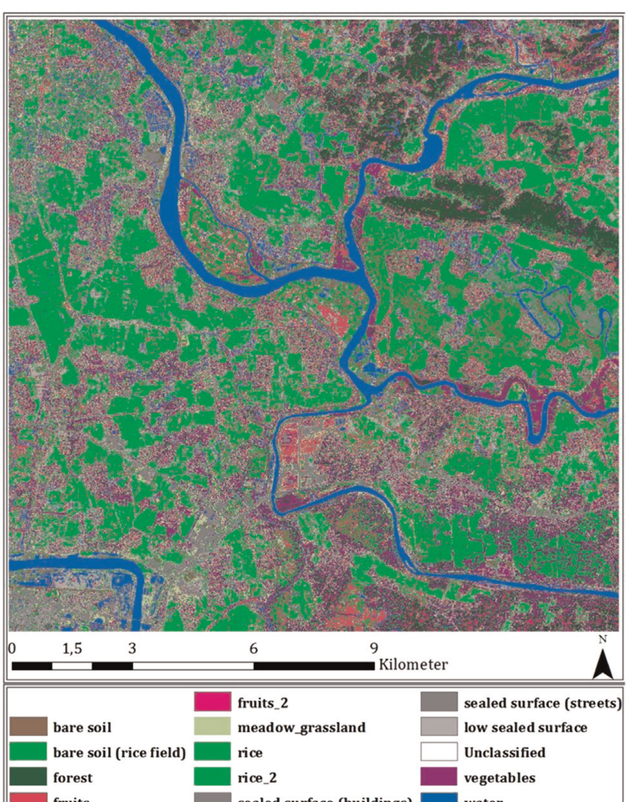


**Fig. 2.** LULC map of the Hai Duong region (VN_1). Classification based on SPOT5-satellite image taken on 22/10/2010.

components (after Burkhard et al., 2012b). *Primary production* has been selected as key ecosystem function as it is of fundamental importance to humans because net primary production (NPP) can directly be correlated to food provisioning ES. Thus, NPP is of high relevance for rice-production systems and agriculture in general, where the NPP of the prevailing human-modified agricultural systems (i.e. the Human Appropriation of Net Primary Production-HANPP) can exceed that of the potential natural vegetation (Haberl et al., 2012).

Regulating ES are highly relevant in agricultural landscapes as they are essential for balancing water, energy and nutrient budgets. In cases of unbalanced budgets, anthropogenic inputs like irrigation water, fertilizers or pesticides are used to modify natural ES potentials (Burkhard et al., 2014). Nutrient regulation, crop pollination and biocontrol of crop pests have been chosen to represent regulating ES in this study. *Nutrient regulation* has a high relevance in rice cropping systems for successful yields but also for the state of the surrounding environment (Power, 2010). The relevance of *crop pollination* in ecosystems has been highlighted frequently in the last years (Lautenbach et al., 2011). Many cultivated crops are dependent on pollination by bees, birds, bats, moths, flies, wind or non-flying animals (Kremen et al., 2007). Rice is actually wind-pollinated but pollinators are a good indicator for landscape structures and habitat quality. Moreover, pollination ESs are needed for other crops and fruits planted in the study regions. *Biocontrol of crop pests* is often disturbed in highly intensified agricultural systems, such as the intensively cultivated rice paddies in the Mekong Delta, by high pesticide uses (Normile, 2013). Ecosystems with high in- and output rates (such as rice paddies) are especially sensitive to any kinds of pests and diseases (Way and Heong, 1994). Nature-based solutions such as increasing the

**Table 3**
Assessed ecosystem features and services.

| Category | No. | Name | Definition |
|---|---|---|---|
| Ecosystem features | 1 | Biodiversity | The presence and absence of important species or the appearance of functional groups of species, including all living habitat components. |
| | 2 | Primary production | The capacity of ecosystems to build up biological material by plants through photosynthesis and nutrient assimilation. |
| Regulating services | 3 | Nutrient regulation | The capacity of an ecosystem to recycle nutrients. |
| | 4 | Crop pollination | The occurrence of bees, birds, bats, moths, flies, and also non-flying animals that contribute to the transfer of pollen. |
| | 5 | Biocontrol of crop pests | The capacity of an ecosystem to control pests and diseases due to genetic variations of plants and animals making them less disease prone and resistant to actions of predators and parasites. |
| Provisioning services | 6 | Crop production | The cultivation of edible plants and harvest of these plants that are used for human nutrition. |
| | 7 | Water provision | Used fresh water, e.g. for drinking, domestic use, industrial use or irrigation. |
| Cultural services | 8 | Recreation and tourism | Outdoor activities and tourism relating to the local environment or landscape, including forms of sports, leisure and outdoor pursuit. |
| | 9 | Cultural identity | The values that humans place on the maintenance of historically important (cultural) landscapes and forms of land use. |
| | 10 | Landscape aesthetics | The visual quality of the landscape/ecosystems or parts of them, which influence human wellbeing and the sense of beauty people obtain from looking at landscapes/ecosystems. |

**Table 4**
Participants of the expert group valuations.

| Region | No. | Profession | Region | No. | Profession |
|---|---|---|---|---|---|
| **VN_1: Hai Duong** | 20 | Public officer | **PH_1: Laguna** | 1 | Agricultural technician |
| | 21 | Public officer | | 2 | Agricultural technician |
| | 22 | Public officer | | 3 | Public officer |
| | 23 | Public officer | | 4 | Agricultural technician |
| **VN_2: Vinh Phuc** | 24 | Public officer | | 5 | Farmer |
| | 25 | Scientist | | 6 | Farmer |
| | 26 | Scientist | | 7 | Farmer |
| **VN_3: Lao Cai** | 27 | Public officer | | 8 | Farmer |
| | 28 | Public officer | | 9 | Farmer |
| | 29 | Public officer | | 10 | Farmer |
| | 30 | Public officer | **PH_2: Nueva Ecija** | 11 | Public officer |
| | 31 | Public officer | | 12 | Agricultural technician |
| | 32 | Public officer | | 13 | Agricultural technician |
| | 33 | Public officer | | 14 | Public officer |
| | 34 | Public officer | | 15 | Agricultural technician |
| **VN_4: Tien Giang** | 35 | Scientist | **PH_3: Ifugao** | 16 | Businessman |
| | 36 | Scientist | | 17 | Public officer |
| | 37 | Scientist | | 18 | Agricultural technician |
| | 38 | Public officer | | 19 | Public officer |
| | 39 | Agricultural engineer | | | |

richness of predator species can reduce the density of herbivorous pests (e.g. Cardinale et al. 2003; Settle et al., 1996; Matteson 2000).

Crop production and water provision were chosen to represent provisioning ES in this study. Both are of special relevance in rice cropping systems. *Crop production* is certainly the provisioning service that is most clearly observable, namely by crop yields. *Water provision* is of specific interest because rice production needs enormous amounts of water, leading to a global use of estimated 24–30% of the world′s developed freshwater resources (Bouman et al., 2007). The amount of available water has impacts on possible rice yields, but has also direct effects on regional human well-being (clean and sufficient drinking water supply).

Cultural ES have a specific relevance in rice-based agricultural systems. Besides being the major staple food, rice is a part of the people′s daily routine, influencing working life and cultural aspects of living (Greenland, 2006). Recreation and tourism, cultural identity and landscape aesthetics were selected to represent the broad range of cultural ES. Tourist abundance may be the most obvious component related to recreation but also short-term recreation of local people in nearby green spaces are included in this ES (Daniel et al., 2012). The cultural identity ES was used to describe the role of rice in local communities, its contribution to identity of land ownership and traditional forms of farming. Landscape aesthetics refer specifically to landscapes′ visual qualities. The benefit obtained is the sense of beauty people obtain from perceiving the landscape (Burkhard et al., 2012b) or the appreciation of natural scenery (De Groot et al., 2010). Service providing units (SPUs) can for example be specific (unique) landscape elements, a special land cover or water features. Table 3 gives an overview of the ecosystem structures, functions and services assessed in this study.

### 2.4. ES assessment matrix

To assess the capacities of the seven research regions to support the selected ecosystem features or to supply ESs, the ES 'matrix' approach (Burkhard et al., 2009, 2012b, 2014) was used. The approach has been applied in several case studies mainly on regional scales (Vihervaara et al. 2010; Nedkov and Burkhard 2012; Kroll et al., 2012; Baral et al., 2013; Sohel et al. 2015). Maes et al. (2011), Kienast et al. (2009) and Haines-Young et al. (2012) applied a similar approach on the European scale. The matrix links ecosystem features and services to LULC types abundant in the respective study region. The ecosystem features and services are plotted on the *x*-axis and the LULC types on the *y*-axis respectively. For the valuation process, a scale from 0 to 5 is used with numbers from 0 = no relevant capacity, 1 = very low relevant capacity, 2 = low relevant capacity, 3 = medium relevant capacity, 4 = high relevant capacity, to 5 = very high relevant capacity of the different LULC types to support a respective landscape feature or to supply a respective ES.

**a — Hai Duong**

| | LULC | Ecosystem features | 1 Biodiversity | 2 Primary production | Regulating services | 3 Nutrient regulation | 4 Crop pollination | 5 Biocontrol of crop pests | Provisioning services | 6 Crop production | 7 Water provision | Cultural services | 8 Recreation & tourism | 9 Landscape aesthetics | 10 Cultural identity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | water bodies | | 3,5 | 3,0 | | 3,3 | 3,0 | 2,0 | | 2,8 | 3,8 | | 3,8 | 3,5 | 3,5 |
| 2 | meadow/grassland | | 3,3 | 3,5 | | 3,8 | 3,8 | 3,7 | | 3,5 | 3,0 | | 3,3 | 3,3 | 3,3 |
| 3 | highly sealed surface | | 1,0 | 0,3 | | 0,5 | 0,8 | 1,5 | | 0,3 | 0,3 | | 2,8 | 1,8 | 1,8 |
| 4 | low sealed surface | | 1,8 | 1,3 | | 1,3 | 1,3 | 1,5 | | 0,8 | 0,8 | | 2,8 | 1,5 | 1,5 |
| 5 | fruit plantation | | 3,5 | 3,8 | | 3,5 | 4,8 | 2,8 | | 3,5 | 2,8 | | 3,0 | 3,0 | 3,8 |
| 6 | irrigated rice | | 3,5 | 4,0 | | 3,5 | 4,3 | 2,8 | | 3,5 | 3,0 | | 2,8 | 3,0 | 4,0 |
| 7 | vegetable plantation | | 3,5 | 3,8 | | 3,8 | 4,8 | 2,8 | | 3,8 | 2,8 | | 2,8 | 3,0 | 3,5 |
| 8 | other agricultural land | | 3,3 | 3,0 | | 3,3 | 4,3 | 2,8 | | 2,8 | 2,3 | | 3,5 | 3,3 | 3,3 |
| 9 | leisure facilities | | 1,8 | 1,0 | | 0,8 | 1,3 | 2,0 | | 0,5 | 0,8 | | 4,3 | 4,5 | 2,8 |
| 10 | mineral extraction | | 1,3 | 0,8 | | 0,3 | 1,3 | 2,3 | | 0,5 | 0,0 | | 3,3 | 2,8 | 1,8 |
| 11 | bare areas | | 1,5 | 1,3 | | 2,0 | 0,8 | 0,3 | | 0,5 | 0,8 | | 1,8 | 0,8 | 1,5 |

**b — Vinh Phuc**

| | LULC | Ecosystem features | 1 Biodiversity | 2 Primary prodcution | Regulating services | 3 Nutrient regulation | 4 Crop pollination | 5 Biocontrol of crop pests | Provisioning services | 6 Crop production | 7 Water provision | Cultural services | 8 Recreation & tourism | 9 Landscape aesthetics | 10 Cultural identity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | water bodies | | 3,7 | 3,7 | | 3,7 | 2,7 | 2,3 | | 2,3 | 4,3 | | 3,7 | 3,7 | 2,7 |
| 2 | ancient forest | | 4,0 | 3,7 | | 4,0 | 4,0 | 3,3 | | 2,7 | 4,7 | | 4,0 | 4,3 | 4,0 |
| 3 | forest | | 3,7 | 3,7 | | 4,0 | 3,3 | 3,3 | | 3,0 | 4,3 | | 4,0 | 4,0 | 2,3 |
| 4 | meadow/grassland | | 2,3 | 2,3 | | 3,3 | 2,7 | 3,0 | | 2,0 | 3,3 | | 2,3 | 3,0 | 2,0 |
| 5 | highly sealed surface | | 1,5 | 1,0 | | 1,7 | 1,0 | 2,7 | | 1,0 | 1,7 | | 4,0 | 2,3 | 1,7 |
| 6 | low sealed surface | | 2,0 | 2,0 | | 2,3 | 1,7 | 2,7 | | 1,3 | 2,3 | | 2,7 | 2,3 | 2,3 |
| 7 | fruit plantation | | 2,7 | 3,3 | | 4,3 | 4,0 | 3,7 | | 3,7 | 3,0 | | 3,0 | 3,3 | 2,3 |
| 8 | irrigated rice | | 3,7 | 3,3 | | 4,3 | 4,7 | 3,7 | | 4,3 | 3,3 | | 2,3 | 3,0 | 2,0 |
| 9 | vegetable plantation | | 3,7 | 3,3 | | 3,7 | 4,3 | 3,7 | | 3,7 | 3,0 | | 2,0 | 2,7 | 1,7 |
| 10 | other agricultural land | | 3,3 | 3,0 | | 3,7 | 3,3 | 3,3 | | 3,0 | 2,7 | | 2,3 | 2,7 | 2,0 |
| 11 | leisure facilities | | 2,3 | 2,0 | | 2,7 | 2,0 | 2,7 | | 1,7 | 2,0 | | 4,3 | 3,7 | 3,3 |
| 12 | mineral extraction | | 2,0 | 2,0 | | 2,0 | 1,3 | 1,7 | | 1,0 | 1,7 | | 2,7 | 1,7 | 1,3 |
| 13 | wetland | | 2,7 | 2,3 | | 3,0 | 2,3 | 2,0 | | 2,3 | 3,7 | | 2,3 | 1,7 | 2,0 |
| 14 | bare areas | | 1,3 | 1,7 | | 1,3 | 1,3 | 2,7 | | 1,3 | 1,7 | | 1,0 | 1,0 | 1,0 |

**c — Lao Cai**

| | LULC | Ecosystem features | 1 Biodiversity | 2 Primary prodcution | Regulating services | 3 Nutrient regulation | 4 Crop pollination | 5 Biocontrol of crop pests | Provisioning services | 6 Crop production | 7 Water provision | Cultural services | 8 Recreation & tourism | 9 Landscape aesthetics | 10 Cultural identity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | water bodies | | 4,0 | 4,0 | | 4,3 | 2,5 | 2,9 | | 3,8 | 4,4 | | 4,0 | 4,0 | 4,1 |
| 2 | ancient forest | | 5,0 | 4,9 | | 4,9 | 4,9 | 4,9 | | 4,8 | 4,9 | | 3,8 | 4,8 | 4,8 |
| 3 | forest | | 4,4 | 4,5 | | 4,5 | 4,8 | 4,5 | | 3,6 | 4,3 | | 3,6 | 4,0 | 4,1 |
| 5 | highly sealed surface | | 0,1 | 0,0 | | 0,1 | 0,1 | 0,0 | | 0,1 | 0,1 | | 1,6 | 0,6 | 0,5 |
| 6 | low sealed surface | | 0,4 | 0,4 | | 0,6 | 0,5 | 0,3 | | 0,1 | 0,1 | | 1,8 | 0,6 | 1,0 |
| 7 | fruit plantation | | 3,4 | 3,4 | | 3,3 | 4,4 | 2,4 | | 3,9 | 3,3 | | 3,1 | 3,1 | 3,4 |
| 8 | irrigated rice | | 3,3 | 3,5 | | 3,8 | 4,3 | 3,0 | | 4,7 | 3,4 | | 2,9 | 3,3 | 4,0 |
| 9 | vegetable plantation | | 3,1 | 3,5 | | 3,6 | 4,0 | 3,4 | | 4,7 | 3,1 | | 2,5 | 2,9 | 3,6 |
| 10 | other agricultural land | | 3,4 | 3,5 | | 3,5 | 3,6 | 3,0 | | 4,0 | 2,8 | | 2,3 | 3,1 | 3,8 |
| 11 | leisure facilities | | 1,1 | 1,1 | | 1,3 | 0,7 | 0,3 | | 0,6 | 0,5 | | 4,5 | 3,3 | 2,5 |
| 12 | mineral extraction | | 0,0 | 0,0 | | 0,3 | 0,1 | 0,1 | | 0,0 | 0,0 | | 1,3 | 1,3 | 0,4 |

**d — Tien Giang**

| | LULC | Ecosystem features | 1 Biodiversity | 2 Primary prodcution | Regulating services | 3 Nutrient regulation | 4 Crop pollination | 5 Biocontrol of crop pests | Provisioning services | 6 Crop production | 7 Water provision | Cultural services | 8 Recreation & tourism | 9 Landscape aesthetics | 10 Cultural identity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | water bodies | | 3,8 | 3,4 | | 2,7 | 0,0 | 2,7 | | 0,3 | 4,6 | | 4,0 | 4,4 | 4,0 |
| 2 | forest | | 4,4 | 4,8 | | 1,3 | 4,6 | 4,8 | | 3,2 | 2,4 | | 4,0 | 4,8 | 4,2 |
| 3 | highly sealed surfaces | | 2,0 | 1,3 | | 0,2 | 0,0 | 0,4 | | 0,0 | 0,0 | | 2,4 | 1,8 | 3,0 |
| 4 | low sealed surface | | 2,3 | 1,4 | | 0,2 | 0,0 | 0,0 | | 0,0 | 0,0 | | 1,8 | 1,4 | 2,0 |
| 5 | fruit plantation | | 3,6 | 4,4 | | 4,0 | 4,6 | 3,3 | | 4,6 | 3,6 | | 3,8 | 3,6 | 4,0 |
| 6 | irrigated rice | | 4,0 | 4,4 | | 4,2 | 4,2 | 3,6 | | 5,0 | 3,8 | | 3,0 | 3,6 | 3,6 |
| 7 | vegetable plantation | | 4,2 | 4,4 | | 3,8 | 4,0 | 3,4 | | 4,4 | 3,6 | | 2,8 | 3,4 | 3,6 |
| 8 | other agricultural land | | 3,4 | 4,0 | | 3,4 | 3,6 | 3,0 | | 4,2 | 3,2 | | 2,4 | 3,2 | 3,2 |

**Fig. 3.** Expert-based assessment results for the 4 study regions in Vietnam: a) Hai Duong (VN_1); b) Vinh Phuc (VN_2); c) Lao Cai (VN_3); and (d) Tien Giang (VN_4). The different LULC classes are listed on the *y*-axis, the ten ecosystem features and services on the *y*-axis of the matrix.

### 2.5. Expert surveys

Expert elucidation has become an accepted method in ES science as it deals with the urgency-uncertainty dilemma by securing best available knowledge (Jacobs et al., 2015). It is difficult or often even impossible to collect all data needed for complex ES assessments based on other data sources such as direct measurements, modelling or monitoring.

In this study, all ecosystem features, ES and LULC types described above were introduced to groups of local stakeholders in each of the seven regions to assess the study areas' capacities to support the selected ecosystem features or to supply the selected ES. One workshop per study region was organised. Local project partners chose the participants for the group valuations according to their expert knowledge about the respective regions. Most of the experts were employees of the local agricultural departments (see Table 4 for an overview of the expert groups′ compositions).

Before the actual valuation process started, the relevant LULC types were elaborately explained during an introductory part of the survey. Only when a clear understanding of the concept and all relevant information could be assumed among all participants (i.e. all related questions and comments were answered), the valuation was started. For this purpose, hand-outs for all participants were distributed including the (blank) ES matrix and the associated 0-5 rating scale as well as information about all LULC types in a summarised form. Then, each component was explained in detail, giving various examples to enable participants to connect the rather abstract concept and their daily routines. Afterwards, the participants were asked to rate the capacities of each LULC type on the scale from 0 to 5.

Participants could discuss amongst each other and had the opportunity to ask further questions in case the task was not clear. It was only proceeded with the next question when all participants had finished their valuation. This course of action was conducted until each participant had completed his or her matrix with all 110 (11 LULC x 10 ES) individual fields. When finished, the matrices were collected and scanned for significant discrepancies, for example deviations of more than 2 levels in the valuation of one particular LULC. If such were found, participants were asked to describe their arguments for the high or low rating. Table 4 gives an overview of all conducted interviews.

In a next step, the collected data were checked for plausibility. Potential outliers were excluded in order to minimise the risk of false data interpretation due to valuations that may have been made under wrong assumptions. There is always the possibility that expert interview participants misunderstand the concept or reject an honest or serious valuation (see discussion about uncertainties in Section 4). Outliers have been defined as following:

(1) For biodiversity: values $\geq 3$ for highly sealed surfaces and values $\geq 4$ for low sealed surfaces. It was assumed that in this case the concept of biodiversity has not been understood correctly, as it is obvious that on sealed surfaces biodiversity rarely exists.

**a** — Laguna

| | LULC | Ecosystem features | 1 Biodiversity | 2 Primary prodcution | Regulating services | 3 Nutrient regulation | 4 Crop pollination | 5 Biocontrol of crop pests | Provisioning services | 6 Crop production | 7 Water provision | Cultural services | 8 Recreation & tourism | 9 Landscape aesthetics | 10 Cultural identity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | water bodies | | 4,3 | 3,9 | | 3,7 | 2,4 | 2,9 | | 4,6 | 4,6 | | 3,1 | 2,9 | 3,5 |
| 2 | meadow/grassland | | 4,2 | 2,4 | | 3,9 | 3,4 | 2,8 | | 3,3 | 2,9 | | 2,9 | 3,1 | 2,6 |
| 3 | highly sealed surface | | 2,0 | 0,0 | | 1,3 | 1,2 | 1,6 | | 2,9 | 3,0 | | 3,2 | 3,3 | 2,7 |
| 4 | low sealed surface | | 2,6 | 2,2 | | 1,1 | 1,1 | 1,4 | | 1,3 | 2,9 | | 3,1 | 3,2 | 2,8 |
| 5 | fruit plantation | | 3,6 | 3,3 | | 4,1 | 4,2 | 3,1 | | 3,8 | 3,8 | | 3,4 | 3,2 | 2,9 |
| 6 | irrigated rice | | 3,8 | 3,7 | | 4,5 | 4,3 | 3,3 | | 4,4 | 4,4 | | 3,3 | 2,9 | 3,2 |
| 7 | vegetable plantation | | 3,2 | 3,4 | | 3,9 | 3,7 | 2,9 | | 3,8 | 3,9 | | 2,8 | 3,3 | 2,6 |
| 8 | other agricultural land | | 3,6 | 3,4 | | 3,5 | 3,0 | 3,1 | | 3,3 | 3,3 | | 3,1 | 2,9 | 2,6 |
| 9 | leisure facilities | | 2,7 | 1,9 | | 1,7 | 1,3 | 1,4 | | 1,0 | 2,9 | | 3,5 | 3,2 | 2,9 |

**b** — Nueva Ecija

| | LULC | Ecosystem features | 1 Biodiversity | 2 Primary prodcution | Regulating services | 3 Nutrient regulation | 4 Crop pollination | 5 Biocontrol of crop pests | Provisioning services | 6 Crop production | 7 Water provision | Cultural services | 8 Recreation & tourism | 9 Landscape aesthetics | 10 Cultural identity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | water bodies | | 3,0 | 3,2 | | 0,6 | 1,2 | 1,4 | | 1,8 | 3,0 | | 3,4 | 3,8 | 3,0 |
| 2 | meadow/grassland | | 1,0 | 1,8 | | 2,2 | 1,8 | 0,4 | | 1,2 | 0,8 | | 2,4 | 3,6 | 2,8 |
| 3 | highly sealed surface | | 0,2 | 0,0 | | 0,0 | 0,0 | 0,0 | | 0,0 | 0,0 | | 1,8 | 2,4 | 0,2 |
| 4 | low sealed surface | | 1,0 | 0,4 | | 0,2 | 0,4 | 0,0 | | 0,4 | 0,0 | | 2,2 | 1,8 | 1,2 |
| 5 | fruit plantation | | 2,8 | 3,0 | | 3,2 | 3,6 | 2,2 | | 4,2 | 1,8 | | 2,8 | 4,4 | 2,8 |
| 6 | irrigated rice | | 4,0 | 4,4 | | 3,8 | 3,4 | 1,8 | | 5,0 | 2,8 | | 2,6 | 4,6 | 2,6 |
| 7 | vegetable plantation | | 2,0 | 3,0 | | 3,8 | 2,3 | 2,8 | | 4,8 | 2,2 | | 3,0 | 4,6 | 2,6 |
| 8 | other agricultural land | | 2,2 | 2,6 | | 2,6 | 2,6 | 2,5 | | 3,4 | 1,8 | | 3,0 | 4,4 | 2,4 |
| 9 | leisure facilities | | 1,2 | 0,6 | | 0,2 | 1,0 | 0,4 | | 0,0 | 0,6 | | 4,0 | 4,2 | 1,2 |
| 10 | mineral extraction | | 1,2 | 0,6 | | 0,2 | 0,2 | 0,0 | | 0,0 | 1,0 | | 1,8 | 3,2 | 1,4 |

**c** — Ifugao

| | LULC | Ecosystem features | 1 Biodiversity | 2 Primary prodcution | Provisioning services | 3 Nutrient regulation | 4 Crop pollination | 5 Biocontrol of crop pests | Provisioning services | 6 Crop production | 7 Water provision | Cultural services | 8 Recreation & tourism | 9 Landscape aesthetics | 10 Cultural identity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | water bodies | | 3,0 | 1,8 | | 2,5 | 2,5 | 2,8 | | 2,8 | 4,0 | | 2,5 | 2,3 | 2,8 |
| 2 | ancient forest | | 4,3 | 4,0 | | 3,7 | 4,7 | 4,3 | | 2,3 | 4,3 | | 3,3 | 3,3 | 2,8 |
| 3 | forest | | 3,5 | 3,8 | | 4,3 | 4,8 | 4,0 | | 4,0 | 4,8 | | 3,5 | 4,0 | 4,0 |
| 4 | highly sealed surfaces | | 1,3 | 0,3 | | 0,0 | 0,3 | 0,5 | | 0,3 | 0,3 | | 2,5 | 2,8 | 2,3 |
| 5 | low sealed surfaces | | 2,0 | 1,0 | | 0,5 | 0,5 | 0,5 | | 0,5 | 0,0 | | 1,5 | 1,3 | 1,8 |
| 6 | irrigated rice | | 4,3 | 3,5 | | 3,8 | 4,0 | 3,8 | | 4,5 | 3,3 | | 4,5 | 4,0 | 4,5 |
| 7 | vegetable plantation | | 3,8 | 3,5 | | 4,0 | 4,3 | 3,8 | | 4,3 | 2,5 | | 3,5 | 3,3 | 3,5 |
| 8 | other agricultural land | | 3,0 | 3,7 | | 3,7 | 3,7 | 3,3 | | 4,0 | 3,0 | | 2,7 | 3,3 | 3,7 |
| 9 | bare areas | | 1,8 | 1,3 | | 0,3 | 2,0 | 2,7 | | 1,3 | 0,5 | | 1,8 | 1,3 | 1,3 |

**Fig. 4.** Expert-based assessment results for the 3 study regions in the Philippines: (a) Laguna (PH_1); (b) Nueva Ecija (PH_2); and (c) Ifugao (PH_3).

(2) Primary production: values ≥ 2 on highly sealed surfaces and values ≥ 3 on low sealed surfaces. It is obvious that primary production is very low on sealed surfaces.
(3) Provisioning and regulating ES: it has been assumed that the values may show a relatively wide spectrum as all participants have different knowledge of the sites. Only values diverging more than two levels from the arithmetic mean were defined as outliers. It was assumed that the average values are close to the real situations in the regions.

These assumptions led to the exclusion of 117 outliers out of 4290 totally collected values. In the following, the standard

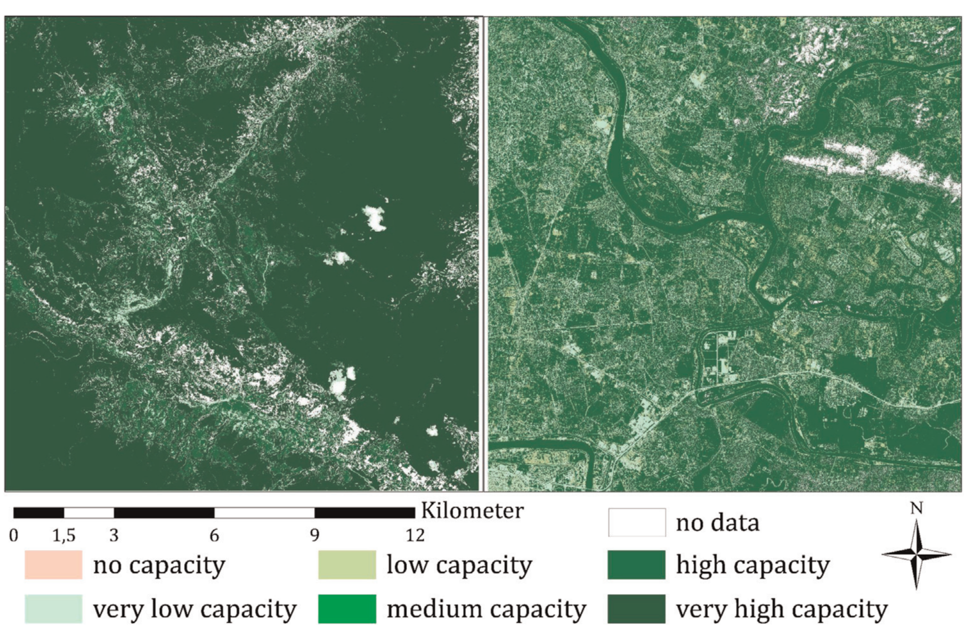


**Fig. 5.** Ecosystem service supply capacities for nutrient regulation in Lao Cai (VN_3, left) and Hai Duong (VN_1, right).

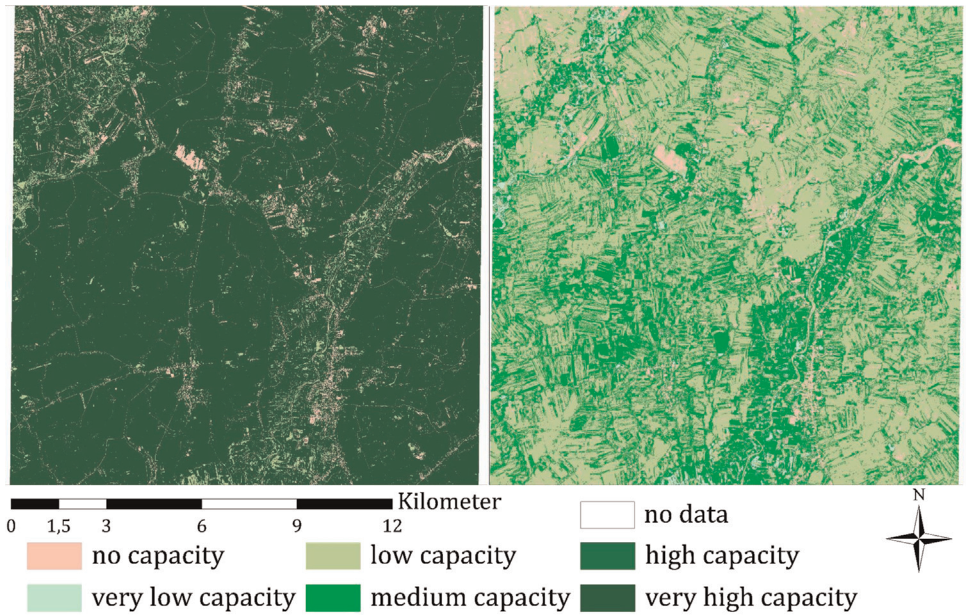


**Fig. 6.** Ecosystem service supply capacities for crop production (left) and biocontrol of crop pests (right) in Nueva Ecija (PH_2).

deviation of the remaining values for each region has been calculated to get an overview of the bandwidth and representativeness of the collected data (see example Fig. S1 in the Supplementary material).

### 2.6. Further data sources

The expert-based data collected at the sites were compared with information from literature, internet searches, statistical sources and LEGATO project field and modelling data. For example, the highly specialised libraries and project databases at the International Rice Research Institutes IRRI[4] and PhilRice[5] were explored. Additional *ad hoc* background interviews have been carried out at all sites in order to get a better overview of current issues and developments in the seven regions.

### 2.7. ES map compilation

The expert survey data were used to compile maps showing the capacities of each region to support the selected ecosystem features and supply ES in a spatially explicit manner. The LULC maps derived from the satellite image classifications were linked with the ES matrix values using ArcGIS 10[6] software. The different LULC types were used as common identifier fields in the respective attribute.

## 3. Results

Fig. 3 shows the average values in the matrices of the four regions in Vietnam as assessed by the participants of the group interviews. The results for the Hai Duong and the Vinh Phuc regions show that very high capacities were assigned to the regulating ES *crop pollination* in the agricultural LULC types. *Nutrient regulation* was assessed with generally high values. *Water provision* received high values in Vinh Phuc in water bodies, ancient forests and forests. For irrigated rice, very high capacities to supply *crop production* ES were assessed. Ancient forests received very high values for *landscape aesthetics*. Sealed surfaces (highly and low sealed) as well as mineral extraction sites received very low respectively no capacities. Forest and especially ancient forests in Lao Cai stand out with very high capacities for almost all ES. Also water bodies have been assessed with high to very high capacities to supply almost all ES, despite *crop pollination* and *biocontrol of crop pests*. For Tien Giang, the matrix shows a comparable pattern except for the high values for *crop production* on agricultural LULC types.

Fig. 4 gives an overview of the results for the study regions in the Philippines. In Laguna, very high capacities to supply *nutrient regulation* and *crop pollination* have been assessed for fruit plantations and irrigated rice systems. Concerning provisioning services, this was the case for water bodies and irrigated rice systems. *Biodiversity* was rated highest for water bodies and meadow/grassland. *Landscape aesthetics* and *crop production* were ranked highest on the agricultural LULC types in Nueva Ecija whereas highly sealed surfaces were assigned zero capacities for all regulating and provisioning services as well as for *primary production*. In Ifugao, lowest values were assigned to sealed surfaces, whereas high respectively very high capacities for nearly all ES were assessed for forests and ancient forests. Concerning the agricultural LULC types, irrigated rice was evaluated with altogether high or very high capacities.

The following maps (Figs. 5, 6 and S2 in the Supplementary material) exemplarily visualise the information from the ES matrices (Figs. 3 and 4). The maps give impression about the spatial distribution of ecosystem features and ES supply and enable the identification of service providing units (SPUs) in the seven regions. Fig. 5 shows the *nutrient regulation* ES capacities in the Hai Duong and Lao Cai regions. The clearly visible light green spots represent sealed surfaces, which were evaluated with very low (highly sealed) to low (low sealed) supply capacities. The map of Lao Cai shows very high capacities for *nutrient regulation* in the spacious forest areas.

Fig. 6 shows the ES supply capacity maps for *crop production* and *biocontrol of crop pests* in the Nueva Ecija province. In the large agriculturally cultivated areas, the supply capacities for *crop production* were evaluated to be very high whereas for *biocontrol of crop pests*, low to medium values were given. Further map

[4] http://irri.org/
[5] http://www.philrice.gov.ph/
[6] http://esri.de/products/arcgis/

examples showing results for *cultural identity* in Vinh Phuc and Lao Cai can be found in Fig. S2 (Supplementary material).

## 4. Discussion

The maps show interesting patterns of ES supply in the seven study regions. Most of the results turned out to be as anticipated, such as high capacities of forests to supply multiple ES, no relevant capacities on sealed surfaces and in mineral extraction sites or high capacities for crop production in the agricultural areas. The highest ES values for forests were assessed in the more extensively managed regions. Various publications (e.g. Foley et al., 2007; Guo et al., 2001; Bond et al., 2009) confirm this high relevance of forests for multiple ES supply. Forests in hilly areas have particular high relevance for regulating ES (e.g. Laclau et al., 2008; Lara et al., 2009).

Other results were indeed more remarkable, for example the comparison of regions with different production intensities. At the more intensively cultivated regions like Nueva Ecija and Hai Duong, the forest LULC types are missing almost completely. This leads to comparably low supply capacities for regulating ES, for which forest ecosystems play a decisive role. Biodiversity in Tien Giang seems to be relatively high despite its intensive agriculture. Capacities for nutrient regulation were assessed to be low to medium here; only the rice fields themselves show very high capacities. The results for various other ES show high values in Tien Giang, which was somehow unexpected. In Vinh Phuc, most of the area has been evaluated with high to very high supply capacities for nutrient regulation. In this region, a large forest cover still exists. In Vietnam, but also in the Philippines, reforestation efforts are already made (Chi et al., 2013). This has a clear potential to increase the supply of several ESs, especially if native species are planted instead of exotic species (like presently eucalyptus or pine; McElwee, 2009).

In general, clear trade-offs between increased crop production and other ES become obvious when comparing the more intensively cultivated rice cropping regions like Hai Duong and Nueva Ecija with more traditional ones like Ifugao and Lao Cai. In both Hai Duong and Nueva Ecija, crop pollination and crop production in the agricultural LULC types were (with the exception of landscape aesthetics in the Nueva Ecija region) the only ESs that have been assessed with very high capacities whereas in Ifugao and Lao Cai various ESs have been assessed with high to very high values. The interview results from the other five regions are consistent with various studies that intensification in agriculture in most cases is only possible at the expenses of ecosystem functioning and the supply of other, not agricultural production-related ES (Power, 2010; Matson et al., 1997).

Cultural ESs have, as expected, a high significance especially at the extensively cultivated regions of Ifugao and Lao Cai, where most of the rice fields are cultivated in a traditional manner. At least in the Ifugao region, cultural aspects of agriculture have a high relevance (Acabado, 2012). Additionally, high capacities for tourism and recreation have been expected due to the rice terraces that are the reason for a growing number of visitors travelling to those regions every year (Hoa et al., 2009; UNESCO, 2008). This was confirmed by the valuation of the Ifugao region but not for the Lao Cai region. Regarding the capacities of irrigated rice systems for recreation and tourism, the latter showed only medium values. This indicates that the interviewed local experts in Lao Cai may not (yet) fully recognise the potential of the unique traditional rice cultivation systems for tourism.

### 4.1. Uncertainties

One major challenge of all complex integrative landscape analyses is the high level of uncertainty related to limited system knowledge, methodological, modelling and technical issues as well as stochastic and non-linear system dynamics (Hou et al., 2013). ES assessments are hereby especially prone to uncertainty and generalisation issues. ESs deal with very high complexities and have an integrating role between environmental and human systems (Scolozzi et al., 2012), different valuation methods and preference settings. In this study, key uncertainties were related to the spatial data base (the LULC map), data collected from the expert group valuations and the normalisation of data to the 0-5 scale.

During the LULC classification based on remote sensing data, the complex diversity of the landscapes had to be reduced to few classes based on technical feasibility, resulting in generalisation and information. Moreover, there is the issue of omission or ignorance reflecting deviations of a landscape with respect to the class to which it was assigned (Bolliger and Mladenoff, 2005; Zhu, 1997). For example, it cannot be assumed that every forest in the forest LULC classes (and within that forest all areas) has the same capacity to supply ES. Although the SPOT satellite images have a relatively high resolution, not all complexities of the ecosystems can be pictured in the resulting maps. One way to encounter local differences in LULC classes and their ES supply capacities could be to include a weighting procedure into the valuation (like in Haines-Young et al., 2012). This procedure could on the one hand lead to a more appropriate accounting of different components and their relevance (Burkhard et al., 2009). On the other hand, advantages of rather simple and rapid ES assessments would get lost (Jacobs et al., 2015). Additionally, clouds shadowing some areas in the satellite image or shadows on slopes make classification difficult, especially in the mountainous regions of Lao Cai and Ifugao.

Expert group valuations were the major data source in this study. This may present a main source of uncertainty. One parameter that might have led to unexpected results was the language barrier and resulting misunderstandings. As the presentation and valuation have been conducted in English, translation was needed for those participants that were not familiar with this language. Due to many specific technical terms which do not have any equivalent in Vietnamese and/or local languages, it could not always be ensured that all information provided has been translated appropriately.

Another relevant aspect in this kind of valuing assessments is related to the concept of *procedural rationality*. The term concerns the rationality of the procedure that is used to reach a decision (Muthoo, 1999) and has first been introduced by H.A. Simon (CMAA, 1999), who said that judging a certain behaviour as reasonable would only be possible when taking into account the context in which that behaviour has been observed. This would include “the situation in which the behaviour takes place, the goals it is aimed at realizing, and the computational means available for determining how the goals can be attained” (Simon, 1986: p. 210). This definition is consistent with Dean and Sharfman’s (1993) understanding of procedural rationality which they define as “the extent to which the decision process involves the collection of information relevant to the decision and the reliance upon analysis of this information in making the choice” (p. 1071). Escalada and Heong (2009) connected this concept with the problem of intensive pesticide application and the associated damages to rice ecosystems. They state that decision makers do not have to bear responsibility for decisions that followed procedural rationality because these decisions have been expected in that way by their supervisor. Decision-makers prefer to stick to guidelines and also would use the opportunity to further his or her personal gains. This would explain why, despite several new developments in research, extension and training, no significant changes have been made in pest management structures, procedures and practices in Asia for 40 years. Adopting the procedural and political rationality strategies would be safer, imply better career opportunities and give the prospect of other benefits.

With respect to this study and especially regarding the valuation results from Vietnam, this concept may explain the very rare assignment of the value 0 (which means "no relevant capacity") in all assessments. Perhaps participants did not want to evaluate "their" regions with low capacities as this might have implicated a low appreciation and might reduce the "value" of the region. This phenomenon could be observed especially in expert group valuations with one or more hierarchically very highly ranked participant. The subordinate participants were not willing to argue about any valuation the higher ranked participant had already expressed. This influence of mentality as well as the relevance of hierarchical structures and their assumed influence on valuations seem to be major sources of uncertainty in the assessments. Additionally, subjective preferences of certain LULC types are expected to have had an influence in the assessment results that should not be neglected.

The number and selection of experts for the evaluation as well as the rather low degree of reproducibility are crucial sources of uncertainty in expert valuations (Hou et al., 2013). However, when surveying highly complex and abstract contexts such as ES supply by LULC types, the actual number of samples or respondents is less relevant than it may be in natural or social sciences otherwise (Jacobs et al., 2015). Therefore, the main criterion for the participation in the group valuations was a distinctive knowledge of the respective region, comparable background and willingness to join the exercise. In practice, most of the groups were composed of government employees from the fields of agriculture or environment with comparable levels of education and professional backgrounds. However, in some cases this demand could not be satisfied. Despite different compositions of the groups, their different professions might have had further influence on the valuation outcomes. The same applies to observed disparities in the commitment of participants. This factor of *preference uncertainty*, i.e. the subjective decisions of the participants as well as the discrepancies resulting from different levels of knowledge and experience (Kumar et al., 2010), is assumed to have a relevant influence on the comparability of valuation results.

Finally, impacts of the normalisation to the 0-5 scale and the suitability of mean values should be considered. Altogether, 39 participants have evaluated the capacities of the different LULC types in the respective region. The group size varied between 3 and 11 participants (see Section 2.5). Only in one case, the evaluation was conducted with only the desired minimum number of three participants (of which two have been familiar with the ES concept before). Nevertheless, the group sizes have been rather small, which is why the 0–5 values have been combined with qualitative information collected during on-site background interviews. In general, the achieved results proved to be very useful to deliver a first overview of the study regions, their ecosystem features and ES supply.

## 5. Conclusions

This study demonstrates the high application potential of the ES matrix method and serves as a screening study and starting point for ES assessments in the further course of the LEGATO project. It was demonstrated that multiple ES are supplied in the seven landscapes with their specific LULC patterns. Forests showed high capacities for many different ESs, agricultural areas are more specialised SPUs for crop production. These differences and related ES trade-offs became especially obvious when comparing areas with more traditional rice cultivation to those with intensive agriculture. It was shown, how local stakeholders can be integrated in landscape assessments, and the matrices/maps offer opportunities to integrate data from future assessments and different research areas. There is of course potential to increase the representativeness, reliability, accuracy and transferability of the results. Delphi approaches could help to receive better-structured answers from the experts and to increase the reliability of the results. A comparison of the survey results with quantitative data from field measurements, modelling and in-depth interviews will further increase the usability of the assessment.

The information content of the ES supply maps could certainly be increased by the integration of further data. Furthermore, the utilisation of concrete indicators and their appropriate quantification would enable a more precise assessment and help to consolidate the information that has been collected within this study. The LULC classification was for example not able to distinguish between low and high cropping intensities in the rice field areas, which would be highly relevant for related ES supply. A combination with further biophysical data in 'tiered approaches' (Grêt-Regamey et al., 2015) has been proven to reduce uncertainties of spatial ES assessments (Schulp et al., 2014). Enhancing the number of interviewed experts as well as a more-targeted selection of them could help improving the validity of the ES matrix values. This would require considerably higher time and logistical efforts. Issues about the influence of local cultural aspects on ES evaluations should be considered in future ES assessments based on interviews, focus group discussions or expert group valuations. Different value systems – regardless if concerning ethical, economic or emotional arguments, or concerning different ecological or societal demands and lifestyles - pose a challenge to scientists in finding more generally accepted approaches of ES valuation. Experiences from this study should be considered an example that shows the potential and limitations of expert-based ES mapping.

Due to the increasing number of pressures affecting the natural environment not only in developing and emerging countries, ESs are part of a growing sector in transdisciplinary research. This sector needs to integrate knowledge and methods from different disciplines including environmental, social and economic sciences as well as local people's knowledge (Braat and de Groot 2012). Encountering the challenges of population growth and increasing food demand entails further adaptations of agriculture. Additionally, it will involve an increase in agriculturally cultivated area by land conversion, which poses a major threat to the planet's biological diversity by destroying or degrading habitats. In order to ensure food security also for future generations, this development has to proceed in a sustainable manner. Spatially explicit ES assessments are a promising approach to encounter this challenge by communicating the value of functioning ecosystems and related ES supply to decision makers.

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[7] http://nachhaltiges-landmanagement.de/en/

## Appendix A. Supplementary information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/%2010.1016/j.ecoser.2015.05.005.

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