Assessment of resilience and adaptability of social-ecological systems: a case study of the Banaue rice terraces

Master Thesis

In Partial Fulfillment of the Requirements for the Degree
Master of Science
Environmental Management

By
Adam Charette-Castonguay

First Reviewer: PD Dr. habil. Benjamin Burkhard

Second Reviewer: Prof. Dr. Felix Müller

February 2014

Institute for Natural Resource Conservation
Faculty of Agricultural and Nutritional Sciences
Christian-Albrechts Universität zu Kiel

Abstract

The rice terraces of the province of Ifugao, Philippines have been cultivated for several centuries. Over this period of time, the ecological system has been strongly influenced by the indigenous Ifugao people cultivating the rice fields. The culture and social habits of the inhabitants have developed deep ties with the rice terraces. Thus, the two systems have become strongly interrelated and interdependent. The processes and structures in this unique system have evolved for centuries to produce an abundance of ecosystem services and benefits in one of the most impoverished regions of the Philippines. In addition to rice production, the system provides several regulating and cultural ecosystem services, such as erosion and flood control, recreational and educational opportunities, as well as a formidable landscape scenery that has strongly contributed to the expansion of tourism in the region.

However, these terraces are at present under increasing pressure. On the environmental side, climate change, invasive alien species and erosion pose the greatest threats to the continuity of the system. Concerning the human-induced pressures, land abandonment and urban migration, application of pesticides and unmanaged tourism are susceptible to further damage the human-environmental system and exacerbate other problems such as erosion.

This research aims at assessing the long-term development of ecosystem services and the adaptive capacity of a rice-based cultural landscape. Taking the different pressures into consideration, the thesis defines a suitable and relevant set of indicators describing the ecological and socioeconomic state of the system. The resilience of the rice terraces and the community living off them is assessed by comparing the result of these indicators with descriptions of the area in the previous literature. The premise of this assessment is that ecosystems are developing through time to a point where the necessary energy for the maintenance of the complexity of the system becomes untenable. Moreover, as linked human-environment systems grow in complexity, they become more vulnerable and susceptible to reorganization on long term through adaptive cycles. Finally, considering the resilience of the system, management options to enhance the adaptive capacity and improve the livelihood of the indigenous people of Ifugao are presented.

Keywords: Resilience, Adaptive capacity, Ecosystem services, Ifugao, Social-ecological systems.

Acknowledgements

I would like to thank my supervisors Benjamin Burkhard and Felix Müller for allowing me in the LEGATO Project, as well as for their inspired teaching on social-ecological systems, ecosystem services and resilience. I am greatly indebted to the Advisory Service on Agricultural Research for Development (Beratungsgruppe Entwicklungsorientierte Agrarforschung, BEAF) program of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) for the financial support that made this thesis project possible. I sincerely hope that this thesis can contribute to the development objectives of GIZ. I also thank the Crop and Environmental Sciences Division of the International Rice Research Institute for hosting me at the Institute.

Special thanks go to Ms. Laeticia Palayon from Bangaan, and Mr. Alfredo Bunnol and Mr. Marcos Mulao from Poitan, who took time to explain me in detail the customs and history of their town and helped me with interpretation and translation during the interviews. Of course, I also thank more generally the inhabitants of the municipality of Banaue, notably for their hospitality, who see their environment change at a very fast pace and who have to deal with several challenges.

Finaly, I am grateful to Robin for his suggestions, to Ting for her inspiration and to my family for their support at each stage of thesis process. I thank you all a lot.

Table of Contents

Table of Figures

List of Tables

1. Introduction

The rice terraces of the Ifugao province in North Luzon, Philippines have long been regarded and praised as a model of sustainability and durability (Conklin, 1967a; UNESCO, 1995, 1996; Araral, 2013). The communities have maintained an ecologically viable integration of natural and human-created systems. The province, with its ecosystems and the indigenous people living off them, is the pride of the Filipino people and the Banaue rice terraces are nationally considered as the “eighth wonder of the world” (Dizon et al., 2012). Moreover, parts of the rice terraces in Ifugao were included in the UNESCO World Heritage List (UNESCO, 2006), as well as one of the few Globally Important Agricultural Heritage Sites identified by the Food and Agriculture Organisation (GIAHS; Koohafkan and Jane, 2011).

However, plenty of challenges face the Ifugao rice terraces system, challenges most common to communities experiencing the transition from subsistence agriculture to market economy and modern intensive agriculture (Tvedten, 1990; Wilson, 2010). The communities and ecosystems in the region have been under different pressures as the country is rapidly developing, and one could wonder whether the “eighth wonder” will remain a wonder in the decades to come, or shift to an alternative state with new social and ecological structures. Considering the fast changes caused by this transition, as well as climate change, the aim of this master’s thesis is to assess the long-term development of the rice terraces of Banaue. Similar assessments have been conducted in the past using biophysical, social and climate models from long-term datasets (Brenkert and Malone, 2005; Burkhard et al., 2011a). This time, due to the unavailability of such datasets for this particular region, the project applies the theories of resilience and social-ecological dynamics using an indicator-based survey.

1.1. Objectives of the research

The objective of the study is to investigate long-term development of the social-ecological system of the Banaue rice terraces in the province of Ifugao, Philippines. The development is not a natural one in the sense of natural succession of undisturbed ecological system. It is rather a co-development of social communities and ecosystems (mostly rice terraces, forests and swidden fields), evolving through limitations and stresses over a long period of time. Several different disturbances have been mentioned in the last decades in the literature concerning the province of Ifugao. Some of the perturbations are site-specific (e.g. tourism in the town of Batad; SITMo, 2008) and discrete in time (e.g. earthquake; Kwiatkowski, 2013), other being continuous (e.g. establishment of exotic pest species; Joshi et al., 2000). These stresses and shocks should be studied individually to assess their specific impacts.

Taking the current status of these pressures into consideration, as well as social and ecological parameters, the study investigates the level of vulnerability, resilience and the adaptive capacity of the rice terraces system of Banaue with the use of indicators. The purpose of assessing resilience is to identify vulnerabilities in social-ecological systems so that action can be taken to create a more sustainable future for people and the land (Berkes et al., 2003). In the specific case of agroecosystems, building resilience gives a system the capacity to maintain its functions, for example the ability to feed and clothe people, in the face of shocks while building the natural capital based upon which they depend and providing a livelihood for the people who make it function (Cabell and Oelofse, 2012). Albeit somewhat theoretical and potentially subjective, the resilience assessment of cultural landscapes is becoming more studied, especially as drivers of change are increasing around the world (Scheffer et al., 2001; Folke et al., 2002, 2004; Rockström et al., 2009). Management options need to be identified to improve the ability of the communities to adapt to current and future pressures, in order to maintain and improve livelihood. With these objectives in mind, three research questions are being investigated in this study:

1- Is the system becoming more vulnerable, resilient or "adapted" as it develops?
2- What is the impact of the development of the system on ecosystem services and benefits?
3- Considering the different disturbances on the area, what management options may be applicable to conserve benefits from ecosystems while improving the communities' livelihood?

As pressures on the system are increasing, it is hypothesized that the traditional system is becoming more difficult to maintain, i.e. vulnerable, and that resilience is declining. Also, the changes in the system may have reduced the links between the ecosystems and the inhabitants of the region, the latter moving away from farming activities to favor paid labor.

The results of this thesis identify possible management options which could be replicated in other areas with comparable social-ecological systems (SES) and similar issues, such as the Hani rice terraces in Yunnan, China, Herath et al., 2013) and the terraces of Tana Toraja in Sulawesi, Indonesia (Adams, 1995). Rice terraces are typically limited in their productivity because of their higher altitude resulting in a cooler climate and less sunshine than on the lowland farms. Southeast Asia is a part of the world with fast growing economies and populations, and as working opportunities in the cities are increasing, rice farming might become less appealing (Jong et al., 1986; Luis and Paris, 2003). Despite the importance of rice production in the region, low productivity and cash crops may lead to a significant reduction of terrace-based rice production in East-Asia, as it was the case in Malaysia (Othman, 1992; Kato, 1994) and Japan (Qiu et al., 2013) in the last decades. Thus, research and policy options are needed to conserve traditional and sustainable production of rice, the ecosystem benefits and the livelihood of the Ifugao people.

1.2. Significance of the study

This thesis examines potential alternative states of rice terracing. While abandonment of terrace farming has been studied in some specific regions of the world, for instance in the Alps (Walther, 1986), the Mediterranean countries (Douglas et al., 1994; Lesschen et al., 2008; Bevan and Conolly, 2011), and the Middle-East (Vogel, 1988; Hammad and Børresen, 2006) alternative states of rice terraces is rather unknown. Differences between resilience and adaptability in the context of rice terraces will be analyzed. The resilience of social-ecological systems is a concept gaining in popularity in the literature, but which is difficult to measure due to its complexity. A cooperation between the Convention on Biological Diversity, Biodiversity International and the Institute of Advanced Studies (IAS) of the United Nations University in Japan has resulted in the development of indicators to assess resilience of agroecological systems in some regions of the world under the the Satoyama Initiative (Bergamini et al., 2013). This present study, focused on a rice-based agroecosystem, will contribute to such endeavor. These indicators and the methods used could be further improved in future assessments.

1.3. Overview of the thesis

The thesis is divided in six sections. Following the introduction, an overview of noteworthy considerations and properties of agroecosystems, including the major attributes of social-ecological systems such as disturbances, vulnerability, resilience, adaptability and adaptive cycles, outlines the analytical background of the study. Indicators of resilience are then identified and described (Chapter 2). In the next section, the study area is presented, with an emphasis on ecological and social organizations, and the modern pressures on the system. The methods used for this research are then presented, with a focus on the household survey used to evaluate proxies of resilience (Chapter 3). Then, the data are compiled, organized and analyzed to give a value to each indicator in order to assess the resilience and the degree of adaptability of the three areas surveyed (Chapter 4). Thereafter, elements related to resilience are discussed, notably concerning the possible future trajectories of the system, the change and trade-offs between the ecosystem services and policy options that could improve the adaptability of the region to pressures (Chapter 5). Finally, the thesis concludes with key findings that could be drawn from this research (Chapter 6).

2. Conceptual framework

This chapter covers the theoretical background of the study concerning the dynamics of long-term development of social-ecological systems. Resilience is an important concept but several other notions need to be taken into consideration to understand the development of human-environment systems, such as disturbances, vulnerability, adaptive capacity and adaptive cycles. After reviewing these concepts, eight indicators used as proxies to determine de level of social and ecological resilience are be described.

2.1. Rice-based agroecosystems as social-ecological systems

A social-ecological system can be defined as a linked system of people and nature in which people depend on nature and nature is influenced by people (Berkes et al., 2003). Social-ecological systems can be studied at different scales, e.g. national or earth scale (Rockström et al., 2009; Liu et al., 2013), but due to the high connections at the local level in Ifugao and comparably low connections with the rest of the Philippines and the world, the social-ecological system is analyzed in this study at a community scale.

Traditional agroecosystems are typical examples of highly connected social-ecological systems. Agroecosystems can be defined as ecological and socioeconomic systems comprising domesticated plants and/or animals and the people who husband them (Di Falco and Chavas, 2008). They are intended for the purpose of producing food, fiber, and other agricultural products, and often produce cultural ecosystem services as an emerging property. Ecological systems are therefore transformed and simplified for the purpose of agriculture. For this reason, ecosystems must be maintained at a certain stage of development, maintenance that requires energy and resources.

The Millennium Ecosystem Assessment mentions agriculture as one of the main drivers behind the degradation and depletion of ecosystem services (MA, 2005). Agricultural systems are seen as a major cause of some of the most important pressures on ecosystems, some of which are soil erosion, eutrophication of water bodies, invasive species occurrence, large-scale land conversion and deforestation. However, the maintenance of the ecosystems through subsistence agriculture in Banaue has created many benefits to humans with comparably low impacts on ecosystems such as those mentioned by the Millennium Ecosystem Assessment. The terraces help to stabilize slopes and reduce the frequency and magnitude of landslides on this very steep terrain, with an average slope of 18° in areas where irrigated pond-fields are located (Acabado, 2003). The terrace structure also guarantees that water and nutrient are recycled as they flow down the terraces from the forest to the river. In this way, nutrient leaching, eutrophication of water bodies downstream and water shortage are very low.

The introduction of non-indigenous plant species brought a new biotic composition in the agroforestry practiced in the woodlots. The arrival of new tree varieties in forested areas does not have documented adverse effects, as could have invasive species, but rather enriches the flora diversity and services and benefits to humans. For instance, sweet potatoes (*Ipomoea batatas*), or *Lapne* in Ifugao, are not indigenous from the Philippines but have long been the main staple food of the Ifugao next to rice, and in some areas, before rice (Brosius, 1988). By cultivating new plant varieties, the Ifugao have multiplied their uses of the landscape for food provisioning, pest control, fertilizer and irrigation, while native species are mainly used for firewood, construction and medicine (Central Cordillera Agricultural Programme, 2003). However, if introduced plant varieties provides benefits to farmers, this might not be the case for alien species in rice paddies. The impacts of exotic aquatic species will be discussed below.

Agroecosystems are characterized by the presence of neighboring “wild” ecosystems and the biodiversity contained within them. Pollinator diversity, pest control, reduced soil erosion and the genetic material necessary for the continuous improvement of crop landraces are among the most important ecosystem services sustaining traditional agriculture (Van Oudenhoven et al., 2011). The cultural ecosystem service of landscape aesthetic supply is higher in the cultural landscape of Ifugao than in the natural landscape. Ecosystem services are in fact enhancing in a context of subsistence agriculture where the community is tightly linked to the agroecosystems, although they seldom translate into monetary value.

2.2. Social-ecological system properties and dynamics

Social-ecological systems develop continually depending on their exposure to disturbances. This development will also result from the vulnerability, the resilience and the adaptive capacity of the system on the long-term. Also, it is suggested that social-ecological systems develop according to an adaptive cycle, and on a longer temporal and larger spatial scale, to a panarchy of cycles.

2.2.1. Disturbances

Understanding disturbances is a critical part to assess the long-term development of a social-ecological system. Schoon and Cox (2011) identify four types of disturbances which enables a better understanding of the resilience of a system and the responses needed. They refer to these four categories as follow:

1- Flow disturbance: a fluctuation of a flow into or out of a system
2- Parameter disturbance: a fluctuation in a parameter that affects a system
3- Network disturbance: a change in the network structure of the system
4- Connectivity disturbance: a change in the social or ecological connectivity between the SES and the external environment

The Ifugao rice terraces experience the increasing effects of a set of disturbances which threatens the conservation of the rice terraces. Following Schoon and Cox classification of disturbances, the different pressures in Banaue can be categorized as in Table 1.

Table 1 Disturbances in Ifugao under four categories (Based on Schoon and Cox, 2011).

Disturbance types	**Disturbances in Ifugao**	**Source**
Flow disturbance	El Niño	Eder, 1982
Parameter disturbance	Population	Barthelmes et al., 1998
Network disturbance	Invasive pest species	Joshi et al., 1999, 2000, 2001, 2005
Connectivity disturbance	Tourism, market economy	SITMo, 2008

Disturbances can also be divided among stress and perturbation. Stress is a continuous or slowly increasing pressure (e.g., soil degradation), commonly within the range of normal variability, whereas perturbations are major spikes in pressure beyond the normal range of variability, e.g. typhoon, in which the system operates, and commonly originate beyond the system or location in question (Gallopín, 2006). Stresses must be adapted to and can be mitigated whereas perturbation must be recovered from. For instance, tourism and invasive species can be controlled and mitigated to a certain extent. If no control is possible, the social-ecological system must adapt to these changes by limiting negative impacts. However, perturbation such as earthquakes and extreme climatic events cannot be controlled and the system can only try to limit damages.

El Niño events (last in 2010) are particularly damaging in Ifugao and will possibly increase in frequency in the future. The climate perturbations are characterized by longer periods of drought and more intense rainfall, increasing the frequency and intensity of landslides and collapsed terraces.

2.2.2. Vulnerability

Vulnerability is defined by Adger (2006) as the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt. It is therefore a system attribute existing prior to the disturbance, often related to the history of disturbances to which the system was exposed in the past rather than an outcome of a perturbation (Gallopín, 2006). Vulnerability is strongly related to exposure; the degree, duration, and/or extent in which the system is in contact with, or subject to, perturbations (Adger, 2006; Kasperson et al., 2005). Exposure is an attribute of the relationship between the system and the perturbation, rather than of the system itself (Gallopín, 2006). Vulnerability also depends on the sensitivity of the system, meaning the degree to which the system is modified or affected by an internal or external disturbance or set of disturbances, which can be measured as the amount of transformation of the system per unit of change in the disturbance (Gallopín, 2003).

Two other common assumptions regarding vulnerability are (1) the multiscale nature of the perturbations and their effects upon the system and (2) the fact that most SESs are usually exposed to multiple, interacting perturbations (van der Leeuw, 2001; Turner et al., 2003; Gallopín, 2006). For instance, the exposure of the Ifugao rice terraces system to the combination of earthworms and droughts cause by El Niño renders the system more vulnerable than if the two perturbation were occurring separately (Eder, 1982).

There is little doubt that exposure, and accordingly vulnerability, increased significantly in Ifugao in the last century. If El Niño and earthquakes are not new perturbations, the integration into the market economy, tourism and introduced species have been more present in the Ifugao rice terraces system since the Second World War. The town of Banaue is more exposed to tourism, as it is the stepping stone for the other areas. For the same reason, it might also be more exposed to alien species. Despite its remoteness, Batad is also very exposed to tourism, as opposed to Bangaan.

Table 2 Resilience-related concepts and definitions.

Adaptability	Ability to adjust multiple disturbances, moderate potential damage, take advantage of opportunities, and cope with the consequences of a transformation that occurs (Gallopín, 2006).
Ecological resilience	Propensity of a system to retain its organizational structure and productivity following a perturbation (Holling, 1973).
	(1) The amount of disturbance that a system can absorb while still remaining within the same state or domain of attraction; (2) the degree to which the system is capable of self-organization (versus lack of organization or organization forced by external factors); (3) the degree to which the system can build and increase its capacity for learning and adaptation (Carpenter et al., 2001).
	The ability of a system to reorganize after a disturbance and remain in the previous basin of attraction. (Müller et al., 2010).
Landscape resilience	Resilience of an entire landscape, viewed as a spatially located complex adaptive system that includes both social and ecological components and their interactions (Cumming, 2011).
Robustness	Robustness refers to the capacity of a system to maintain the structure despite perturbations (Gallopín, 2006).
Social-ecological system	A linked system of people and nature in which people depend on nature and nature is influenced by people (Berkes et al., 2003).
Transformability	Capacity to create a fundamentally new system when the existing system is untenable (Walker et al., 2004).
Vulnerability	State of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt (Adger, 2006).

2.2.3. Resilience

The concept of ecological resilience was first introduced in 1973 by C.S. Holling as a "measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Holling, 1973). In other words, resilience is defined as the propensity of a system to retain its organizational structure and productivity following a perturbation (Holling, 1973). Although the perspective of resilience emerged from studies on predator-prey interaction and their functional responses in relation to ecological stability theory, the concept rapidly gained popularity among other natural and social scientists (Folke, 2006). Furthermore, a profusion of related notions has emerged in the literature to better understand and improve the definition, understanding and applicability of ecological or social-ecological resilience (see Table 2).

In the case of agroecosystems productivity, Di Falco and Chavas (2008) define a system as resilient if, in some state, the system is able to maintain productivity and withstand stress or external shocks. Thus, a resilient agroecosystem is more capable to provide a vital service, such as food production, when challenged by a severe drought or by a large reduction in rainfall (Di Falco and Chavas, 2008).

An important characteristic for ecological resilience is the potentially nonlinear responses of a system to perturbation, including hysteresis and permanent regime shift to an undesirable alternative state (Fletcher et al., 2006). The notion of resilience includes the concept of attractor basin or domain of attraction. Within each domain, the system's state may fluctuate widely (i.e. may be highly unstable) but if it tends to stay within the boundaries of the domain, the system is resilient (Gallopín, 2006). Thresholds, tipping points, depths of attractor basins, latitude, resistance and precariousness are more conceptual components of resilience related to the attractor domain that have been developed following the definition of resilience but won't be discussed in this work because of the inherent difficulty to measure these concepts.

Few studies have gone passed the theoretical level to quantify empirically resilience. One possible measurement of resilience, or engineering resilience *sensu* Holling (1996), is to measure the time needed for the system to recover from a perturbation or return to its domain of attraction after a disturbance. In other words, resilience can be measured by the speed at which the system returns to the relatively "stable" point or trajectory following a perturbation, or by the magnitude of the perturbation that can be absorbed before the state of the system falls outside its domain of attraction

(Pimm, 1984). This *a posteriori* method of measuring resilience, although accurate, can only be measured once the system has returned to its initial state.

Considering the importance of ecological resilience for the livelihood of communities living from surrounding ecosystems, several authors have attempted develop other ways of measuring resilience, either by using surrogates (Bennett et al., 2005), mathematical and spatial models (Fletcher et al., 2006; Fletcher and Hilbert, 2007; Burkhard et al., 2011a) or lately by developing multidisciplinary indicators (Van Oudenhoven et al., 2011; Cabell and Oelefse, 2012; Bergamini et al., 2013).

2.2.4. Adaptive capacity

Similarly to resilience, the concept of adaptive capacity, or adaptability, holds several, and often divergent, definitions in the scholarship. For instance, Gunderson (2000) defined adaptive capacity as the ability of the system to remain in a stability domain, as the shape of the domain changes, Carpenter et al. (2001) use adaptive capacity as a component of resilience that reflects the learning aspect of system behavior in response to disturbance, and Walker et al. (2004) define adaptability as the collective capacity of the human actors in a SES to manage resilience, including making desirable basins of attraction. Sometimes referred to as coping capacity (Turner et al., 2003) or capacity of response, adaptive capacity will be defined in this study as the system's ability to adjust multiple disturbances, moderate potential damage, take advantage of opportunities, and cope with the consequences of a transformation that occurs (Gallopín, 2006).

Capacity of response may include, for certain authors, the resilience of the system (maintenance within a basin) but also coping with the impacts produced and taking advantage of opportunities (Gallopín, 2006). In a social system, adaptability can be seen as the capacity of the system to increase (or at least maintain) the quality of life or livelihood of its individual members through the sum of disturbances (Gallopín et al., 1989). Furthermore, adaptive capacity differs from resilience in that the former entails a reactive and proactive response to perturbation, whereas the latter is a reactive response (Smithers and Smit, 1997). Adaptive capacity of a social-ecological system therefore involves two different components; (1) the capacity of the system to cope with environmental contingencies (the ability to maintain its condition in the face of changes in its environment) and (2) the capacity to improve its condition in relation to its environment, even if the latter does not change, or to extend the range of environments to which it is adapted (Gallopín, 2006).

An attribute related to adaptability is adaptness, the status of being adapted. Also, an adaptive trait is a feature of structure, function, or behavior of the organism that is instrumental in securing the adaptness (Gallopín, 2006). However, high adaptness should not be considered a synonym of high adaptability. Indeed, if a species may be highly adapted to a special and constant environment, it may also have little capacity to adapt to others or new changes in its environment (Gallopín, 2006). For instance, the Ifugaos may show great adaptness for the ability to adapt in such a rugged mountainous environment, carving the terraces on steep slopes and producing rice in harsh climatic conditions, but their adaptability might be low to cope with exotic pest species and market economy. Before becoming adapted of showing adaptness to a particular environment, a system most undergo a process of adaptation, one by which groups of people add new and improved methods of coping with the environment to their cultural repertoire (O'Brien and Holland, 1992). Similar to the concept of adaptability, transformability introduced by Walker and colleagues (2004) refers to the capacity to create a fundamentally new system (that is, experiment untried beginnings) when ecological, economic, or social (including political) conditions make the existing system untenable. It is defined by new state variables, or the old state variables supplemented by new ones. Attributes required for transformability include novelty, diversity, and organization in human capital (including diversity of functional types, e.g. kinds of education, expertise, and occupations), and trust, strengths, and variety in institutions (Walker et al., 2004). An example of transformability related to the Ifugao rice terraces is to introduce new ways for earning a living, such as ecotourism. In the literature, adaptive capacity is often evaluated with a focus on climate change or natural disasters but rarely with other disturbances such as stresses of lower intensity. For instance, transitioning economies experience much pressures and state variables change relatively fast.

The Resilience Alliance states that resilience of a system is key to enhance its adaptive capacity (Resilience Alliance, 2002). However, despite the literature associating resilience to adaptive capacity, it is unclear whether the two concepts are positively related. Indeed, Burkhard et al. (2011b) hypothesize that resilience is at its highest when the number of connections remain low and start decreasing as connections increase, whereas adaptability generally increases with the number of connections within a system. Therefore, resilience and adaptability would not necessarily be connected as the Resilience Alliance suggests.

If adaptation is generally perceived as benefiting the communities in social-ecological systems, resilience (Walker et al., 2004; Levin et al., 2012) and vulnerability (Gallopín, 2006) are neither necessarily good or bad. Communities would prefer to conserve ecosystem services after a disturbance but also overcome patterns of human behavior that sustain poverty, inequity or reduce long-run welfare. Resilience can indeed keep communities in an inflexible state of poverty trap, or under an authoritarian regime. The linkage between resilience and adaptive capacity will be further examined latter in this study.

2.2.5. Adaptive cycles

The long-term development of a social-ecological system cannot be analyzed with the sole angle of resilience, but must also consider multiple stable states in a long-term perspective. To this end, the dynamics of social-ecological systems can be usefully described and analyzed in terms of a cycle, known as an adaptive (renewal) cycle (Gallopín, 2006), wherein the system experiences four phases (see Figure 1). During their development, systems go through periods of exponential change (the exploitation, R phase), periods of growing stasis and rigidity (the conservation, K phase), periods of readjustments and collapse (the release, Ω phase) and periods of re-organization and renewal (the α phase, Folke, 2006). Finally, adaptive cycles that interact across multiple

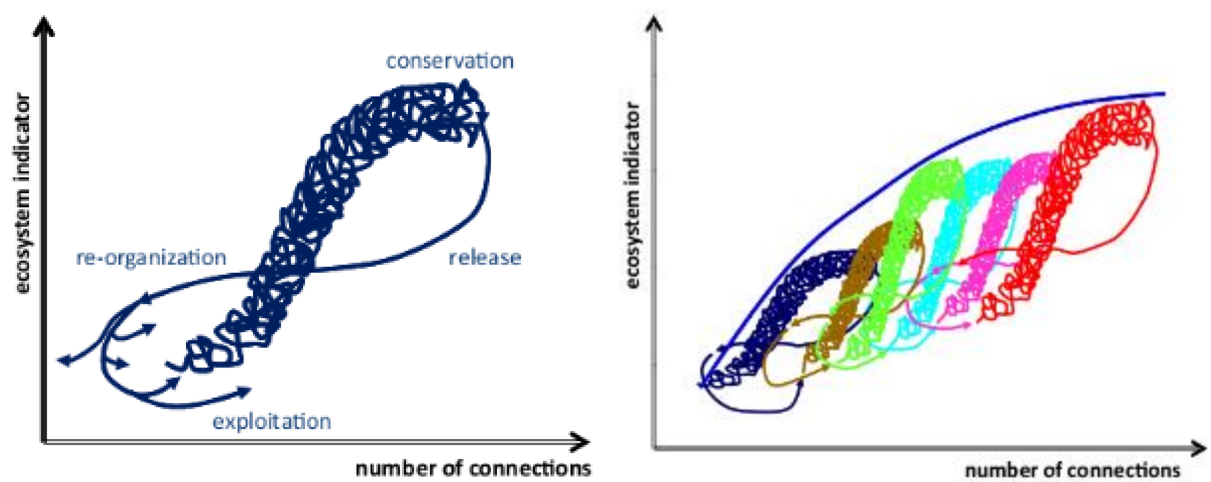


Figure 1 Adaptive cycles and panarchy. On the left, a developing system goes through the adaptive cycle, including the four phases of exploitation, conservation, release and re-organization. On the right, adaptive cycles constitute a panarchy as they occur at multiple temporal as well as spatial scales and are adaptive to a general orientor dynamics (Burkhard et al., 2011b).

temporal and spatial scales are named panarchies (Gunderson and Holling, 2002; Folke, 2006). Keeping in mind these concepts, this studies aims at identifying the location of the system on the cycle. In other words, the results should be able to show at which phase of the cycle the rice terraces in Ifugao currently are.

2.3. Indicators of social-ecological state

Indicators can be defined as a component or a measure that depicts a complex environmental phenomenon in a simple and useful manner (Kurtz et al., 2001; Müller and Burkhard, 2012). They are often used to assess the condition of the environment or to provide an early warning signal of changes in the environment (Dale and Beyeler, 2001).

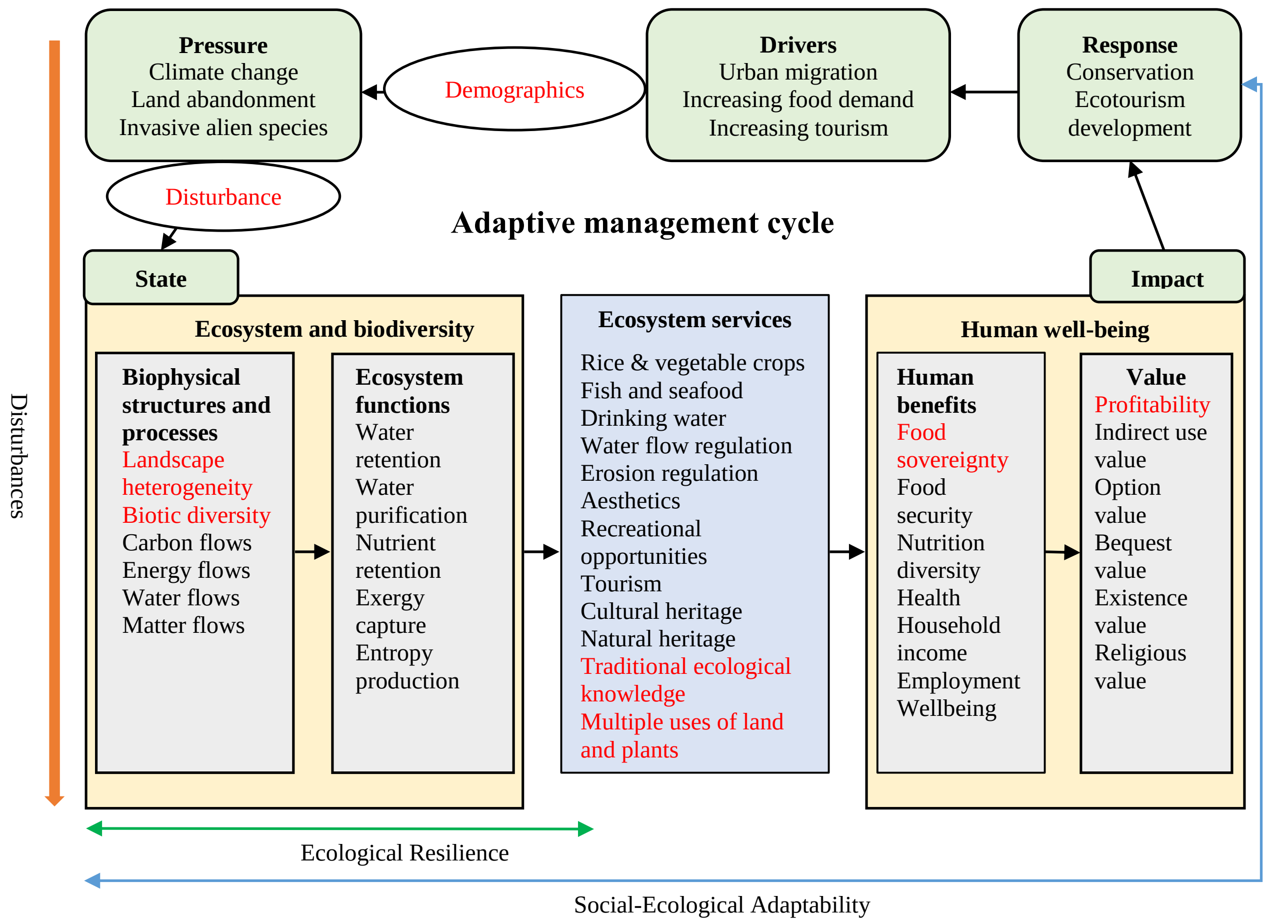


Figure 2 Adaptive management cycle of the Ifugao social-ecological system. The eight indicators used in this study, in red, represent different stages of the DPSIR Framework. Six of the indicators assess the dynamics of the ecosystem services cascade, while one indicator represents drivers and another one depicts pressures (adapted from Haines-Young and Potschin, 2010; Müller and Burkhard, 2012).

Several indicators have been used to describe ecosystem integrity, ecosystem health and ecosystem services. However, assessment exclusively relying on ecological indicators (e.g. species richness, primary production, nutrient and water recycling, soil productivity) fail to capture the social dimensions of a social systems linked to ecosystems and only rarely provide historical depth. In order to assess the adaptive management cycle of the ecosystems' change and communities' responses to adapt to these changes, indicators must represent the different stages of the cycle (see Figure 2). In this regard, landscape heterogeneity and biotic diversity represent the ecosystems structure. Multiple uses of land and plants refer to the number of goods provided to humans by ecosystems functions. Traditional ecological knowledge and practices are seen as services, mostly cultural, derived from ecosystems, but are also part of the response that may mitigate the drivers of change. Food sovereignty is the benefit of food provisioning services, and profitability shows the monetary value than can be derived from the ecosystem services cascade. Demographics is an indicator that can measure the drivers of change related to population dynamics, whereas disturbance regime partly indicates the intensity of pressure on the state of structures and processes of ecosystems.

Of course, many more indicators should be used to measure exhaustively and accurately the state of the social-ecological system of Ifugao. Systems are complex and should be evaluated with as many parameters as possible. Comprehensive vulnerability and resilience analysis considering the totality of the system, however ideal, is unrealistic (Turner et al., 2003). Due to the remote location of the case study and the limited time for the research, indicators were chosen by their applicability and the possibility of deriving them from questionnaire results. For instance, the yield of rice (e.g. measured in kg or bundles) was not taken in this study as an indicator despite its relevance. Rice terraces in Ifugao typically circumvent the steep mountain slopes and as a result, their area and contour are highly variable in shape and size. For this reason, most farmers ignore the area of their fields. They also do not always know the exact amount of harvested bundles every year since bundles are often exchanged for labor and to pay off debts. Furthermore, the bundles are of different sizes in each communities, which makes the comparison inconvenient.

2.3.1. Food sovereignty

The need to import food, pesticides or funding for terraces maintenance is a sign that the system relies on inputs from the outside. This need for the maintenance of the system increases vulnerability, among other things to price fluctuation, and can lead to a change of state or a breakdown if flexibility within the system become too low. Families in Banaue could never be self-sufficient with their own rice crops. However, with other crops such as sweet potatoes, communities did not rely on trade with the rest of Philippines to get enough food for a year. As the production of rice becomes insufficient to feed larger families, imported rice from other regions, as well as from other Southeast Asian countries started to appear in the stores of Banaue. The availability of rice from outside Banaue may create a stronger dependence on imports, but may also help to overcome crop failure provoked by pests or natural disaster. Hence food sovereignty is an indicator that is strongly related to demographics on the one hand, and to disturbances on the other hand.

2.3.2. Profitability

In order to pursue rice farming, those who manage the agroecosystems must have their needs met. Local communities should be able to make a living from work directly related to their labor, if they want to, without depending too much on off-farm income or subsidies (Cabell and Oelofse, 2012). Different benefits result from ecosystem services of agricultural systems, such as religious or spiritual experience and improved health, and different types of valuations can be used to assess these services (Davidson, 2013). But without economic benefits, maintaining the system becomes too demanding in resources and time, especially when compared to other more attractive lowland job opportunities. This is especially an issue in Ifugao where the rice terracing activity has never been profitable because of the low yields rendered by the local rice variety (Barton, 1919) and where the climate does not allow the introduction of more productive rice varieties. Therefore, a profitable Ifugao system would be a proof that the system is able to adapt to the new conditions, e.g. market economy, whereas a system where farmers do not sell farm products would be a resilient system. This refers to the “negative” resilience that keeps a system in a poverty trap, in which a systems may, as Young (2010) states, “linger on relatively unchanged even after they have become ineffective”.

2.3.3. Traditional ecological knowledge

Traditional agricultural knowledge and practices are part of the self-organization of the agroecosystem and contribute to the structure and function of the landscape. The resilience of this system, depends as much on these practices (the links between human and ecological components), as it does on ecological characteristics (biodiversity, habitat, ecosystem services) and social ones (institutions, networks, education; Van Oudenhoven et al., 2011). Traditional knowledge icludes local languages that encode the co-evolution of rural communities and ecosystems or oral traditions of knowledge transmission, for instance the *hudhud* chant in Ifugao (Lambrecht, 1967; Stanyukovich, 2003). This legacy of culture and traditions, from one generation to another, may also come in the form of seed banks or heirloom varieties and other biophysical resources that are inherited from forefathers (Cabell and Oelefse, 2012). A loss of such knowledge, for example caused by the extinction a local language, can cause the disintegration of traditional social-ecological systems, landscape degradation and loss of biodiversity, further eroding traditional knowledge in the process (Van Oudenhoven et al., 2011). Retention of indigenous knowledge is dependent on its use; it is not only embedded in people's minds, but it is also reflected in the environment with which they engage (Kassam, 2009). In other words, to conserve resilient social structures, knowledge must also be transferred to next generations. The continuity of the system depends on whether or not the next generation is willing to take over the farming activities of the forefathers.

2.3.4. Demographics

Population is rarely taken into account as a variable to measure the resilience of social-ecological systems. However, all aspects of demographic change, including migration, influence the social resilience of communities and the sustainability of the underlying resource base (Adger et al., 2002). A high density of population and high birth rate tends to increase the poverty trap issue (Verner, 2007). Higher population can also increase pressures on the system causing landscape fragmentation, soil erosion, pollution and may reduce arable land per capita (Blaikie and Brookfield, 1987; Grepperud, 1996).

Conversely, emigration or urban migration and lack of workers to maintain the rice terraces can lead to a shift of the system, resulting in terrace abandonment and the development of a different landscape. Migration, especially overseas, and remittances can also improve the livelihood of the communities. The money sent home from the migrant workers can be used for investments, for instance in the agricultural sector (McKay, 2003). Therefore, migration rate can enhance resilience by offsetting high birth rate and adaptability by improving the livelihood at the household level (Adger, 2000).

2.3.5. Landscape heterogeneity

Spatial heterogeneity can be defined as the complexity and variability of a system property in space, such as patch mosaics, plant biomass, or soil nutrients (Li and Reynolds, 1996). As it buffers disturbances across the landscape, spatial heterogeneity is generally regarded as enhancing ecological resilience (Cabell and Oelefse, 2012; Turner et al., 2013). However, the correlation between spatial heterogeneity and disturbance in terrestrial ecosystems has still not yet been entirely demonstrated as positive. Heterogeneity has mainly been shown as reducing disturbances such as forest fires (Turner and Braton, 1987; Harrison et al., 2003) but it might not be the case concerning other disturbances such as exotic pest outbreaks, which may be increased by landscape patchiness (Nair, 2001). Furthermore, there are few studies on the relationship between landscape heterogeneity and the vulnerability to climate hazards such as floods and landslides.

Rice terraces in Banaue are very different from lowland rice paddies. The landscape is much more heterogeneous as forests are historically an essential part of the landscape. Rice fields are also more temporally heterogeneous than in the lowland. As opposed to intensive culture in other provinces, rice fields in Ifugao often have only one rice crop per year. After harvest, rice fields are transformed in vegetable fields or in a wetland that increases the diversity of structure in the landscape. Moreover, shifting cultivation represents further temporal heterogeneity on a different scale, as forest plots are temporarily replaced by root crops.

Fragmentation of the landscape through urban sprawl may increase the impact of disturbances on the landscape. For instance, roads and sealed surfaces tend to redirect the water flow along a certain pathway, thus increasing peak flow and erosion, as well as decreasing the time lapse of base flow after a precipitation event. This is an important hydrological factor since rice terraces need a continuous inflow of water and too much water at a time increases the probability of collapsed terraced walls. Increasing tourism and population have been major drivers in the building of new infrastructures such as paved roads, hotels and shops mostly in the surrounding of the town of Banaue.

2.3.6. Biotic diversity

The capacity of ecosystems with higher biodiversity to overcome disturbances has been demonstrated in several studies. Higher biodiversity enhances the following properties:

1. Growing more diverse crop species increases the probability of growing the best-adapted species. This is known as the "sampling effect" (Di Falco and Chavas, 2008).
2. Complementarity effect stresses the role of niche partitioning and facilitation (Loreau and Hector, 2001). Broader range of traits will be more likely to perform under different environmental conditions (Sala, 2001).

Having a diversity of plants with similar functions, but with different responses to weather and temperature variance contributes to resilience (Holling, 1973) and ensures that "whatever the environmental conditions, there will be plants of given functional types that thrive under those conditions" (Heal, 2000). Biodiversity is buffering against the negative effects of adverse environmental conditions at least in the longer term, and it can help to keep the agroecosystem at a level of productivity that is similar to the one obtained without the shock (Di Falco and Chavas, 2008) The local rice varieties are adapted to climatic peculiarities of the region which determine the communities of plants and animals in the paddies. Plant diversity in the rice fields also improves the response to disturbances such as invasive pest species, e.g. the golden apple snail (Martin and Sauerborn, 2000). The province of Ifugao is known for its high number of different varieties of Japonica (*tinawon*) and Indica (*pinidua*) varieties. However, the number seems to be decreasing, notably given the introduction of lowland high yielding varieties.

2.3.7. Multiple uses of land and plants

Intercropping and agroforestry are agricultural techniques that boost multiple crops for the same area of land. These multi-species cropping systems offer several benefits, such as consistency in food provisioning and increased capacity to recover from perturbation (Trenbath, 1999). Inversely, the intensification and simplification of agrological systems often lead to a higher reliance on external agricultural inputs and products to compensate for the lower agricultural diversity (Altieri, 1999). Therefore, deriving different goods from ecosystems generally increases resilience because the system is less dependent on imports to obtain, for instance, daily nutritional needs (Morimoto et al., 2010). Productive multifunctional ecosystems have a positive influence on other indicators, such as food sovereignty and landscape heterogeneity.

The notion of multiple uses of land may refer to the ecosystem services concept. However, only tangible ecosystem goods will be taken into account here to assess the multiple uses of the ecosystems. The reason to exclude intangible ecosystem services is that little information exist and more data are needed especially for regulation services, which makes measurement difficult, and temporal comparison with a traditional “stable” state is arduous. However, some cultural ecosystem services are taken into account under a different indicator, i.e. religious experience and knowledge system in the traditional ecological knowledge indicator.

2.3.8. Disturbance regime

As previously mentioned, disturbances are strongly related to the resilience of a system. Resilience being the response of a system to disturbance, one could think that disturbances are necessarily detrimental to social-ecological systems. However it has been argued that controlled and limited disturbances can improve some aspects of ecological functioning (Glitzenstein et al., 1995; Platt, 1999), e.g. biodiversity (Connell, 1978; Svensson et al., 2007). On the other hand, this dynamics of disturbance strengthening resilience depends heavily on the capacity of the system to absorb stress, its flexibility, vulnerability and adaptability. Further, disturbances may not be positively regarded in subsistence agroecosystems since food provisioning is severely needed and variations in harvests may have great consequences, regardless of the long-term beneficial effects.

3. Methods

The following section explains the context in which this thesis was conducted and describes the area of study, referring to the earliest (early 20th century) accounts of the social-ecological system. It also reviews the current pressures that have influenced the recent development of the system. The last part of this chapter outlines the methodology used for the collection and analysis of data.

3.1. The Legato Project

The study was carried out within the LEGATO project, which "aims to advance long-term sustainable development of irrigated rice fields, against risks arising from multiple aspects of global change"[1]. The project, which gathers different partner institutions in Germany, Vietnam, the Philippines and few other European countries, focuses on the activity of rice production in seven study sites across Vietnam and the Philippines. This thesis concentrates on one of the three sites in the Philippines, i.e. Banaue in the province of Ifugao, and falls within the work package 4.2 regarding the development of indicators. According to the Description of Work (LEGATO, 2011), the main objectives of this work package will be to:

1) Identify suitable (feasible and effective) sets of indicators characterizing the state of the environment and related socio-economic and cultural factors on different scales and in different bio-geographic regions;
2) Quantify the indicators as far as appropriate based on results generated by the whole consortium;
3) Play an integrating role within LEGATO by providing an integrative interdisciplinary indicator framework system which will be used by the project collaborators and which can be transferred into practice after the project works.

Furthermore, a secondary objective of the work package 4.2 is to derive measures for resilience and adaptability (LEGATO, 2011).

[1] The LEGATO acronym stands for "Land-use intensity and Ecological Engineering – Assessment Tools for risks and Opportunities in irrigated rice based production systems". URL: http://www.legato-project.net/.

3.2. Description of the study area

The Ifugao rice terraces are located on the northern part of the island of Luzon, in the Philippines (Figure 3). The production of rice in Ifugao is negligible. On the 16.6 million metric tonnes of rice produced in the whole country in 2011, only 62 thousand tonnes (0.3%) came from Ifugao (Bureau of Agricultural Statistics, 2013).

It is still unclear to date when did the Ifugao people really start with the construction of the terraces in North Luzon. Barton (1919) and Beyer (1955) first estimated the terraces to be of at least 2000 years old (Table 3). Other scholars later proposed a much more recent origin, of a few centuries, pretending that the Ifugaos were forced to migrate up the mountains by the arrivals of the Spaniards.

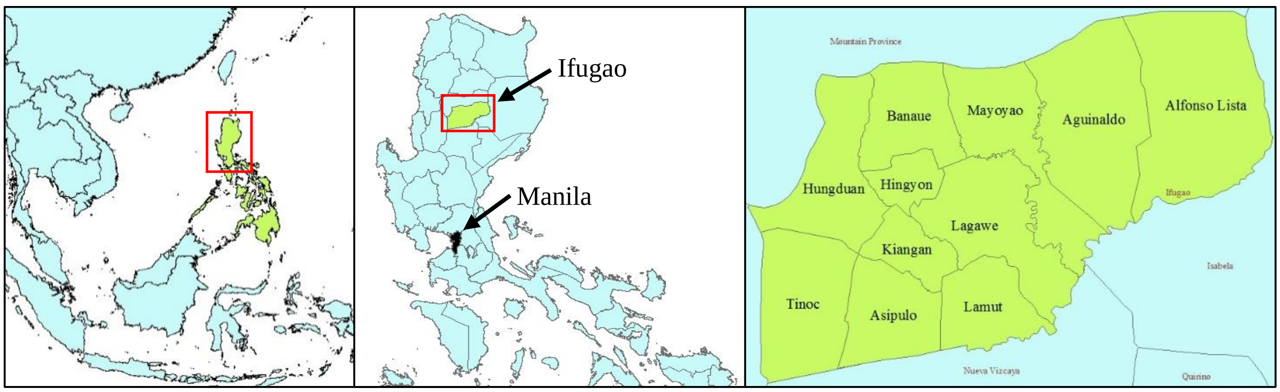


Figure 3 Location of the Ifugao province (middle) and its municipalities (right) in the Philippines (left). Source: http://www.philgis.org/.

Table 3 Age estimations proposed for the creation of the Ifugao rice terraces (adapted from Acabado, 2009).

Author	Date	Evidence
Barton (1919) & Beyer (1955)	2000-3000 YBP	Estimated how long it would have taken to construct the elaborate terrace systems which fill valley after valley of Ifugao country.
Keesing (1962) & Dozier (1966)	< 300 YBP	Movements to upper elevation of Cordillera peoples were associated with the Spanish pressure.
Lambrecht (1967)	< 300 YBP	Used lexical and linguistic evidence by analysing Ifugao romantic tales (hudhud); observed short duration of terrace building and concluded a recent origin of the terraces.
Maher (1973)	205 ± 100 YBP 735 ± 105 YBP	Radiocarbon dates from a pond field and midden.
Acabado (2009)	< 500 YBP	Radiocarbon dates of charcoal sample from a pond field in Banaue and Bayesian modelling.

Table 4 Timeline of major events in Banaue.

Year	Event
~0-1600	Start of the construction of the terraces (Acabado, 2009)
1868	Discovery of the valley of Banaue (Scott, 1974)
1899-1946	US colonization and catholic and protestant missionary activities (Conklin, 1980)
1946	Incorporation of Ifugao in the Philippine nation-state (Conklin, 1980)
1950-1980	Possible period of introduction of giant earthworm (Conklin, 1980)
1986-1990	Introduction of the golden apple snail (Joshi et al., 2001)
1990	Earthquake of magnitude 7.8 (Kwiatkowski, 2013)
1994	Creation of Ifugao Terraces Commission (ITC) for the restoration and preservation of the Ifugao Rice Terraces (1994-1999) (DENR, 2008)
1995	Inclusion of the Ifugao Rice Terraces as UNESCO-WHS (UNESCO, 1995)
1999	Creation of Banaue Rice Terraces Task Force (BRTTF) 1999-2002 (DENR, 2008)
2001	Inclusion of UNESCO-WHS on the Danger List (UNESCO, 2002)
2002	Creation of Ifugao Rice Terraces and Cultural Heritage Office (IRTCHO) 2002-2006 (DENR, 2008)
2006	Creation of Ifugao Cultural Heritage Office (DENR, 2008)
2006	Inclusion of Ifugao Rice Terraces (IRT) in the GIAHS initiatives (Koohafkan and Jane, 2011)
2010	El Niño causing extended drought and major crop loss (Yumul Jr et al., 2010)
2012	Removal of UNESCO-WHS on the Danger List (UNESCO, 2012)

But regardless of the exact date, the uniqueness of the Ifugao rice terraces no longer has to be proven. A UNESCO World Heritage Site since 1995 (UNESCO, 1996), the rice terraces also became a site of the GIAHS selected by the FAO since 2002 (Koohafkan and Jane, 2011). Several other national Initiatives have been implemented to promote the restoration and Conservation of the Ifugao Rice Terraces (Table 4), although success has limited. Because of the extent of the terraces, estimated at 20,000 km in length, they are believed to be the most extensive terraces in the world and are a major landmark in the country, described as an "irreplaceable treasure"

(Nozawa et al., 2008). The terraces are also widely considered as the eighth wonder of the world by Filipinos (Joshi et al., 2000; Araral, 2009; Dizon et al., 2012).

The Ifugao rice terraces are also characterized by a lack of information because of the remoteness and isolation of the province. Indeed little is documented on the area: rice productivity per hectare is only estimated at the municipality level, as is the total number of rice and other plant varieties.

Difficulty to compile data also comes from the fact that the same information may be found under different names depending on the dialects in the different municipalities of Ifugao. This is especially the case for rice varieties, which can be bred locally and hold local names.

The climate in Ifugao is relatively cool and wet throughout the year, with an annual average rainfall of 3500 mm (Figure 4). Monsoon winds bring clouds covering the forested mountain peaks resulting in intermittent drizzles or heavy rainfall (Roxas, 1996). These climatic conditions provide a dependable source of water, but also causes recurrent landslides (Gonzalez, 2000).

Due to flooding in the terraces, Banaue soil is deficient in zinc, which can become a limiting factor for rice growth (Roxas, 1996). The concentration of zinc increases again when the fields are drained or during short periods of drought and becomes available for use as traditional rice varieties recover. Soil acidity is relatively high (pH ranging from 4.8 to 6.8) and deficient in N, P, K and S (Sigari et al., 2003).

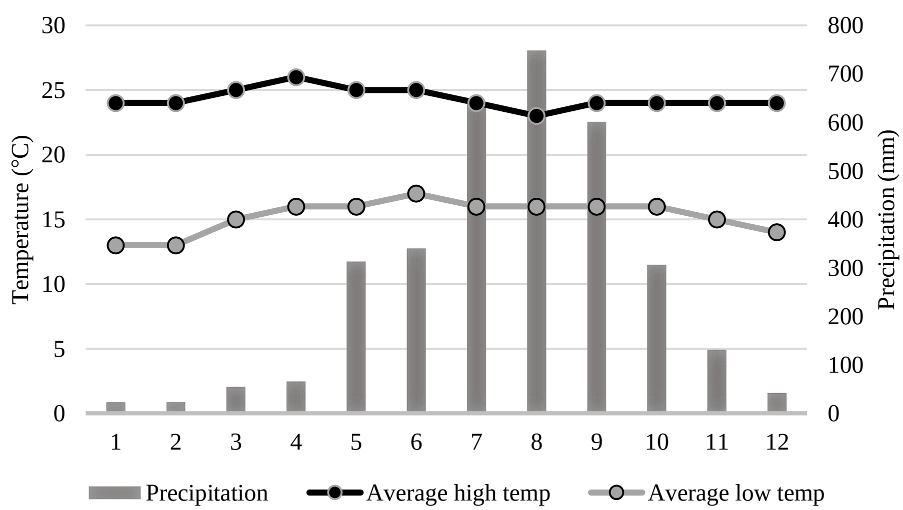


Figure 4 Climate chart of the Ifugao Province. Source: World Weather Online, 2014.

3.2.1. Agroforestry

Typically, farmers who own a rice paddy also own a forested area that is more or less managed, called *Pinugo* or *Muyung* in the local dialects. This forest or woodlot, usually enclosing or adjacent to the settlements, is private and can only be used by others after permission.

The woodlots measure in general around 0.5-3 hectares and they are separated by a demarcation of around one meter wide (Gomez, 2003). Besides providing the inhabitants with firewood, fruits, lumber and medicinal plants, the woodlots have a great importance in terms of regulating ecosystem services. As they are typically located above rice fields, the woodlots are a source of nutrients from decomposed litter (Magcale-Macandog et al., 2013). They also contribute to water regulation and provide uninterrupted presence of water in the fields, thus preventing the layers of clay beneath the topsoil and behind the stone walls from cracking and eroding (Villalon, 1995). Hence most farmers depend on forests for the irrigation of their rice ponds (Gomez, 2003).

3.2.2. Swidden cultivation

The Ifugao people is also known for its shifting cultivation, namely the *habar* or *uma* in local dialects (sometimes seen as *kaigin* in Tagalog). Swidden fields have a size ranging from 0.3 to 1.5 hectares and normally remain fallow for 7-8 years before the next cultivation (Gomez, 2003). The swiddens are used to plant tubers, more importantly sweet potatoes (*Ipomea batatas*), with yields averaging 2.4 tonnes per hectare per year (Guy, 1995). Since one rice crop in a year is generally insufficient to feed families for the whole year, sweet potatoes are the second, and sometimes the most important staple food for Ifugao households (Barton, 1922; Brosius, 1988). The swidden fields are cultivated on slopes too steep for terrace farming, and therefore maximize food production on the available area of land.

3.2.3. Rice terracing

Most families own at least one rice field, called *payo*, of a size of 0.33-0.5 hectares (Gomez, 2003). The stairway-like configuration of the rice terraces entails that nutrients and water overflow in the top terraces will be recycled at each lower terraces. Another particularity of the rice terraces is the anaerobic conditions in the soil, protecting organic nitrogen from denitrification and leaching (Margraf and Voggesberger, 1984). Further, considerable biological nitrogen fixation in the rice paddies comes from the *Azolla-Anabaena* symbiosis, which is more effective in climatological conditions of higher altitudes (Roger et al., 1986). Weeds growing on bunds and rice straws are directly inserted into the soil after harvest, providing additional nutrients for the following cropping season. This green manure is important considering the fact that Ifugaos have not widely adopted the use of inorganic fertilizers.

Though rice science has shown that alternate flooding in rice fields is preferable to reduce greenhouse gas emission and enhance water use efficiency (Sass et al., 1992; Bouman et al., 2007), the terraces of Ifugao must be flooded as often as possible to prevent erosion and landslides. The steep slopes make terraces vulnerable to erosion and the lack of water is likely to create cracks that eventually cause walls and dikes to collapse (Roxas, 1996; Nozawa et al., 2008).

The farmers have developed traditional agroecological practices to improve the food production and secure food security. A widespread intercropping practice across the province is the *pingkol* (*inago* in Banaue and Bangan, *pen'er* in Batad), consisting of small mounds of composting rice straw, *Azolla* ferns and grasses covered with mud on the rice paddies on which farmers plant vegetables, while water level in the rice pond is maintained. *Pingkol* are mostly a post-harvest system but can also been seen occasionally while rice is growing. Vegetables growing on these mounds of decaying organic matter are mainly Chinese cabbage (*Brassica rapa*), locally known as *pechay,* and onions (*Allium cepa*). *Pingkol* have the double function of providing food while paddies are idle and, as mentioned above, providing nutrients for the next cropping season (Nozawa et al., 2008). Other crops are planted on terrace dikes, bunds and walls, including grain, legumes and root crops such as sweet potatoes, taro and ginger (Wackernagel, 1985).

3.2.4. Ifugao rice

The main local rice varieties, of the Japonica category, are gathered under the generic word of *tinawon*, meaning “yearly” in the local dialect (Conklin, 1980). *Tinawon* is characteristic for its slow growth (6-9 months) reaching a height of 120-160 cm and can only be planted once a year (Roxas, 1996). Despite the low yield, the *tinawon* varieties present a number of advantages to farmers. They are non-shattering, have long panicles and are taller than most varieties, which are qualities appreciated for manual harvest. They also have large grain and the texture is preferred by the Ifugaos to the modern varieties. They are cold-tolerant and therefore produce more rice than lowland varieties (Indica) at elevations higher than 1000 meters above sea level (Wackernagel, 1985). Beside the *tinawon*, varieties of the Indica category were adapted to upland production and were called *pinidua* in the region, meaning "second" (Conklin, 1980). These varieties can be grown as a second crop after the *tinawon* and outyield traditional Japonica varieties at elevation lower than 1000 meters above sea level (Wackernagel, 1985). Nonetheless, *tinawons* traditionally made up for a large part of the production considering that roughly 80% of the varieties and 95% of the quantities of rice grown in the Ifugao terraces are *tinawon* varieties (Conklin, 1980), although this situation is starting to change.

Native varieties yield in average 2 tonnes per hectare per year, although exceptionally fertile fields may reach 6 tonnes per hectare per year (Conkin, 1980). Introduced high yielding varieties such as C4 may be slightly more productive, averaging 2.4 tonnes per hectare per year (Guy, 1995). However, these high yielding varieties, as well as double-cropping systems, can only be introduced at lower elevations. There has been many attempts to breed new cold-tolerant rice varieties through hybridization initiated as early as 1974 by the Bureau of Plant Industry of the Philippines (Roxas, 1996). However, owing to cultural practices, some grain quality traits and climate variability, such initiatives have remained until now unsuccessful around Banaue (Roxas, 1996).

It is also common for farmers to grow glutinous rice varieties. The latter are used to prepare delicacies and rice wine served during special occasions or in daily needs of the Ifugaos (Evangelista, 2005). There is no official count of the rice varieties in the province. Settele (1998) estimated the number of varieties at more than 100. Evangelista (2005) numbered 107 non-glutinous traditional, 42 glutinous traditional and 21 modern varieties for a total of 170 planted during the 2002 cropping season. Also, rice paddies in Banaue are known for the high biodiversity. Settele (2003) showed that the rice ponds in Banaue have an above-average diversity of aquatic species (more than 100 species) compared to other wetland ecosystems in the worlds.

3.2.5. Other landscape components

Besides rice terraces, private forests and swidden fields, Conklin (1967a) identified the following land uses as part of the typical Ifugao landscape:

- Caneland or cane grassland: mostly slopeland, unworked soil, covered with various stages of second growth herbaceous and ligneous vegetation dominated by dense clumps of tall canegrass (dominated by *bilāu* in Ifugao, *Miscanthus* spp.); some protection and management (canegrass much used for construction, fencing, and so forth).

- Grassland: ridge and slopeland, untilled, covered with herbaceous grasses (*gūlun* in Ifugao, *Imperata* sp., *Themeda* sp., and others), public and unmanaged; open, unbounded, minimally valued; a source of outer roof thatch. Without new sources of irrigation water such land is not normally brought under cultivation.
- Public forest: slopeland, undisturbed soil, covered with various types of dense woody vegetation (from lower altitude mid-mountain climax forest to pine forest and mossy cloud forest types), public (for residents in the same general watershed area), and unmanaged; a source of firewood, other natural forest products, and game.
- House terrace (settlement, hamlet terrace, residential site): leveled terrace land, the surface of which is packed smooth or paved but not tilled; serving primarily as house and granary yards, work space for grain drying, and so forth; discrete, often fenced or walled, and named.
- Drained field (drained terrace, ridged terrace): leveled terrace land, the surface of which is tilled and ditch mounded (usually in cross-contour fashion) for cultivation and drainage of dry crops, such as sweet potatoes and legumes. Drained fields, though privately owned, are kept in this temporary state for only a minimum number of annual cycles before shifting (back) to a more permanent form of terrace use.

These land covers, especially the public forests, although very relevant in the study of social-ecological systems, will not be considered in this thesis because of their small proportion of land cover in the studied areas.

The traditional Ifugao land use system has often been described as having high connections between the different ecosystems forming the landscape, allowing production and consumption of food in the same landscape units (Settele, 1998). For instance, the farmers, who generally live in a hamlet concentrated on lower terraces, get most of the biomass needed, in the form of rice, seafood, fruits, lumber and firewood, from the surrounding ecosystems (Figure 5). Therefore, a flow of biomass connects the ecosystems to the hamlet. A cascading flow of water-carried nutrient is observed from higher primary forests, to private woodlots and swidden fields to rice terraces, and also from hamlets to lower rice terraces. For this reason, nutrient cycles are considered as nearly closed with optimal recycling of nutrients (Margraf and Voggesberger, 1984; Settele, 2003).

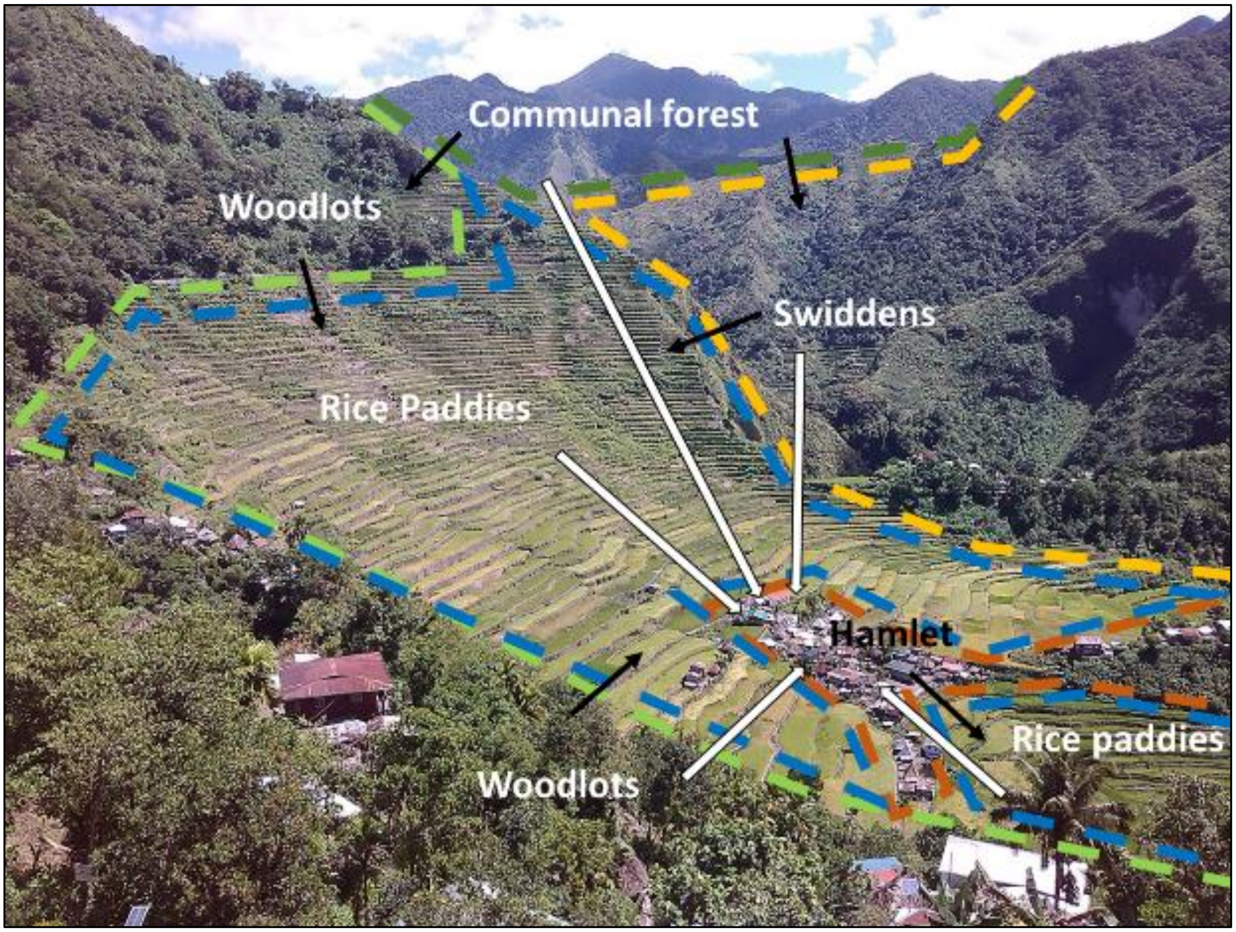


Figure 5 The Ifugao land use system. Rice fields receive water-carried nutrients from ecosystems located above ➔. Harvested products are transferred to the hamlet (biomass flux) ⟹. The terrace shape of the rice paddies allows for the optimal use of nutrients and minimal erosion despite the steep slope (Modified from Margraf and Voggesberger, 1984; picture taken in Batad, 2013).

3.2.6. Societal features

The rice farming system in Ifugao is one of subsistence and much time and resources must be invested in this activity. As the region is isolated from major cities in Luzon, few employment opportunities offer cash income for farmers or other workers. It is therefore difficult to assess the well-being of the population merely with standard development indicators such as monetary income.

The communities living from rice farming in Ifugao have developed closely with their environment. The rice plant more specifically, strongly influenced the generation of religious beliefs of the communities. For example, the *Bulol*, a wood carving representing the rice god is believed to be a protector of harvested rice crops (Bulilan, 2007). It is also believed that the first Ifugao settlers were given the first plant of *tinawon* by the gods (Druguet, 2012). *Baki* or rituals associated with rice production (Bulilan, 2007) are practiced at different stages of the agricultural production cycle. The people of Ifugao have developed specific customary laws and practices. One of these practices is the *ubbu*, a type of exchange farm labor provided by group work among neighbors (Conklin, 1980; Araral, 2013). A similar practice is *baddang* which helps in constructing and repairing the terraces walls and irrigation canals (Conklin, 1980). These customs contribute the social organization of the communities and to the proper maintenance of the system through cooperation without paid labor.

Another traditional custom is the primogeniture rights, which entails the inheritance by the oldest child of the entire or a substantial part of the property of his parents, while younger siblings need to acquire their own property, become tenants or seek different employment (Barton, 1919). The land owned by a family is seen as an article of value that has been handed down from generation to generation, not as the property of any individual. Therefore, property will be seldom sold or divided. In case the owner leaves the area, the rice fields will be rented to tenants who did not inherit rice fields in their own family. This inheritance system also has a great impact on the social-ecological system as it regulates the property sizes and prevents the division of the fields. The adverse effect of this measure is of course to create imbalance in wealth and inequities within families (Cagat, 2013).

The marketing of rice has never been common in the area (Barton, 1922; Acabado, 2012). In some cases, farmers practice a barter system wherein rice is the medium of exchange to acquire other goods or commodities such as fruits, meat or seeds (Evangelista, 2005). Farmers in Ifugao typically produce their own seeds through seed or panicle selection. This selection is done before harvest by women, who are aided by elders considered as expert seed selectors. The seed selection knowledge is passed on through generations.

Rituals are a big part of the culture of the Ifugaos (Figure 6). With 17 agricultural rites known to be linked with rice production and consumption, although 8-10 are more frequently practiced throughout the province (Conklin, 1980). One of the consequences of rituals is that all members of a community plant and transplant their seedlings, and harvest the rice at the same time, resulting in the synchronization of crops. This timeliness has the benefits of lessening the length of time when the crop is attractive to pests and diluting the damage for each field by spreading it over a large area (Wackernagel, 1985).

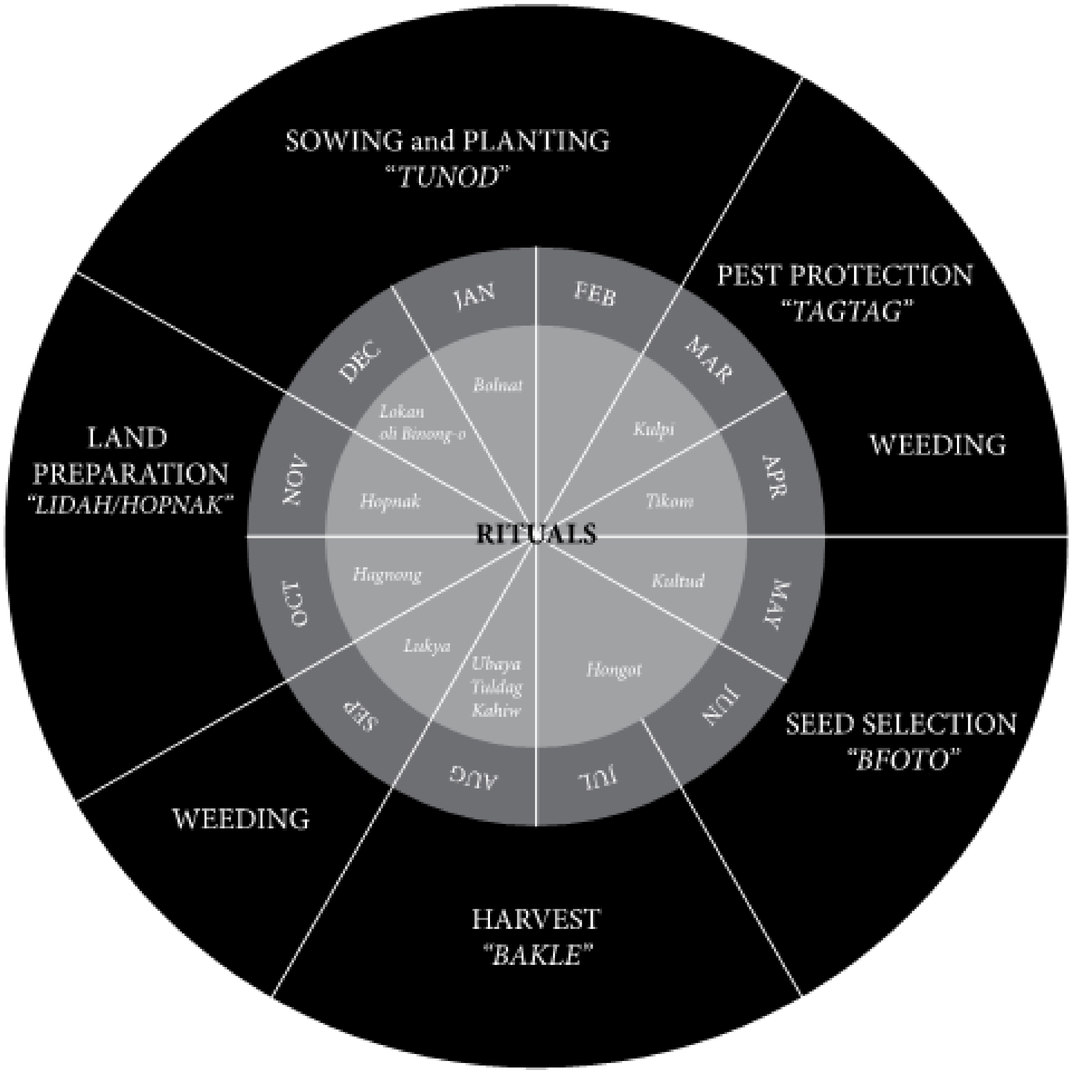


Figure 6 Cropping seasons and related rituals (SITMo, 2008).

As most traditional social-ecological systems in the world, the Ifugao rice terraces are changing rapidly. Changes associated with development are not new however. Already in the early 20th century, Barton (1922) noticed that the genuine traditional system had already vanished. For instance, the American government had already introduced remunerative employment, replacing the feudal system and rice by money for the main currency (Barton, 1922). Seasonal migration for work had also started at that time. As roads were developed in North Luzon to facilitate mining activities, men were already moving to neighboring provinces to find paid labor, returning home for harvest and planting seasons. Some formerly frequent traditional practices, for instance head-hunting and the selling of children to pay off debts, had also stopped.

Drastic changes in the system have been noted starting in the early 1980's (Eder, 1982; Settele et al., 1998). More specifically, changes of the climate and the hydrological balance were observed (Eder, 1982; Sawey et al., 2010). The lack of water in the terraces caused the accelerated erosion and collapse of the stone walls and more frequent landslides. The World Heritage Site was placed on the list of sites in danger from 2001 to 2012, mostly on the basis of the abandonment of terraces, unaddressed needs of tourism and irregular development (UNESCO, 2002, 2012). Signs of a decline of interest in traditional culture have also started to appear. For instance, rituals are becoming infrequent and the introduction of high yielding varieties may disturb the traditional knowledge of seed selection since modern seeds are provided by government or non-governmental organizations (Evangelista, 2005).

3.2.7. Pressures on the system

Several pressures on the Ifugao rice terraces system have been documented since the early 1980's. Pest species, which cause continuous disturbances increasing in intensity, are one of them. It may have combined effects with the El Niño phenomenon, for instance when terraces dry out due to the lack of rain and water seepage caused by earthworms (Eder, 1982). Although some species of earthworms are known to have beneficial effects on soil aggregation, residue decomposition, nutrient mineralization, water infiltration (Lee, 1985), soil aeration in flooded paddies (Owa et al., 2003), as well as productivity in tropical agroecosystems (Pashanasi et al., 1996), the species found in Ifugao have rapidly become a major pest. In a survey conducted by Joshi and colleagues (1999), 93 out of 103 rice farmers in the municipality of Banaue identified earthworms as the most important pest species in their terraces. Besides causing undesirable seepage of water and drainage of the fields, they can also damage young rice plants by friction, scraping root tissues of seedlings when the population becomes too dense, and interfere with germination by covering seeds or seedlings in the seedbed (Barrion and Litsinger, 1997). The lack of response to this threat comes from the little information available on the cryptogenic worm. Indeed, Conklin (1980) first mentioned that the locally called *kolang* or "giant earthworm" would be the *Pheretima elongata* (Gates) that could have spread from the regions south of the North Central Ifugao during the three decades preceding his publication. More recently, Joshi et al. (1999) mentioned two different species that could be the problematic earthworm, *Polypheretima elongata* (Perrier) or a "large mystery worm" of the *Pheretima* or *Metaphire* genera, yet unidentified. It is unclear when the “giant earthworm”, became a pest in Banaue. Joshi et al. (1999) and Gomez (2003) suggest that the earthworms became a problem in the early 1980’s, but according to Gates (1972) and Conklin (1980), it would have already been present in the early 1960’s. Therefore, it is still unknown from where and when the problematic earthworm first arrived in Banaue, and research is still needed to establish a program of ecosystem-based management to reduce the negative impacts of the worm without applying ecologically harmful pesticides.

Another important invasive species is the golden apple snail (*Pomacea canaliculata*), locally known as *golden kuhol*. It was introduced in the Philippines from South America and Taiwan between 1982 and 1984 as a source of protein in human diet (Mochida, 1987; Joshi et al., 2001). First seen in Ifugao in 1990, the apple snail spread rapidly, becoming a pest globally for rice production, as attests its inclusion in the International Union for the Conservation of Nature’s (IUCN) list of top 100 worst invasive species globally (IUCN, 2013). Damages from the snail are poorly quantified in Ifugao compared to other areas of Philippines. For instance, yield loss caused by *P. canaliculata* of around 40% have been reported in 1990 in Luzon rice fields, and nearly half the farmers in the neighboring province of Nueva Ecija had a 25% harvest reduction in 1990-1991 (Martin and Sauerborn, 2000). The snail does not only reduce the rice production. It possibly led to the extirpation of the native snail species (*Pila luzonica*) which was traditionally appreciated as a food source by the inhabitants, without damaging the rice plants.

Tourism and the opening of the area to market economy considerably altered mentalities and traditions, especially around the town of Banaue. The increasing number of tourists in the region can be seen as detrimental for forested areas because of the increasing demand for lumber from the wood carving industry. An overexploitation of forests would certainly result in lower water regulation from the forested zone above rice fields and thus, drier terraces. Tourism could also lead to water diversion for the industry’s purposes. Apart from tourism, several other changes occur in a traditional social-ecological system once a community opens up to the rest of the country. One of the first consequences of greater relations with the rest of the Philippines, was the introduction of Christianism that can potentially produce a “cultural disturbance”.

Another example of such change is the controversial introduction of high yielding varieties of rice. The Ifugao people take a great pride in growing the native variety. On the other hand, many observers have been suggesting the introduction of more productive varieties as being the only solution for the continuity of the rice terraces. This represents a typical trade-off in ecosystem services and benefits, as farmers must choose between the protection of biological and genetic diversity in their field, which has, for centuries, influenced their cultural heritage, and a higher crop production, needed in most families of the region.

All these disturbances tend to move the social-ecological system of Banaue away from its "traditional" domain of attraction, as described between the first ethnological accounts and 1980's start of drastic changes. Among consequences of the pressures are biodiversity loss, and damage or abandonment of rice terraces. However, there are still important gaps in knowledge concerning these two impacts. Many species are still to be discovered or monitored and all introduced species do not have adverse effects. Concerning the abandonment of terraces, different figures have been given, ranging from 1% (Bantayan et al., 2012) for Batad and Bangaan, to 15% for the municipality of Banaue (Herzmann et al., 1998) and 25-30% for the Ifugao province (UNESCO, 2002). Such a high figure for the whole province comes from the fact that more abandonment occurs outside the Banaue area, e.g. Nagacadan. In these municipalities, the little interest of tourists results in lower funding from the government to repair damaged terraces and the conversion of rice terraces for cash crops are needed to insure a monetary income (Gomez, 2003).

3.3. Literature review

Information on the study area was first collected through a systematic search of the scientific and grey literature at the library of the International Rice Research Institute (IRRI)[2] during a six week stay at the Institute, from March to May 2013. IRRI is a major research center on rice in the world and its library collects an important amount of publications on rice production. Since the inhabitants of the municipality of Banaue rely heavily on rice production, most publications from any fields ultimately relate to rice cultivation. Furthermore, as IRRI is hosted by the University of the Philippines in Los Baños (UPLB), the library of IRRI holds many master theses and doctoral dissertations from past students of one of the Universities of the Philippines. Online literature search was done using google.com and the ISI Web of Science search engines by employing the following key words to identify relevant papers;

[2] URL link: http://irri.org/

- For background information on the rice terraces: Topic=(Ifugao OR Banaue OR Poitan OR Bangaan OR Batad OR “Cordillera Administrative Region” OR “Philippines rice terraces” OR “Luzon rice terraces”)
- For conceptual considerations related to resilience: Topic=(Resilience OR Adaptability OR Vulnerability OR Agroecosystem OR “Social-ecological” OR “Human-environmental system”)

There were no requirements concerning the publication date of the articles, but recent ones were preferred in the case of the theoretical framework. This literature review was necessary to acquire background information on the rice terraces and culture in Banaue to build a questionnaire for the household interviews. The search resulted in 116 publications concerning Ifugao, most of which were used for this study. Relevant data that will complement the information received during the surveys were also gathered from the literature search.

3.4. Household surveys

Household surveys were conducted in the municipality of Banaue in the province of Ifugao in a four week period, from May to June 2013. A questionnaire (in Appendix I) was designed to obtain data concerning the eight indicators to assess the state of the social-ecological system (see the flowchart of the questionnaire conception and survey methodology, Figure 7). A prior field work with interviews involving other LEGATO project members in Lao Cai, Vietnam in April 2013 helped for the conception of the questionnaire. Semi-structured interviews were carried out in three areas of the municipality; barangay (smallest administrative unit in the Philippines and almost synonymous with the traditional agricultural district sharing the same watershed) Batad, barangay Bangaan and the town of Banaue composed of barangays Tam-an, Viewpoint and Poitan (Figure 8). These barangays are five of the six sampling sites chosen as part of the LEGATO Project.

The last site, Hingyon Poblacion, is in a different municipality, Hingyion, and was not included in this present research owing to its remoteness and because it is in a different municipality. The rice terraces of the municipality of Banaue are characteristically situated on the middle and lower slopes of the mountain landscape, between 900 and 1,100 meters above sea level (Joshi et al., 2004).

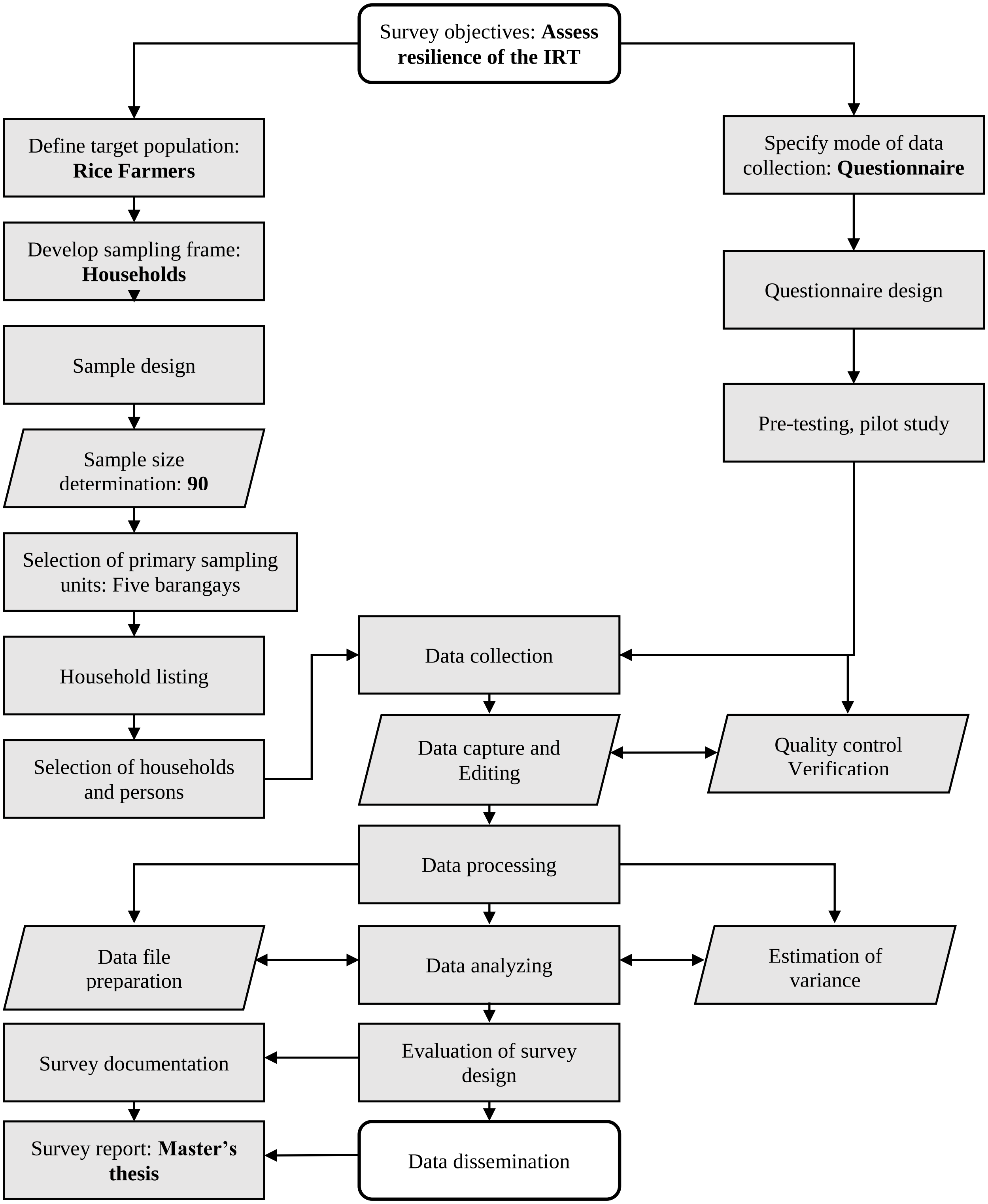


Figure 7 Flowchart of the survey process (based on Yansaneh, 2005).

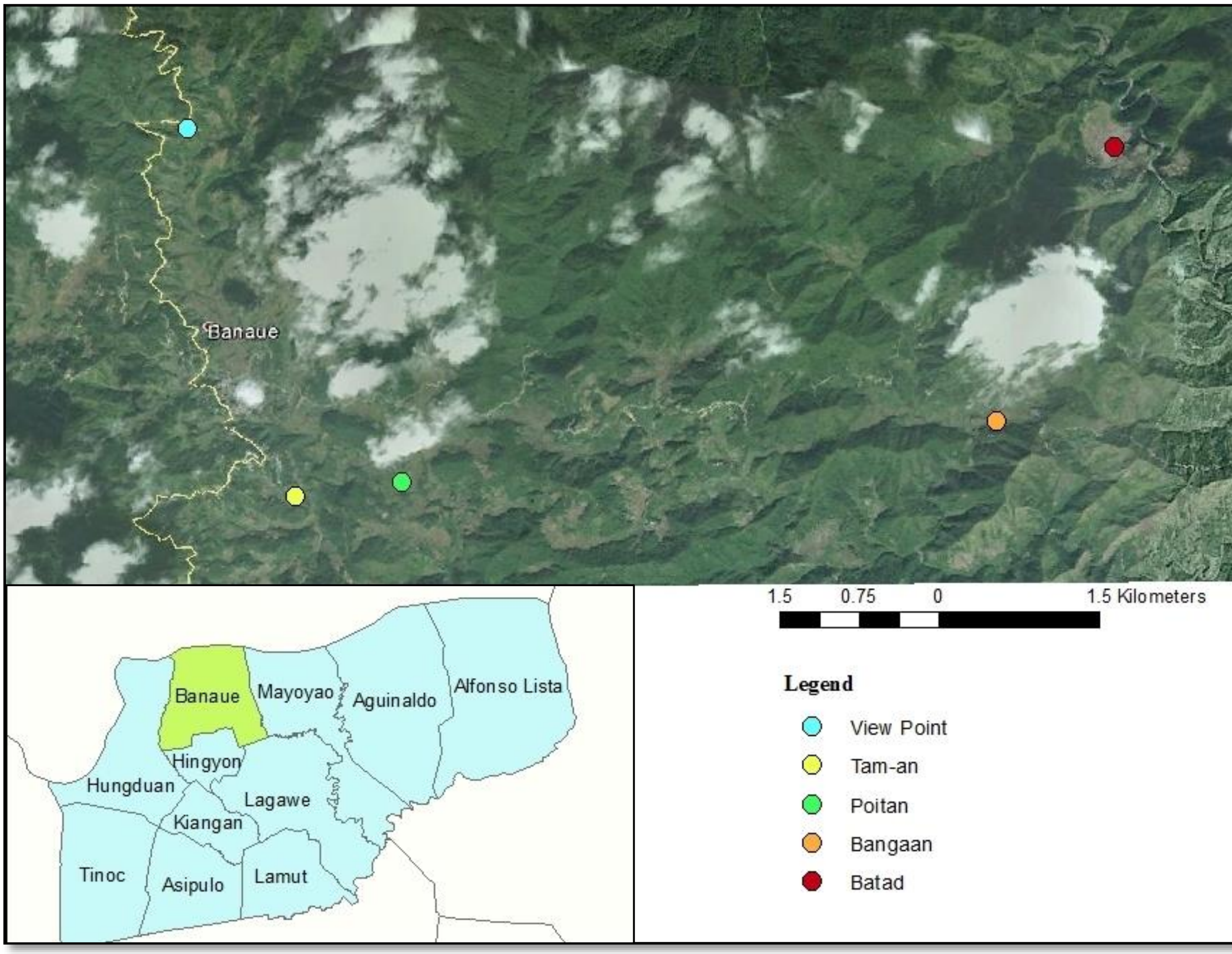


Figure 8 Location of the five research sites in the Municipality of Banaue (Source: Google Earth).

Among the selected sites for this research, only Batad and Bangaan are part of the UNESCO-WHS of the Ifugao Rice Terraces (UNESCO, 1995). The rice terraces of Viewpoint, Tam-an and Poitan, despite the impressive landscape, were allegedly excluded from the UNESCO sites because of the unregulated urban sprawl and cemented trails between the paddies (Marcos Mulao, personal communication, May 2013). 30 households were surveyed randomly in Bangaan, as well as in Batad. 10 households were surveyed in each Poitan, Tam-an and Viewpoint, for a total of 30 in the surroundings of the town of Banaue. Most people, including farmers, can speak English in Banaue. Thus, the questionnaires were not translated to Ifugao, the local language.

In accordance with the Nagoya Protocol on Access and Benefit-sharing, the barangay *capitan* (community leaders of each areas) were contacted personally at the barangay halls (i.e. town hall) or at their residence before starting the interviews in the respective barangay. Indeed, under the

Article 7 of the Protocol, consent from community leader must be given before using traditional indigenous knowledge concerning biodiversity (Kamau et al., 2010).

In two cases (barangays Tam-an and Viewpoint) the barangay *capitan* provided a person knowledgeable of agriculture, the local Committee Chair on Agriculture, who assisted the interviews and facilitated the interpretation. For other areas, a local farmer (in Bangaan) and a tourist guide (in Batad) assisted the interviews and helped to find farmers to participate to the interviews. In Poitan, interviews were done in the presence of the barangay *capitan*.

The surveys were followed by key informant interviews with two employees of the Municipal Agriculture Office of Banaue, one barangay *capitan* and two homestay owners. This step was important to identify species and rice varieties under different names depending on the localities, as well as having a general overview of the municipality.

The questionnaires included different questions relating to the eight indicators chosen to assess the state of the social-ecological system (Table 5). The results were analysed with descriptive statistics, including means, frequencies and percentages. The geographic mean was used to normalize the results of each proxies and compare the values for each barangay with the mean.

Biodiversity of rice varieties, aquatic species and plants species in woodlots were measured using the following two indices of biodiversity;

1) Richness R, which quantifies the number of different species in the community.
2) Shannon index (H) and Shannon's equitability (E_H):

$$H = -\sum_{i=1}^{R} p_i \ln p_i$$

$$E_H = H / \ln R$$

where p_i is the proportion of individuals found in species i (Shannon, 1948; Magurran, 1988).

When possible, the respondents were asked about changes in indicators in the last 10 years. Alternatively, the results from the questionnaires were compared to data from previous literature and data from the Bureau of Statistics of the Philippines. Graphics were generated using the software MS Excel 2013 and the R statistical software v2.15.2 (R Development Core Team, 2011).

Table 5 Indicators for social-ecological resilience of indigenous cultural landscapes.

		Sectorial indicators	Proxy variables	Original value and source
Social resilience	Food security	Food sovereignty and self-sufficiency	Number of months that households can self-sufficient with their rice production.	6-12 (Barton, 1919)
			Number of food sources produced by farmers (excluding from rice fields).	4 (Conklin, 1980)
	Economics	Profitability	Income from agricultural production.	~0 (Conklin, 1980)
			Proportion of household involved in tourism.	~0 (Barton, 1919)
	Knowledge	Traditional ecological knowledge and practices	Proportion of households practicing rituals related to rice production.	100% (Conklin, 1980)
			Proportion of households still maintaining traditional land use (*Inado*).	100% (Conklin, 1980)
	Demographics	Population change	Proportion migrating household members.	Low (Barton, 1919)
			Number of households practicing traditional inheritance system (primogeniture).	100% (Barton, 1922)
Ecological resilience	Ecosystem structure	Landscape heterogeneity and fragmentation	Variety of land uses cultivated.	4 (Conklin, 1980)
		Biotic diversity	Diversity of rice varieties grown.	30-80 (Conklin, 1980)
			Diversity of woodlot plants.	171 (Conklin, 1967a)
			Diversity of aquatic species.	-
	Ecosystem processes and functions	Multiple uses of land and plants	Number of uses of plants collected in the woodlots.	7 (Conklin 1980)
			Proportion of households using rice plants for mulching.	100% (Conklin 1980)
		Disturbance regime	Damaged terraces per household.	low
			Damaged irrigation canals.	low
			Proportion of invasive pest species.	0 (Barton, 1922)

3.5. Indicators

The development of the rice terraces in Ifugao cannot merely be considered as two stable states separated by a period of drastic change. For instance, the introduction of exotic species modifying the biotic composition occurred at different periods. Most changes occurring are continuous and a state may be considered as stable only if the agents are adapted to the new structures. However, some periods have been described as more stable and experiencing less drastic changes. The indicators describing the social and ecological organizations are used to assess the change between the early "traditional" and the current state of the system (Table 5). Information and data from previous literature was taken to give a value to the indicators for the "traditional" state of the system. To assess the current state, the information received from the surveys was applied.

Some values were well described in the literature, e.g. food sovereignty, traditional ecological knowledge and multiple uses of land and plants, but some proxies, e.g. diversity of aquatic species and rice varieties have not been thoroughly documented. In the latter case, only a trend can be assumed from the farmers' interviews.

Because of the very high complexity in social and ecological systems, it is virtually impossible to measure with certainty the resilience level and the development stage. Indicators are therefore a useful tool to simplify such complex dynamics. However, it is important to keep in mind that indicators must be analyzed in a combination since single parameters may be misleading.

3.6. Limitation of the study

The areas surveyed are the most visited by tourists of the Banaue municipality, the latter receiving 90% of the tourists going in the Ifugao province (SITMo, 2008). Other towns may have a very different development without the impacts or opportunities of tourism. Therefore, conclusions from the present case study may not be applicable to every barangay of the municipality of Banaue or the Ifugao province. Furthermore, the interviews targeted mostly farmers to give an overview of the dynamics of the cultural landscape, although not every residents in Banaue own a rice field. The biodiversity assessment relates to species being used by the farmers. Exhaustive biodiversity investigation, including for instance arthropods, which can play an important role in biological pest control, would render a better assessment of biodiversity and resilience. However, due to the limited time and resources available for this study, a complete assessment could not be done.

4. Results

The following section refers to the analysis of data obtained from the household surveys. The results are divided among the eight indicators of the state of the system. The section ends with a compilation of the results for all indicators and a comparison of the current state with the "traditional" state to assess the resilience of the system.

4.1. Socio-demographic characteristics

Overall, slightly more than half of respondents (54%) were female (Table 6). The same proportion of males and females were surveyed in Batad while more females were surveyed in Bangaan (63% as opposed to 37% males).

Table 6 Gender in percentage of respondents.

	Male		*Female*	
Barangay	Number	%	Number	%
Banaue (*n*=30)	12	40	18	60
Bangaan (*n*=30)	11	37	19	63
Batad (*n*=30)	15	50	15	50
Total (*n*=90)	38	42	52	58

The population sampled in Bangaan is the youngest in average, with a mean age of respondents of around 47 years old. The mean age of Batad respondents is the highest at around 53 years old, while the mean age of respondents of Banaue stands in the middle at 49 years old. Batad also had the largest range in the age of respondents with 67 years between the youngest and the oldest respondents (22 and 89 years old, Figure 9). This high discrepancy can be useful to give different information about the survey. For instance, younger respondents might give a better idea about the contemporary status of traditional knowledge and practices, as older respondents might have more extensive knowledge of biodiversity in woodlots and in rice paddies.

As birth certificates were not available before World War II, some of the respondents did not have any records of their year of birth and therefore did not know their age. This was the case for six respondents in Batad, three in Bangaan and one in Banaue. In this case, their age was estimated to an average of 80 years old.

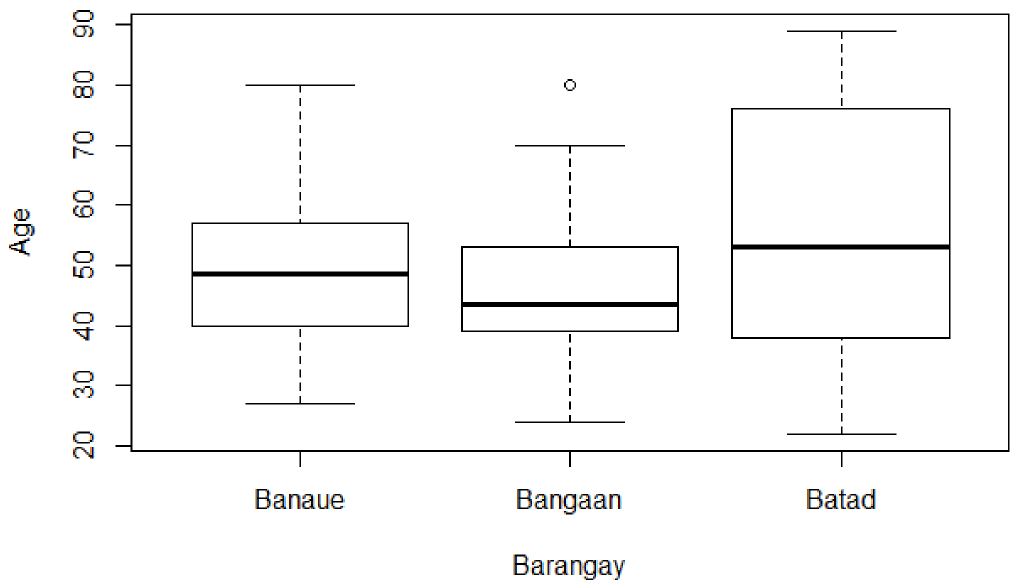


Figure 9 Boxplot of the respondents' age in the three areas surveyed (*n*=83).

4.2. Food sovereignty

Food sovereignty was measured by the number of months the households can satisfy themselves with their rice production. Also, the number of food sources produced by farmers (from rice fields, forest, swidden fields, *inado*) is used as the second proxy of food sovereignty.

4.2.1. Autonomy from own rice field

The mean number of months for which households could consume their own rice ranged from 4.8 to 6 months (Table 7). These number do not differ significantly from the numbers given in the literature, which was around six months (Conklin, 1980). However, the mean number of months of self-sufficiency was lower in the three barangays compared to the recalled number of months of 10 years before.

A small majority of households in Banaue (56%) and Bangaan (53%) have noticed a decreasing sufficiency of rice in the last 10 years. Only a minority of households in the three barangays have enjoyed an increased sufficiency of rice (20% in Banaue and Batad and 26% in Bangaan).

Most respondents (76%) explained their decreasing food sovereignty by having a bigger family than before. Other reasons were the lack of sweet potatoes from the discontinuation of swidden fields (10%), the abandonment of rice terraces (8%) and decreasing yields (8%).

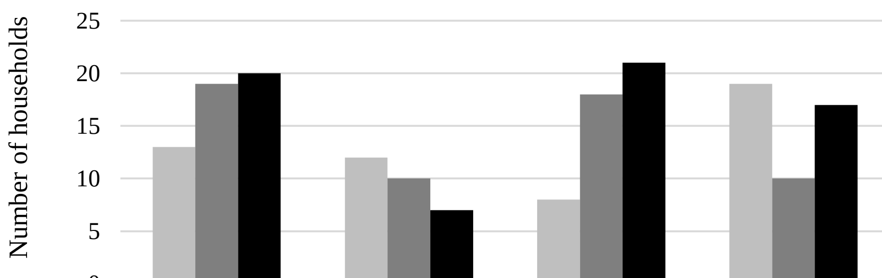
Table 7 Self-sufficiency of households from their own rice fields by the number of months and number of households witnessing a change in self-sufficiency.

	Banaue (*n*=30)	Bangaan (*n*=30)	Batad (*n*=30)
	Number of months		
Mean number of months of self-sufficiency per household	5.7	6.0	4.8
Estimated mean number of months of self-sufficiency 10 years ago	6.0	6.9	5.2
Change in the months of self-sufficiency	-0.3	-0.9	-0.3
	Number of households		
Households with increasing sufficiency	6	8	6
Households with decreasing sufficiency	17	16	13
Households with no change in sufficiency	7	6	11

The reasons for higher yields were the introduction of a new rice variety and a better maintenance of their terraces (8 and 2 households respectively). Reasons for decreasing yields were more plentiful. These ranged from pest damage (33 households), climate and hydrological regime change (13), erosion (12), abandonment of rice terraces (6), late planting (3) and other reasons (3).

4.2.2. Number of food sources

Households in Batad are the ones conserving more land uses for food with a mean of 2.1 sources of food per household, followed by Bangaan (1.8) and Banaue (1.7). This order is to be expected since Banaue is the location of the regional market where plenty of goods can be bought, while the remote location of Batad may compel farmers to be more self-sufficient.



	Woodlots	Swiddens	Garden	Inado
Banaue	13	12	8	19
Bangaan	19	10	18	10
Batad	20	7	21	17

Figure 10 Different sources of food maintained per household in each barangay (*n*=90).

The traditional *inado* is still practiced in more than half of households in Banaue and Batad but in only one-third of Bangaan households (Figure 10). Gardens and private forests are maintained by nearly two-thirds of households in Batad and Bangaan, whereby they are cultivated by less than half (gardens) and less than one-third (forests) of Banaue households. Swidden fields have definitely decreased in Banaue, being maintained by only 12 households in Banaue, 10 in Bangaan and 7 in Batad. This change was to be predicted since swidden cultivation is rapidly decreasing around the world (Van Vliet et al., 2012).

Households cultivate in average 3.42 different crops in their swiddens and 3.26 in their gardens. Most cultivated varieties in swiddens and gardens include sweet potatoe (*Ipomoea batatas*), ginger (*Zingiber officinale*), string bean (*Phaseolus vulgaris*), Chinese cabbage (*Brassica rapa*) and onion (*Allium cepa*).

4.3. Profitability

The current level of profitability of the social-ecological system is measured here by the different sources of income for the farmers. Although migration remittance could be considered as a source of income, it is not taken into account here because the income comes from the outside of the system and can be difficult to measure. Therefore, the two proxies of profitability used are the income from agricultural products and the income from tourism.

4.3.1. Income from agricultural products

Because of the low yield of the *tinawon* variety, rice production in Ifugao has never been a profitable activity (Barton, 1922; Acabado, 2012). This characteristic of the system did not seem to change since only three households could sell rice in a small quantity in Bangaan compared to one in Batad and none in Banaue (Table 8). Other agricultural products were comparably more

Table 8 Number of households with different forms of income.

	Number of household					
	Banaue (*n*=30)		Bangaan (*n*=30)		Batad (*n*=30)	
	n	%	n	%	n	%
Households selling agricultural products	4	13	9	30	5	17
Household selling rice	0	0	3	10	1	3

profitable in the three barangays. Indeed, nine households in Bangaan, five in Batad and four in Banaue were able to sell some vegetables for a source of income.

4.3.2. Income from tourism

Wood carvings were the products mostly commercialized, especially by farmers in Banaue (40% of households), understandably because of the greater accessibility to the market and retailers (Table 9). Overall, wood carving was the most common source of income from tourism, especially in Banaue, followed by tourist guiding, the selling of handicrafts (e.g. as a middlemen), homestay and massage. In total, half the population surveyed received some income from tourism. However, most households were unable to give a number or percentage concerning the income from tourism on the total income. Only two households received around 90% and 100% of their income from their homestay. Farmers in Banaue and Batad had a long experience in tourism, with an average of 18.6 and 19.1 years per person respectively, compared to 9.5 years for farmers in Bangaan, which is often overlooked by tourists.

Table 9 Number of households with at least one member involved in different forms of tourism (more than one answer was possible) and mean number of years of experience for households currently involved in tourism.

	Number of household			
	Banaue (*n*=30)	Bangaan (*n*=30)	Batad (*n*=30)	Total (*n*=90)
Wood carving	12	6	3	21
Guide	2	4	10	16
Selling handicrafts	7	4	2	13
Homestay	0	1	2	3
Massage	0	0	2	2
Households involved in tourism	21	11	14	46
Previously carving wood	6	2	1	9
Mean number of years of experience in tourism	18.61	9.50	19.14	15.75

4.4. Traditional ecological knowledge and practices

The traditional ecological knowledge of the Ifugao is vast and should be further examined and documented. In this study, the number of households still practicing rituals, the number of rituals exercised and the proportion of households cultivating the *inado* are the three proxies to quantify the remaining traditional ecological knowledge.

4.4.1. Number of households still practicing rituals

The surveys showed that very few households still practice rituals related to agriculture in the municipality of Banaue. Only three households have kept rituals in Batad and Bangaan, while 11 households have conserved this traditional custom in Banaue (Table 10). The reasons mentioned by the farmers to explain this change are the erosion of the traditional culture due to Christianization, and the costs associated with the sacrifices required during rituals involving chickens and pigs. Households in Banaue still retaining rituals also practice more rituals with a mean of 4.5 rituals per household per year. Bangaan households still do in average 3 rituals and only 1.3 rituals are practiced in average in Batad.

Table 10 Number of households still practicing rituals and average number of rituals per households per year.

	Households still practicing rituals		Average rituals practiced by households
	n	%	
Banaue (*n*=30)	11	37	4.55
Bangaan (*n*=30)	3	10	3
Batad (*n*=30)	3	10	1.33
Total (*n*=90)	17	19	

4.4.2. Proportion of households doing inado

The *inado*, or mounds made of rice straw, weeds and mud in the rice field, is a traditional ecological practice from Ifugao. It has the double function of providing food in the rice off-season and recycling nutrients. More than half of households interviewed still cultivated the traditional *inado* in Banaue and Batad (63% and 53%, respectively), whereas only a minority did in Bangaan (27%, Table 11). The reasons mentioned to explain why *inado* was no more practiced is the lack of time or the hard work required, because of the insufficient amount of water in the paddies and because of the lack of biomass caused by apple snail grazing.

Table 11 Proportion of households cultivating *inado*.

	Number of household					
	Banaue (*n*=30)		Bangaan (*n*=30)		Batad (*n*=30)	
	n	%	n	%	n	%
Households still cultivating *inado*	19	63	8	27	16	53
Households not cultivating *inado* anymore	11	37	21	70	13	43
Households occasionally cultivating *inado*	0	0	1	3	1	3

4.5. Demographics

Population dynamics may be one of the most important indicator of resilience, and can also have a great influence on other indicators such as food sovereignty. Settele (1998) notes that population growth may have been the main reason why rice and sweet potatoes can no more supply the local population, forcing the farmers to find jobs outside the agricultural sector. Population growth, with market forces, is seen as the cause for rapid and widespread deforestation that occurred in the upland Philippines after the World War II (Hayama, 2003).

In the last 20 years, the population of the barangays near the town of Banaue has constantly increased (Figure 11). Conversely, the more isolated barangay of Batad has seen its population

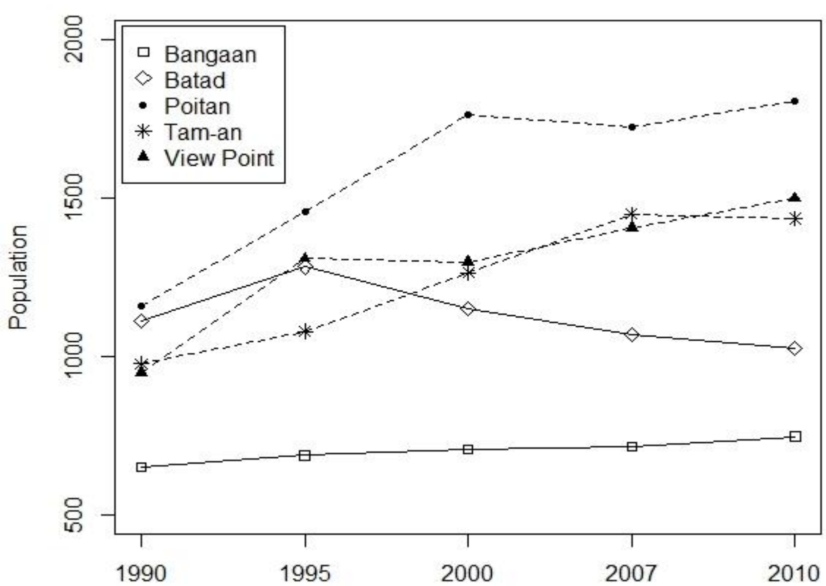


Figure 11 Population change in Banaue from 1990 to 2010. Dashed lines represent the barangays near the town of Banaue (sources: Barthelmes et al., 1998; NSCB, 2012).

decrease since 1995 and the population growth of Bangaan has been more moderated than in Banaue.

The two proxies used to assess the dynamics of population change are the application primogeniture inheritance rights and the migration rate among households.

4.5.1. Proportion of households practicing primogeniture

A majority (60% in Banaue, 97% in Bangaan and 77% in Batad) of households across the municipality of Banaue still practice primogeniture (Table 12). There is also a slight proportion (10% in Banaue and 3% in Batad) using a variation of primogeniture as inheritance rule. This variation generally entails leaving the biggest terrace to the first child and small parcels for the remaining children. Few households divide the terraces equally among their children in Bangaan and Batad (3% and 7%, respectively) although the equal division seems to be gaining in popularity among Banaue households (16%).

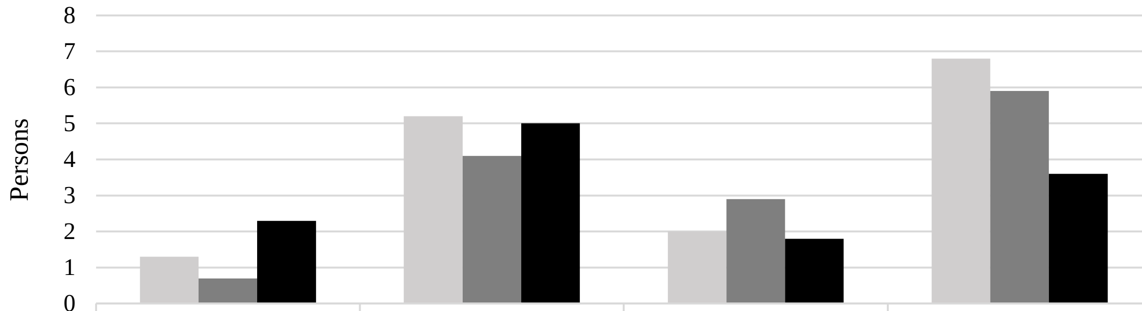
Table 12 Number of households currently practicing primogeniture in each barangay.

	Number of households practicing primogeniture							
	Yes		No		Variation		Not applicable	
	n	%	n	%	n	%	n	%
Banaue (*n*=30)	18	60	5	17	3	10	4	13
Bangaan (*n*=30)	29	97	1	3	0	0	0	0
Batad (*n*=30)	23	77	2	8	1	3	4	13
Total (*n*=90)	70	78	8	9	4	4	8	9

4.5.2. Household size and migration

Biggest families were found in Banaue where families have a mean of 5.2 children, followed by Batad 5 children) and Bangaan (4.1 children). Families in Banaue and Bangaan have been reduced in the last generation since the families now count in average 1.6 and 1.8 persons less. Families in Batad however have increased of 1.4 persons more on average by family compared to the previous generation. However, this difference maybe be due to the higher age of respondents in Batad.

Batad had the highest proportion of migration among children in households with 2.3 children on average leaving the barangay (46% of all children), followed by Banaue (1.3 children) and Bangaan (0.7 child). Children in Banaue and Bangaan are less going abroad than the previous



	Children abroad	Total children	Siblings abroad	Total siblings
Banaue	1.3	5.2	2	6.8
Bangaan	0.7	4.1	2.9	5.9
Batad	2.3	5	1.8	3.6

Figure 12 Population figures in Banaue per household in each barangay.

generation. The high proportion of migrating children is coherent with the population dynamics of Figure 12, which shows a constant declining trend of the population of Batad.

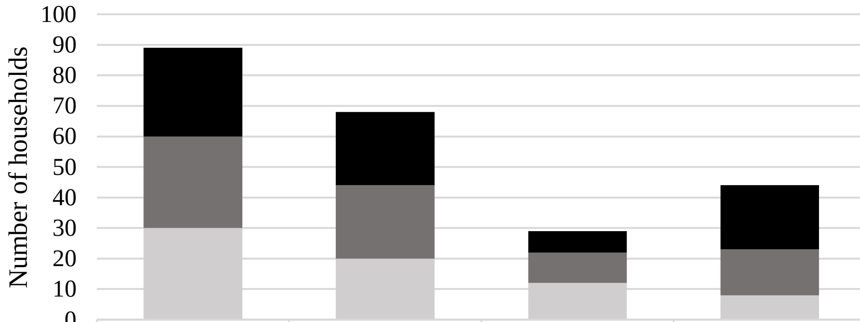
4.6. Landscape heterogeneity

Landscape heterogeneity was calculated by the number of land uses still cultivated by the Ifugao farmers. It is complemented by figures of land cover in the literature.

4.6.1. Land uses maintained per household

Beside rice fields, the forested areas were the most common land uses, being maintained by 67% of households in Banaue and 80% of both Bangaan and Batad households (Figure 13). The third most common land use was the private gardens cultivated in a quarter of Banaue households, half of Bangaan households and 70% of Batad households. Finally, less than half of respondents in each barangay are still maintaining swidden fields. The main reason for the abandonment of swiddens is the labor and time needed for the maintenance and also pests such as rats and wild pigs.

In their land cover assessment, Herzmann and colleagues (1998) noticed a change in land cover characterized by less swidden and caneland. By comparing land cover maps of 1963 and 1998, they noted that caneland and swidden declined from 35% to 14% and 7% to 1% of the total land cover of Banaue, respectively. The authors also noticed an increase of forest cover, rising from 15% to 35% of the total area.



	Paddies	Woodlots	Swiddens	Gardens
Batad	29	24	7	21
Bangaan	30	24	10	15
Banaue	30	20	12	8

Figure 13 Land uses maintained in each barangay (*n*=90).

4.7. Biotic diversity

As mentioned earlier, biodiversity is an essential underlying basis for ecosystem functions and services, as well as for resilience. It is important to note here that the Ifugao paddies, the primary forests and even the cultivated woodlots are rich in biodiversity (Conklin, 1967b; Settele et al., 1998; Madulid, 2010). The proxies used to measure biodiversity are the diversity of rice varieties grown, the number of aquatic species used for food and the plants cultivated in the woodlots. Although many more "unused" aquatic species and plants varieties may be overlooked, an exhaustive biodiversity assessment would require a more resource-intensive and lengthy field work.

4.7.1. Diversity of rice varieties

There is no official count concerning the number of traditional rice varieties in Ifugao. It was stated in the past that more than 100 varieties could be cultivated in the province (Roxas, 1996; Settele, 1998) although more recently, Druguet (2009) counted only around thirty. This present study allowed to identify in total 17 varieties in the three barangays surveyed (Table 13). As mentioned previously, *tinawon* and *pinidua* are the two most common traditional varieties. Several varieties were grown exclusively in Batad, including *buyabuoy, ingeneh, imbongo and ingulla* (Figure 14). *minangan* and *minayao* are two varieties from Ifugao although originally from different municipalities – Hungduan and Mayoyao, respectively.

Table 13 Rice varieties cultivated in the three study sites

	Ifugao name	Origin
1	Buyabuoy	Native from Batad
2	Linagwang/pinidua	Native from Banaue
3	Tinawon	Native from Ifugao
4	Ingulla	Native from Batad
5	California/Minayao	From Mayoyao, Ifugao
6	Ingeneh	Native from Batad
7	Imbongo	Native from Batad
8	Tobja	Unknown
9	Okland	Native from Ifugao
10	Minangan	From Hungduan, Ifugao
11	Intan	From lowland
12	Tutu	Unknown
13	C4	From Lowland
14	IR72	From Lowland
15	Biit	From Lowland
16	Tadian	From Mt Province
17	Palawan	Upland variety

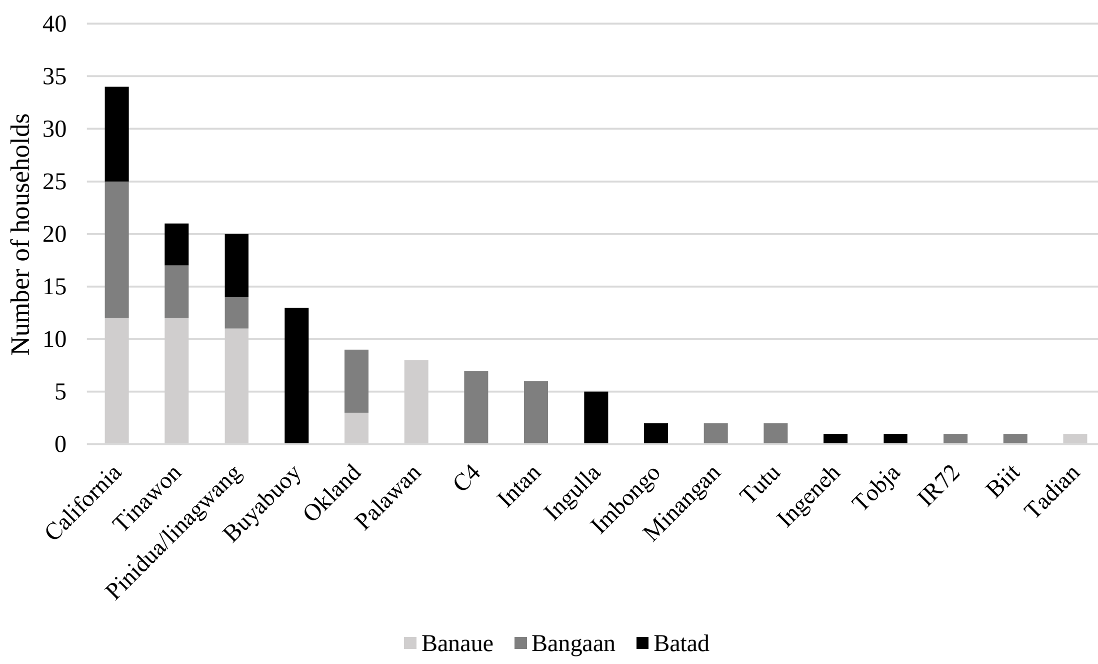


Figure 14 Rice varieties in each barangay by number of households (*n*=90).

Two varieties were of unknown origin (*tutu* and *tobja*) while five were introduced from outside the province (IR72, C4, *intan*, *biit*, *tadian*, *palawan*).

Batad was the barangay growing the highest proportion of endemic (from the municipality of Banaue) varieties (76%), compared to nearly half in Banaue. Farmers in Bangaan grow the highest proportion of introduced varieties, with only 17% being endemic. This may be a sign of a shift towards the intensification of rice production while traditional varieties are being lost.

4.7.2. Diversity of aquatic species in rice fields

The data gathered to assess the diversity of aquatic species in rice fields does not come from an exhaustive census but rather comes from the following questions asked to farmers:

1) How many sources of food do you have in your rice field? and;
2) How many sources of food did you previously have that you don’t find in your rice field anymore?

The aquatic species in question thus concern those that are used for food and do not concern those species that are not used by farmers or used for different purposes, e.g. as livestock feed. The results show that many different species are used for food in the rice fields. *P. canaliculata, Potamides* spp.*, Vivipara burroughiana,* the native bivalve called *te’am* (*Dalliella* spp.) and the *tamtampi*, small introduced fish, are found in half the rice fields or more in the three barangays (Table 14). *Lymnaea viridis* and *Pila luzonica* are two native snails (Conklin, 1980) that are currently only rarely found around Banaue.

4.7.3. Diversity of plant species in woodlots

Forested areas, called *muyung* in Banaue, hold an impressive array of varieties despite being managed for centuries. In total, 67 species were recorded in the municipality. This is certainly an underestimate since not every respondent knew plant varieties very well and because farmers are more likely to know the varieties of plants that are useful to them. Therefore, this analysis of plant diversity refers to the plants varieties useful to local people. Batad was the barangay with the highest number of varieties recorded (50) followed by Banaue (33) and Bangaan (31). The overall biodiversity figures do not provide clear conclusions concerning the overall biotic diversity in each barangay.

Table 14 Number of households collecting aquatic species for food consumption. The first category refers to the number of household currently collecting aquatic species. The second category refers to the number of households that previously (10 years ago) collected the species, the latter not being present anymore.

	Number of households with currently occurring species				**Number of households with previously occurring species**			
	Banaue (*n*=30)	Bangaan (*n*=30)	Batad (*n*=30)	Total (*n*=90)	Banaue (*n*=30)	Bangaan (*n*=30)	Batad (*n*=30)	Total (*n*=90)
Molluscs								
Golden apple snail (*Pomacea canaliculata*)	30	30	28	88	0	1	0	1
Aggudong (*Potamides* sp.)	22	29	18	69	3	0	10	13
Olippo (*Vivipara burroughiana*)	15	23	20	58	2	3	6	11
Te'am (*Dalliella* sp.)	15	17	17	49	2	8	7	17
Introduced *te'am*	13	10	15	38	0	0	1	1
Ginga (*Lymnaea viridis*)	1	1	0	2	21	26	29	76
Batikul (*Pila luzonica*)	0	1	0	1	14	23	28	65
Fish								
"Million fish" (*tamtampi*)	18	24	27	69	1	1	3	5
Yuyu (*Miagurnos anguillicaudatus*)	13	21	7	41	14	7	20	41
Tilapia (*Tilapia nilotica*)	3	17	17	37	7	3	7	17
Dulog (*Channa striata*)	0	1	10	11	11	8	18	37
Crustacea								
Native crab (*allama*)	7	10	14	31	5	2	5	12
Introduced crab (*allama*)	0	2	1	3	0	1	0	1
Crayfish (*uchang*)	1	1	1	3	7	9	17	33
Amphibians								
Toad (*tuyong*)	9	7	16	32	3	3	14	20
Frog (*tukat*)	0	2	2	4	0	1	0	1

The most commonly grown variety across the three study sites is the betel nuts tree (*Areca catechu*), locally named *moma*, which is widely used for chewing in the province of Ifugao (Table 15). Other varieties frequently used for food are avocadoes (*Persea Americana*), rattans (*Calamus trispermus*) and native and introduced banana varieties (*Musa errans and Musa* spp., respectively). Many varieties are used for construction, especially the *palayon* (*Lithocarpus ilanosis*) and *hangatchen* (*Symplocos* sp.), as well as the introduced *jermelina* (*Gmelina arborea*) and pine trees (*Pinus kesiya*). Finally, sunflower plants (*Tithonia diversifolia*) were used as fertilizers in rice fields.

Table 15 Number of households cultivating the most common plant varieties in woodlots (n=90). i and e represent indigenous and endemic species respectively.

Local name	Family	Scientific name	Use	Number of households
Moma[i]	Palmae	*Areca catechu*	Food, medicinal	37
Palayon[e]	Fagaceae	*Lithocarpus Solerianus*	Firewood, timber	34
Avocado	Lauraceae	*Persea americana*	Food	28
Sunflower	Compositae	*Tithonia diversifolia*	Fertilizer	28
Jermelina	lamiaceae	*Gmelina arborea*	Construction, wood carving	25
Rattan[e]	Palmae	*Calamus* spp.	Food, handicrafts	25
Pine tree	Pinaceae	*Pinus kesiya*	Construction	21
Hangatchen[i]	Symplocaceae	*Symplocos* sp.	Timber, medicine, firewood	19
Tuwor[i]	Euphorbiaceae	*Bischofia javanica*	Timber, firewood	16
Banana[e,i]	Musaceae	*Musa errans*/spp.	Food	15

Richness for rice varieties and aquatic species was slightly higher in Bangaan than in the two other barangays, but was significantly higher regarding plant species in Batad (Table 16). The Simpson's index (*H*) was also higher in Batad plant varieties in woodlots and aquatic species in paddies but the Evenness (E_H) was similar for the three barangays concerning rice and plant varieties and aquatic species.

Table 16 Diversity indices for rice varieties, aquatic species and private forests.

	Rice varieties			Plant varieties in woodlots			Aquatic species in paddies		
Barangay	H	Eh	Species Richness	H	Eh	Species Richness	H	Eh	Species Richness
Banaue	1.81	0.87	8	3.25	0.93	33	2.22	0.89	12
Bangaan	2.15	0.87	12	3.06	0.89	31	2.37	0.85	16
Batad	1.87	0.85	9	3.47	0.89	50	2.41	0.91	14

4.8. Multiple uses of land and plants

A few decades ago the Ifugao farmers were nearly self-sufficient by using the products from their surrounding ecosystems and requiring minimal imports (Barton, 1922). To measure whether the system is resilient in terms of utilization the farmers make of the ecosystems, the number of different uses of forest products and the number of households using rice plants as fertilizer were calculated.

4.8.1. Uses of forest products

The main use of plant species in the private forest is for firewood, followed by food and construction (Figure 15). In Batad, farmers use some plants (mostly *Tithonia diversifolia*) as fertilizer, whereas only a minority of farmers use forest plants for this purpose in Banaue and Bangaan. This shows a capacity to adapt to new conditions by using new plant varieties. Indeed, *Tithonia diversifolia* in not a native plant from the Philippines, but can be used as fertilizer given that the plant decays rapidly, and provides organic nutrient to the paddies (Magcale-Macandog et al., 2013).

A minority of households cultivated plants for medicinal uses or as pesticide to apply to rice fields. Also, few households used the wood from their woodlot for wood carving or tying (e.g. the use of rattan branches for furniture or cages). The farmers in Bangaan and Batad are using forest products for 4 and 4.1 purposes in average, respectively, whereas Banaue farmers use forest products in average for 3.4 purposes.

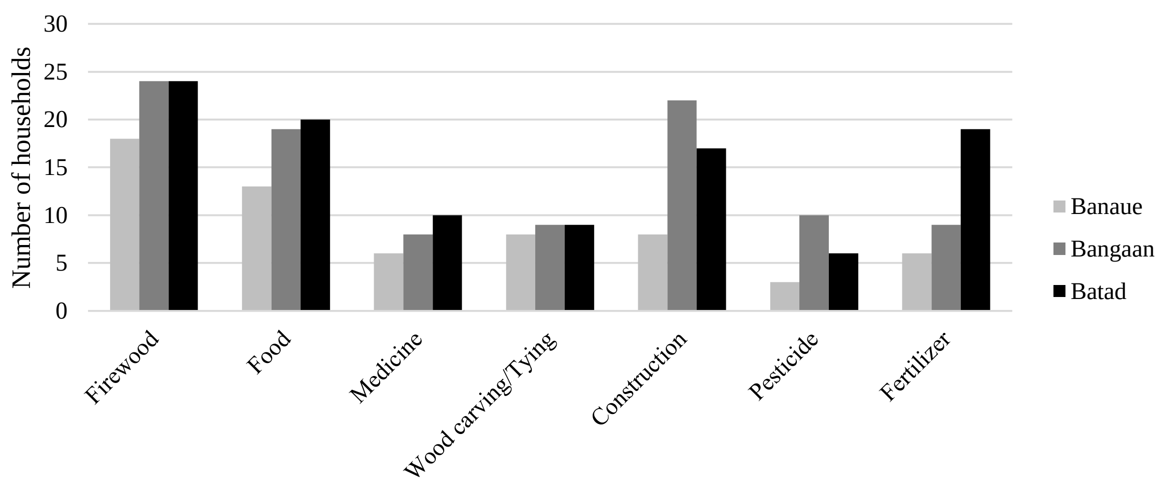
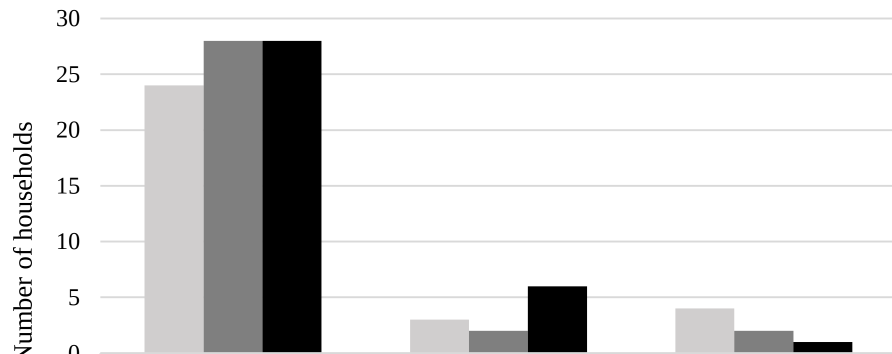


Figure 15 Different uses of plant species found in forested areas in each barangay by number of households (*n*=90).

4.8.2. Uses of rice plant

The use of rice stalks as fertilizer is part of the traditional ecological practices of the Ifugao people. Rice farmers in the lowlands of the Philippines normally burn rice residues after harvest to dispose of the rice biomass. Conversely, the Ifugao farmers harvest only the panicles from the rice plants and insert the rice stalks and straws in the soil. Although this biomass management practice has not been thoroughly studied, it is thought that it improves the recycling of nutrients, reduces greenhouse gas emissions and provides biomass for vegetable culture. Figure 16 shows that the mulching practice is still very common. Respondents mentioned that since rice stalks are inserted in the soil by trampling, harder stalks sometimes have to be burned, with the ashes distributed on the rice field.



	Mulching	Burning	NA
Banaue	24	3	4
Bangaan	28	2	2
Batad	28	6	1

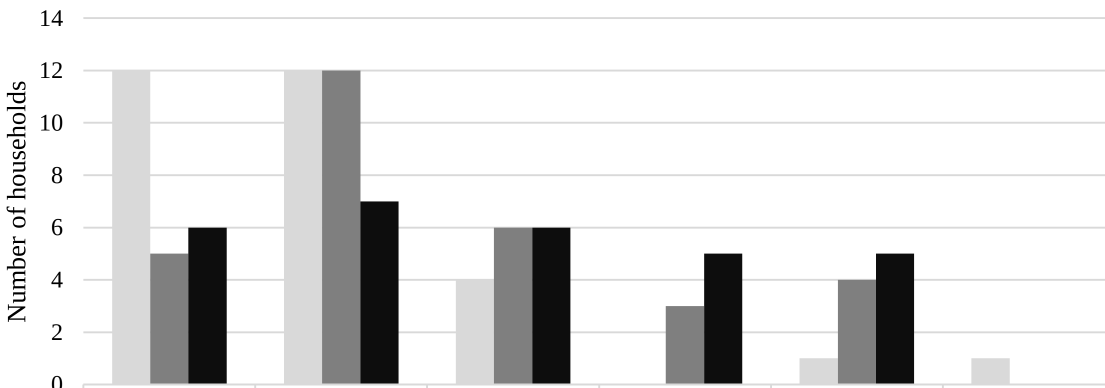
Figure 16 Uses of rice plant after harvest by number of househlds (*n*=90, more than one answer possible).

4.9. Disturbance regime

Abandonment of rice terraces has been noted on several occasions in the recent literature and is a concern among the inhabitants. The disturbances leading to the abandonment of terraces was measured by three proxies: the amount of damage on the terraces, the amount of damaged irrigation canals and the proportion of exotic species.

4.9.1. Amount of damaged terraces

Most households in the three barangays had less than 40% of damage on their terraces. Farmers in Banaue were the ones with terraces in better condition with 80% of respondents having less than 40% damage. Rice paddies in Batad were the ones in the worse condition with around 55% of surveyed households having more the 40% of their terraces damaged (see Figure 17). This result is unsurprising since Batad has steeper slopes than the other areas and is therefore more vulnerable to landslides and erosion.

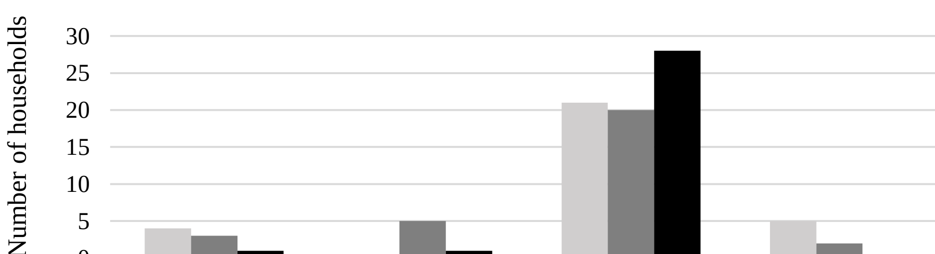


	0-20%	20-40%	40-60%	60-80%	80-100%	Does not know
Banaue	12	12	4	0	1	1
Bangaan	5	12	6	3	4	0
Batad	6	7	6	5	5	0

Figure 17 Proportion of damaged terraces by number of households (*n*=90).

If the condition of terraces does not seem alarming, most farmers noted a degradation of their terraces in the last 10 years (Figure 18). A majority of farmers in Batad (28) noted a deterioration compared to 21 in Banaue and 20 in Bangaan. Only 5 households in Bangaan and one in Batad thought that their terraces were in a better shape now.

The main reasons for the degradation of the terraces are climatic conditions and natural hazards (mainly drought and landslides), and pests (earthworms). Other notable reasons are the lack of time for the maintenance of the terraces and road widening (especially in Bangaan). The reasons noted for the improvement of the paddies are the financial help from UNESCO and from the Department of Agriculture of the Philippine government (Table 17).



	No change	Better now	Worse now	Does not know
Banaue	4	0	21	5
Bangaan	3	5	20	2
Batad	1	1	28	0

Figure 18 Change of the condition of the terraces over the last 10 years by number of households (*n*=90).

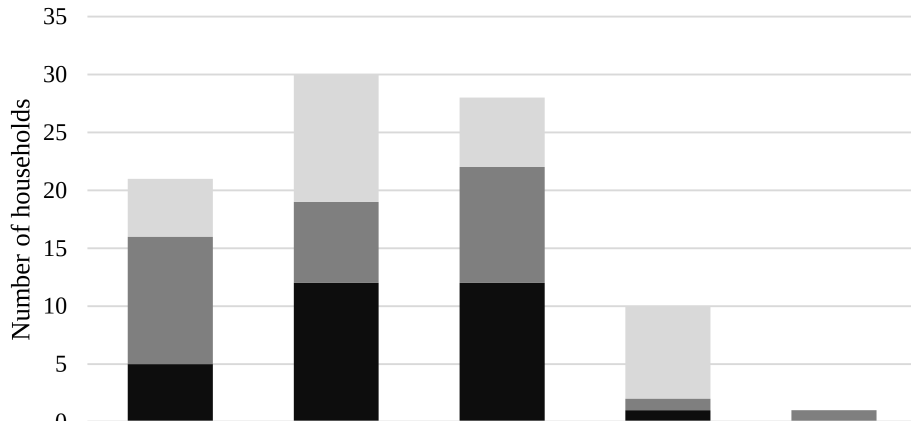
Table 17 Main reasons for the degradation and the improvement of rice terraces by number of households (more than one answer was possible).

		Number of households			
	Reasons for degradation	Banaue (*n*=30)	Bangaan (*n*=30)	Batad (*n*=30)	Total (*n*=90)
Climatic conditions, environmental disasters	Drought	3	8	13	24
	Landslides	5	8	8	21
	Too much rain	7	0	5	12
	Typhoon	2	2	2	6
	El Niño	1	2	3	6
	Eathquake	2	0	1	3
Total		**20**	**20**	**32**	**72**
Pest species	Earthworm	12	10	7	29
	Kiwit/eel	1	0	0	1
Total		**13**	**10**	**7**	**30**
Infrastructure development	Road widening	**0**	**5**	**1**	**6**
Others	Less time for maintenance	3	3	4	10
	No money for repair	1	0	0	1
	Takes more time to repair	1	0	0	1
	Terraces located oo far	1	0	0	1
Total		**6**	**8**	**5**	**19**
	Reasons for improvement				
	Funds from UNESCO	0	3	0	3
	Repaired by the Department of Agriculture	1	0	1	2
	Repaired	1	0	1	2
Total		**2**	**3**	**2**	**7**

4.9.2. Amount of damaged irrigation canals

Since paddies must be kept flooded during the rice growth season, irrigation canals should be functioning properly. Irrigation canals were in a relatively good condition in Banaue, although nearly one-third of the respondents did not know the condition (Figure 19).

If farmers in Banaue and Bangaan have noticed a slight deterioration of their irrigation in the last 10 years, most farmers in Batad (80%) have seen their irrigation system improved. This is largely because irrigation canals have been cemented and therefore less maintenance is required. Reasons for deterioration of irrigation systems were landslides and erosion, the lack of cement in canals, reliance of farmers on governments, less maintenance from farmers, earthworms, harder rain than before, narrow canals, and road widening creating erosions.

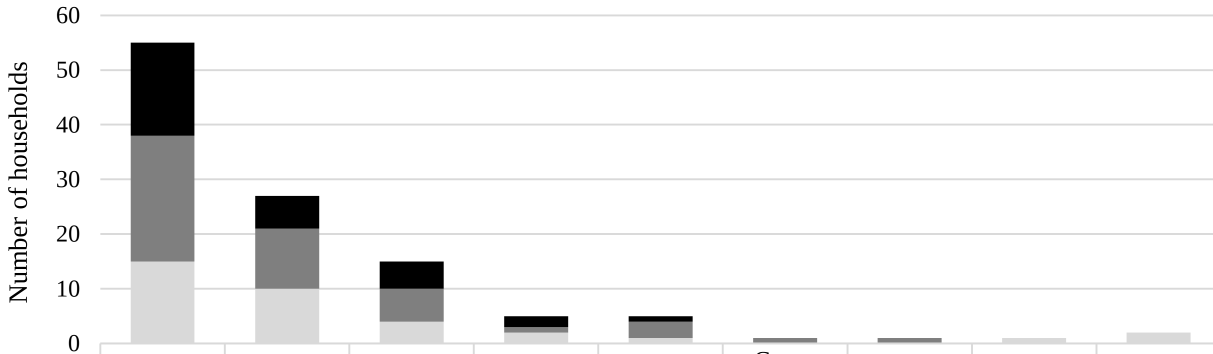


	Average	Good	Bad	Does not know	Rainfed/no irrigation
Banaue	5	11	6	8	0
Bangaan	11	7	10	1	1
Batad	5	12	12	1	0

Figure 19 Condition of irrigation canals by number of households in each barangay (*n*=90).

4.9.3. Proportion of invasive species

Pest species are becoming a major issue in the municipality of Banaue and contribute to a large extent to crop failures. Novel species combined with the loss of traditional knowledge of natural pesticides have made rice farming increasingly laborious. Farmers of the three barangays consider the “giant earthworm” to be the major pest in their rice fields (Figure 20). This observation is consistent with previous studies on pest species in Banaue (Joshi et al., 1999; Gomez and Pacardo, 2005). Rice terraces around Banaue are known to have a high organic matter content, a moderately acidic soil and high level of moisture. This explains the higher density of earthworms than in other municipalities of Ifugao with different soil conditions such as Nagacadan (Gomez and Pacardo, 2005). They do not have a direct negative impact on rice crops, as they do not compete for rice provision with humans. However, they alter the physical dynamics of the rice terraces. The holes burrowed by earthworms cause water seepage and prolong the drought in the dry season. This



	Earthworms	Rats	Apple snail	Rice bugs	Birds	Grass-hoppers	Leaffolders	Stem-borers	Eels
Batad	17	6	5	2	1	0	0	0	0
Bangaan	23	11	6	1	3	1	1	0	0
Banaue	15	10	4	2	1	0	0	1	2

Figure 20 Major pest species by number of households in each barangay (*n*=90, more than one answer was possible).

creates cracks along embankments and erosion when the rainy season starts. They provoke a shift in the hydrological regime that is detrimental to the structure of the rice terraces.

Next to the earthworm, rats and golden apple snails are causing most damages. As secondary pests, rats, apple snails, rice bugs (*Leptocorisa acuta*) and birds (weaver birds, *Lonchura* spp.) represent a threat for several farmers in Banaue. Of these, rodents, rice bugs and the birds may not be considered as "native", but have not been introduced in the last decades. Pest species that are a major concern in lowland paddies across Southeast Asia, such as locust pests, leaffolders and stem-borers, do not have a significant impact in Banaue. Only three respondents mentioned one of the latter pest species in the three barangays (Figure 20). The proportion of households exposed to pest species that have been introduced in the last 50 years (earthworms, golden apple snails and eels) as opposed to the total number of pest species reaches 60% in Banaue, 63% in Bangaan and 71% in Batad.

Rodents are the most important mammal pests in the rice terraces and can cause great crop losses (Figure 21). However, not all rodent species are detrimental to rice harvests. Mainly, *Rattus tanezumi* and to a lesser extent *Rattus exulans*, both non-native species, are considered as pests in Ifugao. Conversely, the indigenous common Philippine forest rat (*Rattus everetti*), the Luzon striped earth-rat (*Chrotomys mindorensis*) and the montane striped earth-rat (*Chrotomys whiteheadi*) have been considered as beneficial for rice cultivation. These indigenous vermivorous rodent species are thought to feed on important pests, e.g. on "giant earthworms" and on golden apple snails (Stuart et al., 2007). Moreover, they are thought to increase the decomposition rates of leaf litter, thus releasing nutrients into the soil through their burrowing activities (Stuart et al., 2007). Therefore, pest management should aim at reducing the impacts of *Rattus tanezumi* while preserving the populations of non-target rodent species. According to Miller and colleagues (2008), 15% of 360 farmers interviewed in Banaue were using unlabeled chemicals (zinc phosphide), given free of charge by the municipal agricultural officer, albeit most respondents believed rodent damage still occurs after the application of chemicals. Rodent pest control measures should avoid the free distribution of non-specific chemicals to rice farmers for rodent control, assuming the ineffectiveness of these chemicals, their impact on non-target species, the environmental health implications, and the general desire of Banaue farmers to use non-chemical control measures (Miller et al., 2008).

Invasive species are a major problem mostly because of the lack knowledge concerning pest management. In total, only 14 households out the 90 surveyed (6 in Batad, 6 in Bangaan and 2 in Banaue) were trying to solve pest problems with natural pesticides (mostly using tobacco leaves), though acknowledging that efficiency of the method is uncertain. Conversely, half of the

Figure 21 Damage caused by rodents on a rice paddy. *Rattus Tanezumi* is one of the major cause of crop loss in Banaue (picture taken in Banaue, 2013).

respondents (45) in the three barangays indicated using chemical pesticides regularly or occasionally, “if needed”.

Concerning the apple snail, farmers mostly hand-pick the snails as often as they can to reduce damage on seedlings, resulting in extra labor. The problem is definitely not as important as in the rest of the Philippines. Only 16% of respondents consider the snail as the most serious pest problem whereas this number reaches 75-100% in the rest of the country (Martin et al., 1998). This is mainly because more plants are available in the rice fields of Ifugao, for instance *Azolla pinnata*, for the consumption of the snail, while weeding is more intensive in the lowlands. In their experiment, Martin and colleagues (1998) found out that the apple snail prefers other plants to rice, and would only eat the seedlings if alternative food is absent in the paddies.

Farmers also clean the surroundings of the rice fields and cover rats holes to prevent them to come close to their paddies. Finally, before harvest time, the owners of the rice fields have to scare birds with rope and plastic, a method also used in the lowland. All these activities, combined with the maintenance of terrace dikes after erosion caused by earthworms, require more time than before for the same amount of rice production. The energy needed for the maintenance of the system has increased but productivity has not.

4.10. Social-ecological state

The results of the survey show different figures (e.g. frequencies and means) and must be normalized to be interpreted and compared together. A factor of 1 to 5 was applied to the number of households with damage of 0-20% to 80-100%, respectively. The number for each damage proportion was then aggregated. The same was done for the irrigation canals condition proxy using factors of 1 to 3 to the number of households possessing “good”, “average” and “bad” irrigation infrastructure, respectively.

The results of each proxy were compared between the three barangays, with the mean equaling 1. In other words, each proxy value represents the distance to the mean of the three barangays (Table 18).

Also, the results for each sub-indicators (e.g. Autonomy from own rice field and number of food sources) are averaged to represent the sectorial indicator (e.g. food sovereignty).

Table 18 Indicator values compared to the mean.

Indicators and proxies	Banaue	Bangaan	Batad
Autonomy from own rice field	1.04	1.09	0.88
Number of food sources	0.91	0.96	1.13
Food sovereignty	**0.98**	**1.03**	**1.01**
Income from agricultural products	0.33	1.88	0.79
Income from tourism	1.37	0.72	0.91
Profitability	**0.85**	**1.30**	**0.85**
Households practicing rituals	1.94	0.53	0.53
Number of rituals practiced	1.54	1.01	0.45
Cultivation of *inado*	1.33	0.56	1.12
Traditional ecological knowledge	**1.60**	**0.70**	**0.70**
Practicing of primogeniture	0.77	1.24	0.99
Migration rate	0.85	0.58	1.57
Demographics	**0.81**	**0.91**	**1.28**
Land uses maintained per household	0.92	1.03	1.05
Landscape heterogeneity	**0.92**	**1.03**	**1.05**
Diversity of rice varieties	0.96	1.07	0.98
Diversity of aquatic species in rice fields	0.97	1.02	1.01
Diversity of plant species in woodlots	0.98	0.96	1.06
Biotic diversity	**0.97**	**1.02**	**1.02**
Uses of forest products	0.68	1.14	1.18
Proportion of households using rice plants for mulching.	1.08	0.79	0.90
Multiple uses of land and plants	**0.88**	**0.97**	**1.04**
Proportion of damaged terraces	0.74	1.10	1.16
Proportion damaged irrigation canals	0.75	1.13	1.12
Proportion of invasive pest species	0.92	0.97	1.1
Disturbances	**0.80**	**1.07**	**1.13**

4.10.1. Resilience

To measure resilience of the social-ecological system of Banaue, one way is to compare the current state of the system with the traditional state, or the state of the “basin of attraction”. Although it is not possible to accurately set a specific value on most indicators for the traditional state of the system (e.g. on biodiversity), one can assume that the traditional system in Banaue is characterized by the indicators of Table 19. For instance, relatively high food sovereignty (6-8 months with own

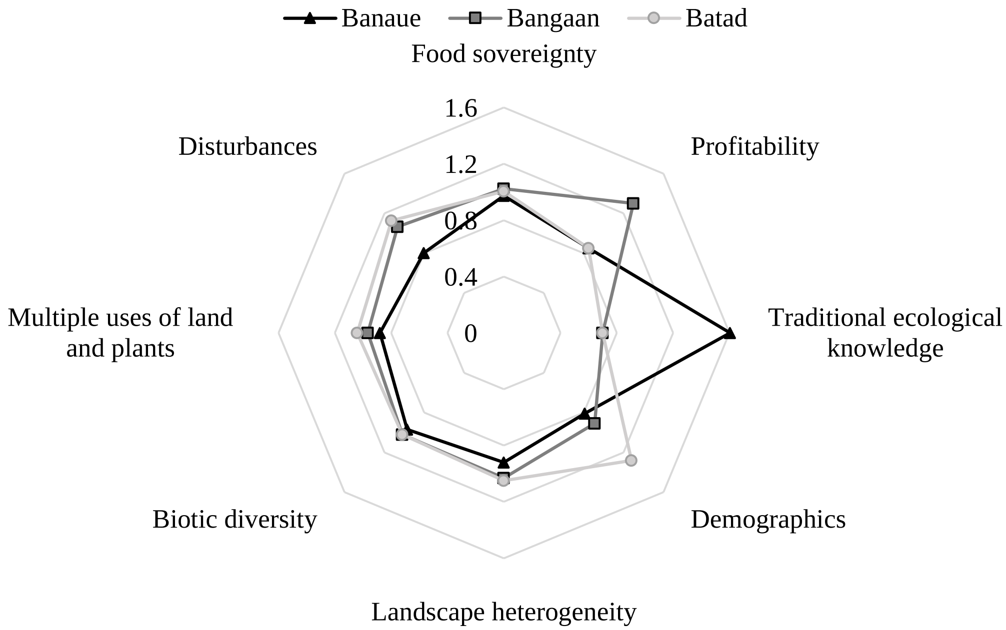


Figure 22 Comparison of the current state of the social-ecological system between the three barangays.

rice yield), traditional ecological knowledge (around eight rituals per year), a high landscape heterogeneity including the cultivation of swidden fields, several uses forest products and widespread use of rice plant as fertilizer characterize the traditional system. The traditional state experiences low disturbances and there is very little opportunity to gain cash income (i.e. low profitability). Finally, population should be stable, since after several centuries, the area still has a relatively low population.

Overall, the three barangays show similar results in food sovereignty and biotic diversity (Figure 22). Banaue exhibits higher resilience in terms of traditional ecological knowledge and a relatively low degree of disturbances. The system in Banaue is also characterized by a low degree of profitability of the social-ecological system, though this is understandable since a lot more off-farm job opportunities are available in Banaue. Bangaan and Batad show similarities in terms of food sovereignty, traditional ecological practices, landscape heterogeneity, biotic diversity and multiple uses of land and plants.

The trends observed for each indicators show a relatively high degree of change in the system if compared to the system described by ethnologists Barton (1919, 1922) and Conklin (1967a, 1967b, 1980).

Table 19 Comparison of the current value of indicators of the state of the social-ecological system with the "traditional" value as described in the literature. Also, the trend in the value of each indicator is shown as an arrow.

Sectorial indicators	Proxy variables	Traditional value and source	Current range of value	Trend
Food sovereignty and self-sufficiency	Number of months that households can self-sufficient with their rice production.	6-12 (Barton, 1919)	4.8-6	↘
	Number of food sources produced by farmers (excluding from rice fields)	4 (Conklin, 1980)	1.7-2.1	↘
Profitability	Income from agricultural production	0 (Conklin, 1980)	0-30%	-
	Proportion of household involved in tourism	0 (Barton, 1919)	37-70%	↗
Traditional ecological knowledge and practices	Proportion of households practicing rituals related to rice production.	100% (Conklin, 1980)	10-37%	↘
	Proportion of households still maintaining traditional land use (*Inado*)	100% (Conklin, 1980)	27-63%	↘
Population change	Proportion migrating household members	Low (Barton, 1919)	17-46%	↗
	Number of household practicing traditional inheritance system (primogeniture).	100% (Barton, 1922)	60-97%	-
Landscape heterogeneity and fragmentation	Variety of land uses cultivated	4 (Conklin, 1980)	2.3-2.7	↘
Biotic diversity	Diversity of rice varieties grown.	30-80 (Conklin, 1980)	17	-
	Diversity of woodlot plants	171 (Conklin, 1967a)	67	-
	Diversity of aquatic species	-	16	↘
Multiple uses of land and plants	Number of uses of plants collected in the woodlots.	7 (Conklin 1980)	3.4-4.1	↘
	Proportion of households using rice plants for mulching	100% (Conklin 1980)	80-93%	-
Disturbance regime	Damaged terraces per household	low	medium	↗
	Damaged irrigation canals	low	low	↘
	Proportion of invasive pest species	0 (Barton, 1922)	63-71%	↗

The greatest changes observed were the number of sources of food, the proportion of households involved in tourism, the proportion of households practicing rituals, the number of rituals practiced and the proportion of households cultivating *inado*, the migration among households, the number of uses of plants collected in the woodlots and the proportion of invasive pest species. On the contrary, the income from agricultural production, the number of household practicing primogeniture and the proportion of households using rice plants for mulching did not change significantly. The self-sufficiency of households, by the number of months they can eat their own rice and the variety of land uses cultivated have slightly decreased, whereas damaged terraces change have increased. Interestingly, respondents noticed an improvement of their terraces. Lastly, it is difficult to assess the trend concerning the diversity of plants species in woodlots and rice varieties since no inventories for Banaue exist in the literature. It is probable that introduced plants have enriched the biodiversity in the woodlots, although more research would be needed to demonstrate this hypothesis. The biodiversity of aquatic species in the rice paddies has likely decreased since several species mentioned in previous studies (Conklin, 1980) are not, or rarely, seen in the paddies anymore, i.e. *Thiara asperata*, *Lymnea cumingiana*, *Limnea veridis* and *Pila Luzonica*.

4.10.2. Adaptability

Important elements of adaptability are the existence and implementation of mechanisms for the evolution of novelty or learning that facilitate experimentation, discovery, and innovation (Carpenter et al., 2001). For instance, experimentation of new rice and plant varieties may help to improve the livelihood of the communities. In this matter, Bangaan seems to show higher adaptability since a higher proportion of modern varieties can be found in this barangay. Profitability is also higher in Bangaan, compared to the two other barangays. Households in Bangaan were able to sell more agricultural products, which allows the farmers to receive an income while pursuing rice terracing. This does not lead to a reduction of disturbances, however, since rice fields in Bangaan are the most sensitive to pressures. Although Banaue shows several signs of resilience, the fact that several farmers have moved to off-farm employment while conserving traditional practices may also be a sign of the capacity of adaptation to the new reality of the market economy.

5. Discussion

The social-ecological system of the rice terraces in Banaue is in constant development. However, stability is generally preferred to evolution in cultural production landscapes, as the maintenance of the provisioning service of rice production is needed for the community. For the best or the worst, ecosystem structures have changed with introduced species in the rice terraces and the surrounding forests. The new biological composition has influenced the ecosystem properties in a way that more energy is needed now than before to maintain the ecosystem at the desirable stage of development. Climate change will undoubtedly add to this energy requirement with stronger rain events and more recurrent collapsed terraces. This chapters discusses two important considerations related to resilience and adaptability, the possible alternative states and future trajectories. Furthermore, the changes and trade-offs in ecosystem services caused by the modification of the system in the last three to five decades are examined. Finally, seven options to enhance the adaptability of the system are outlined.

5.1. Alternative states and future trajectories

Alternative states and regime shifts are topics that are gaining in popularity in the resilience literature (Folke et al., 2004; Kinzig et al., 2006), but few researches have explored the alternative states, and their consequences, of traditional rice terracing. Some prior studies have investigated the successional stages in Ifugao after terrace and swidden fields' abandonment, and also what pathways can the system take considering the social factors (tourism, need for cash income, high yielding varieties). Climate change is expected to require an adaptive response from the system in order to maintain and improve the livelihood of the farmers.

5.1.1. Alternative ecological states

In the case of abandonment, Serrano and Cadaweng (2005) noticed that succession of fallow swiddens is characterized in a first stage by the development of *cogon* (*Imperata cylindrica*) to *talahib* (*Saccharum spontaneum*) to form a caneland land cover, followed by the appearance of ferns, and later the emergence of miscellaneous shrubs and medium-sized trees. Eventually, dipterocarp tree species such as *lauan* (*Shorea contorta*), *guijo* (*Shorea guiso*) and *bagtikan*

(*Parashorea malaanonan*) may begin to grow, which leads to a reconstituted forest (Serrano and Cadaweng, 2005). This process of natural secondary succession may take 20 years or more depending on initial soil conditions.

Considering the rapid abandonment process at the province scale, an alternative state of the present system is the terraces in a dry idle state due to emigration. This state was observed after the collapse of the Inca society resulting from the invasion of the Spaniards in Peru (yellow cycle, Figure 23). Such a development of the system would mean a considerable decline in connectedness within the system (e.g. fewer and lower ecosystem services) and lower ecosystem indicators (e.g. lower primary production and carbon sequestration). Because of the high amount of precipitation in the Banaue area, it is unlikely that abandoned terraces would remain idle with low primary production. Conversely, a natural secondary succession characterized by reforestation of the slopes would significantly increase ecosystem indicators (e.g. higher carbon sequestration and water regulation)

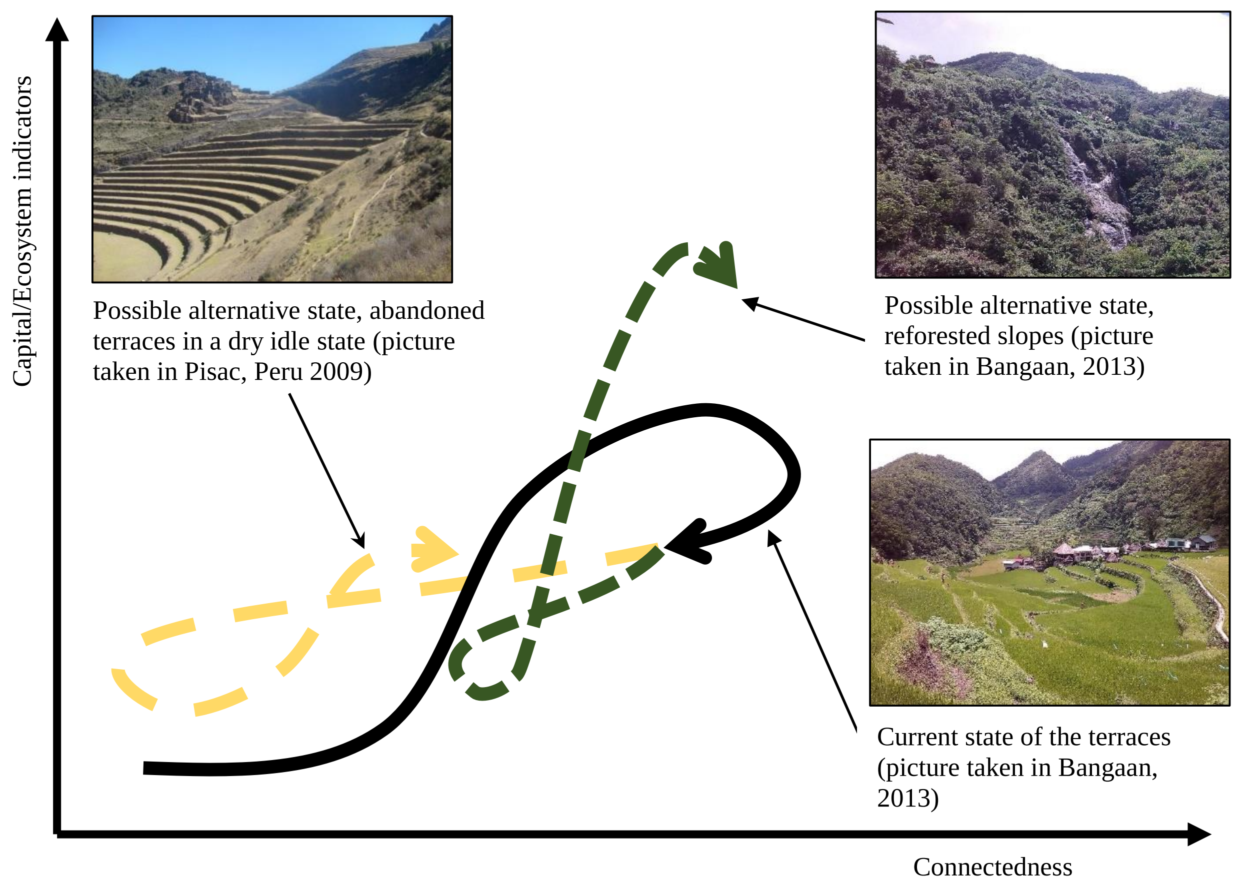


Figure 23 Adaptive cycles of the Ifugao rice terraces. In black is the current development of the system, compared to agricultural terraces after abandonment in a dry idle state (yellow cycle) and forested terraces after secondary succession (green cycle).

although with lower connectedness if we consider cultural services. Nevertheless, as most indicators are in a declining stage, one could assume that the system is in a phase of readjustment (Ω phase) rather than conservation (K phase, see Figure 1 and Figure 23).

5.1.2. Future trajectories

Plachter et al. (1998) identified four possible trajectories that could be taken by the system in Banaue in the coming decades (Table 20). The first scenario is the continuation of the present state consisting of the development of infrastructure and increasing tourism. This would lead to further abandonment of rice terraces and slow deterioration of agricultural biodiversity in paddies as farmers turn towards alternative means of living. Rising wood prices would make handicrafts less profitable and developing infrastructures would eventually degrade the primary forest of the watershed and forest biodiversity.

The second scenario concerns an increase in short-term mass tourism, which would divert farmers from rice farming. The higher demand for handicraft would lead to accelerated depletion of the watershed and the forest biodiversity. Higher demand for handicrafts would also increase wood demand and thus its price, making handicrafts less profitable on the long-term. As farmers would migrate towards tourist hotspots, abandonment would be accelerated in smaller barangays far from the tourist route, and so would be the loss of aquatic biodiversity and endemic rice varieties.

The third scenario projects a development centered on agricultural intensification. In this scenario, the watershed would be protected considering its importance for the rice terracing. Consequently, forest biodiversity would be maintained. High yielding rice varieties or vegetable crops would be introduced to the area. However, nutrient input from green manure would not be sufficient for two crops per year and therefore farmers would need to apply fertilizer and possibly pesticides. This change would induce lower biodiversity in rice fields. The income from higher agricultural production would decrease the dependence of rice farmers on tourism for cash income and the deleterious impacts of tourism, such as deforestation of handicrafts, would be lower.

The last scenario refers to a better integration of tourism and agricultural development. As in the previous scenario, watershed would be strictly protected thus preserving biodiversity and water flow.

Table 20 Four possible scenarios for the Banaue region and their consequences on primary forest in the watershed, agriculture, tourism, handicrafts, agricultural biodiversity and forest biodiversity developed by Plachter and colleagues (1998). The arrows ↘ and ↗ indicate a negative and positive outcome of the scenario of the social-ecological system parameter, respectively, whereas – does not show clear impacts.

Scenarios	Primary forest	Agriculture	Tourism	Handicrafts	Agricultural biodiversity	Forest biodiversity
1. Continuation of present state	↘	↘	↗	↘	↘	↘
2. Short-term mass tourism	↘	↘	↗	↘	↘	↘
3. Agricultural intensification and technical modifications	↗	↗	-	-	↘	-
4. Integrated development	↗	-	↗	↗	-	-

Traditional rice varieties would be conserved and grown with high yield varieties and vegetables in restricted areas. Entrance fees would be charged to promote ecotourism and longer stay for fewer tourists.

On the short-term, the second scenario is unlikely. Tourist arrivals have levelled off in recent years, and due to the remoteness of the area, it is hardly imaginable that Banaue will be the site of mass tourism. Furthermore, the survey results showed that few respondents produce handicrafts and for most of them, the activity was carried on only in their free time. Furthermore, Herzmann et al. (1998) mention an increase of the forested area from 15% to 35% between 1963 and 1997. However, this situation could change if public transportation would be facilitated, for instance by a construction of an airport nearby.

New rice varieties have been introduced, mostly in Bangaan, reflecting a trend in Ifugao since 40% of farmers are now using hybrid rice varieties of Indica sub-species at the province level (Druguet, 2012). Farmers in Nagacadan and Mayoyao have successfully introduced high yielding varieties and can now plant two crops per year. However, the introduction of new varieties in Nagacadan was related to the occurrence of brown plant hoppers, *Nilaparvata lugens* (Gomez, 2003). Additionally, the replacement of traditional varieties by high yielding ones means trading off biodiversity and natural heritages for higher production and higher economic benefits.

The cultivation of other crops seem to be a viable option to increase food security and profitability. In a previous study, it was shown that rice farmers obtained 67% of their cash income from agroforestry species (Guy, 1995). It would be possible to use abandoned terraces and unused swidden fields or caneland to expand the culture of agroforestry products or vegetables that do not require as much water as rice. Conversion of rice terraces to vegetable terraces is a potential path that has already been taken by farmers in Nagacadan. In a survey by Gomez (2003), 37.8% of farmers converted their field to vegetable terraces as opposed to 3% in Bocos, Banaue. The main reason for this conversion was the lack of water in paddies and also the accessibility to a market. Furthermore, Nagacadan has never been a tourist hotspot comparable to the Banaue municipality and, consequently, benefits less from governmental support. However, monocropping, as in the case of *Phaseolus vulgaris* in Nagacadan, is ill-advised as price fluctuation could leave the region more vulnerable and deteriorate soil conditions.

5.1.3. Climate change

Despite the likelihood that climate change will strongly influence the future development of the system, few scholars have investigated the possible impacts of climate change. The literature related to disturbances in Ifugao focuses mainly on the integration to the market economy, tourism and pest species but rarely mentions upcoming climate change.

Ifugao farmers, including those in Banaue, are well aware of climate change. They have noticed changes in timing of rains, increase in temperature, and decrease of water from sources and frequency of drought (Licyayo, 2013). Beside the change in the timing of rains, they also felt that the volume of precipitation is more important than before. Decrease in yield attributed to changes in climatological condition such as temperature and decrease supply of water from watershed have also been observed (Licyayo, 2013).

Ifugao farmers have already had to adapt their farming practices to changing climatic conditions. Due to the prolonged cold season, the farmers in Ifugao started to move their transplanting season from December of each year to January, thus altering the rice cycle cropping (Nalliw-Licnachan, 2009). This adaptation might not be without consequences since farmers reported important vulnerability of their crop to rice bugs (*Leptocorisa oratorius*) when they harvest later than usual (i.e. in August and September instead of July).

5.2. Ecosystem services and well-being from rice terraces

The transformation of the system in recent decades has brought a number of trade-offs in ecosystem services and wellbeing. The introduction of new aquatic species is a good example. Although it has been mostly beneficial in the case of *M. anguillicaudatus* and the *T. nilotica* fish species, the golden apple snail and the *tamtampi* have resulted in negative impacts. Martin et al. (1998) argued that the phytophagus apple snail does not compete with native snails, which feed on detritus and periphyton. Further, some authors (Settele, 2003; Joshi et al., 2005) stated that the introduced snail has been regarded as beneficial, as they reduce work efforts for weeding. However, farmers surveyed believed in a large majority that the golden apple snail was responsible for the absence of native snails in their rice field. This may be caused by the time lag between the introduction of the exotic species and its negative impacts (Crooks and Soule, 1999). Brought in the area to increase food provisioning, only few farmers have adopted the snail in their diet. It has also reduced net primary production available for green manure for the vegetable mounds (*inado*) and reducing the concentration of *Azolla*, resulting in less nitrogen fixing. Therefore, if a new source of food and perhaps less labour was gained from the introduction of the new snail, the farmers lost more snail species to eat, harvest smaller rice and vegetables crops from the rice fields (see Table 21).

In the case of the *tamtampi*, also introduced to provide food (Aida Paganahe, personal communication, May 2013), farmers have acknowledged that it was one of the main reason beside the apple snail for the declining number of appreciated native aquatic species such as *P. luzonica, L. viridis* and *C. striata.* Now that this species of fish is present in nearly all fields, although few other species remain, farmers have lost nutrition diversity. Finally, the introduction of the large bivalve locally called *te'am* as an additional food source is detrimental to farmers as it cuts their feet when they have to work in their rice paddies. In this case, the trade-off lies between higher seafood provision and lower environmental security.

Tourism is a relatively new cultural service from Banaue ecosystems. Although it is delivered *in situ* (according to the classification of Fisher et al., 2009), the service and benefits are appreciated by non-local beneficiaries, since tourists come from other Philippine provinces and overseas.

Tourism can be either a source of revenues promoting development and environmental conservation (Akama and Kieti, 2007; Morrison et al., 2012), or a source of environmental degradation (Mbaiwa, 2003; Mateu-Sbert et al., 2013).

Table 21 Trade-offs in ecosystem services and benefits related to new ecosystem structures (introduced species) and social parameters (tourism).

Changes	Services gained	Services lost	Benefits gained	Benefits loss
Introduced species				
Golden apple snail	Seafood	Seafood, Rice and vegetable crops	Less labour	Nutrition diversity
Tamtampi	Seafood	Seafood		Nutrition diversity
Te'am	Seafood			Environmental safety
Earthworm		Water flow regulation, erosion regulation, rice production		
Tourism				
For Banaue residents	Tourism	Water flow regulation, erosion regulation, aesthetics	Household income Employment, Cultural heritage	Cultural heritage
For tourists	Landscape aesthetics, recreational opportunity, cultural heritage		Leisure, wellbeing,	

Tourist come to Banaue for the recreational opportunity of hiking between rice terraces, appreciate the landscape and the unique culture of the Ifugao.

These services provide them with benefits such as leisure and wellbeing (Table 21). The residents also benefit from the tourist arrivals, for instance by working in the tourist industry (e.g. as tourist guides or craftsman) which provides much needed cash income. The fact that most tourists go to Banaue instead of other municipalities of Ifugao (see Figure 24) adds value to the traditional culture and the terraces for the farmers themselves (SITMo, 2008). However, tourism also has its load of environmental issues. For example, tourist infrastructure may divert water sources that would otherwise contribute to keep the terraces flooded, and accelerate erosion. If unregulated, tourist accommodation can also reduce the attractiveness of the cultural landscape, originally composed of traditional houses, rice terraces and the natural environment. Finally, the commercialization of some cultural symbols, e.g. the rice god carving, can lead to the desacralization of these symbols and result in the decline of the cultural heritage value (SITMo, 2008).

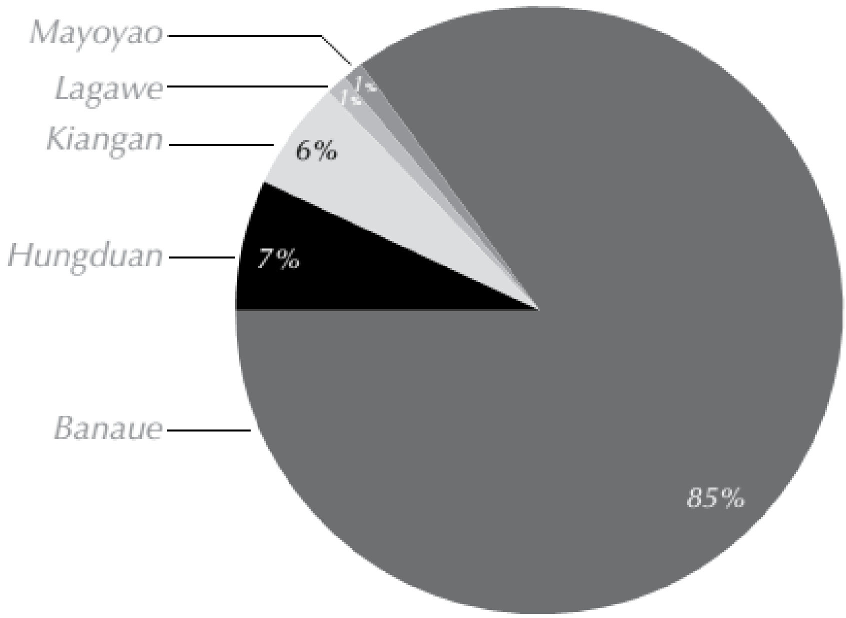


Figure 24 Tourist arrival contribution by municipality in 2006 (SITMo, 2008).

The unintentional introduction of giant earthworm species did not bring any services to farmers but rather several disservices (Figure 25). The presence of the new worm disrupt the biophysical structure and processes of the rice terraces by boring holes in the dikes, causing water seepage. The lack of water, in turn, increases erosion and reduces the potential crop and harvest of the farmers. In fact, farmers need to mobilize more resources now to reach the same harvest as before since they repeatedly have to repair the collapsed walls. The lower harvest decrease the food security of the population and the higher cost of maintenance reduces the value of the terraces.

Besides altering the water and erosion regulation in a detrimental manner to rice farmers, earthworms may increase the release of greenhouse gases from rice paddies. Indeed, the presence of earthworms is thought to increase net soil greenhouse gas emissions in rice paddies (Lubbers et al., 2013), although these findings need to be further investigated (Zhang et al., 2013). The impacts of earthworms are little studied and new species are discovered regularly in the Cordillera Administrative Region (Hong and James, 2008, 2010, 2011). The movement of tourists, scientists and locals around the region is likely to intensify the introduction of cryptogenic species of earthworms and exacerbate the problems that farmers are now coping with.

Another similar issue is the newly introduced Asian swamp eel (*Monopterus albus*) locally known as *kiwit*. Although the eel is not yet widely distributed in Ifugao comparably to earthworms and *P. canniculata*, the farmers having eels in the fields believed it could soon become the major pest for

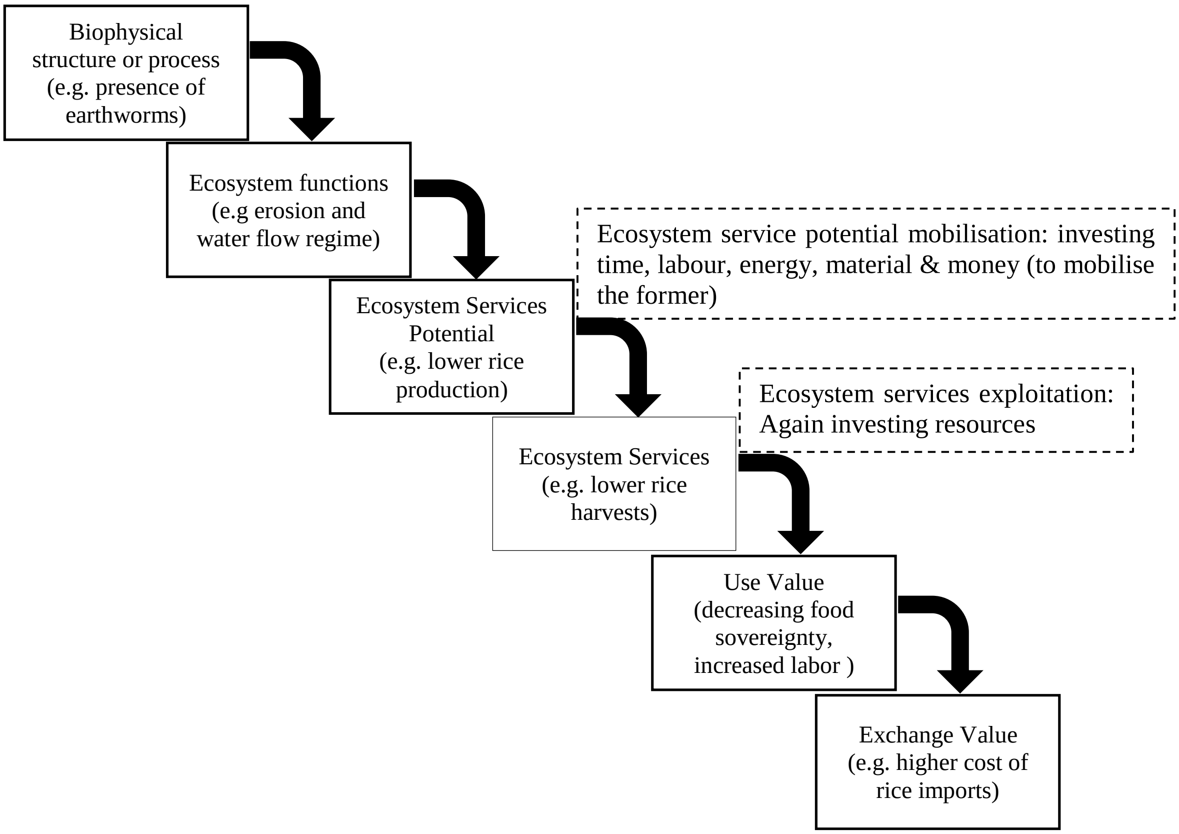


Figure 25 Shift in the supply of regulating and provisioning ecosystem services. The non-intentional introduction of the earthworms generated disservices and resulted in a loss of benefits for the inhabitants (adapted from Spangenberg et al., 2013).

them. It has already become a major invasive species causing severe ecological damage to native communities in other wetland ecosystems, e.g. in Florida (Clay, 2003). The swamp eel burrows holes in dikes which causes water seepage, similarly to the earthworm. Tough it is edible, farmers interviewed had no interest in eating the new fish.

Some cultural services (religious experience, cultural heritage, and rituals) are gradually being lost, possibly after the integration to the market economy, the increasing number of tourists and Christianisation. Although the ecosystem services potential is still present, e.g. heirloom varieties are still grown, the services give lower benefits from the ecosystems than before because of religion shift. The public religious interest has changed, from the traditional religion including several gods from the nature (Conklin, 1980) to Christianism. Therefore, the farmers have a different relation with the land and rituals are no more needed for the production of rice. This change in value system also affects terracing techniques (e.g. late transplanting) that were strongly influenced by rituals (Figure 26).

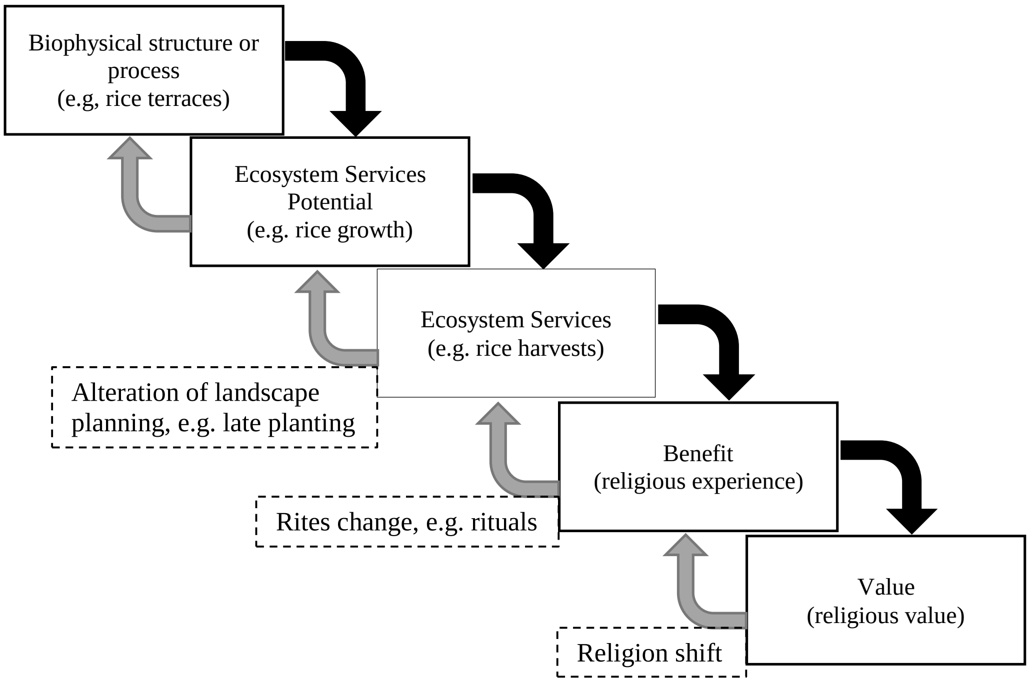


Figure 26 Shift in the demand of cultural ecosystem services. The Christianisation of the area led to a disruption of the values and preferences resulting in a shift in the demand of the cultural ecosystem services related to religious experience (adapted from Spangenberg et al., 2013).

5.3. Options to increase adaptability

Most authors agree to say that conservation initiatives needs to be applied with a bottom-up approach (Settele, 2003; Nozawa et al., 2008). Since the Ifugao province is a culturally rich area, discrepancies and tensions concerning conservation objectives and priorities may easily arise (Guimbatan and Baguilat, 2006).

5.3.1. Environmental fees

One common economic incentive for conservation is to implement environmental fees for visitors enjoying the services of the rice terraces to contribute to the maintenance costs of the terraces (Calderon et al., 2008). Some barangays, for instance Batad and Hungduan, collect environmental fees at the entrance of the barangay. However, these fees are considered too low compared to the willingness to pay (WTP) of tourists. After surveying tourists in different municipalities of Ifugao, Calderon et al. (2008) concluded that local tourists' WTP fell in average between P 440 and P 506[3] per person whereas average WTP of foreigners reached USD 71 and USD 77 per person. Therefore, barangays could collect a P 50-fee per person from local tourists and USD 20 per person from foreign tourists (significantly higher than the fees that are currently being collected, which range from P10 to P30 per visitor), which could generate a total annual revenues of P 6.65 million (Calderon et al., 2008). These revenues generated from cultural and environmental fees should be retained where the fees are collected (i.e. in the barangay or municipality) and be placed in a trust fund to be managed by a council that is not controlled by politicians to ensure continuity (Calderon et al., 2008). Taxes on tourism infrastructure would be another way to capture the willingness to pay of tourists and prevent excessive construction of hotels and guesthouses. Revenues from tourists have the potential to significantly finance the restoration of the terraces and offset the negative impacts of the tourism industry in the area.

5.3.2. Commercialization of tinawon rice

The commercialization of the local rice variety was suggested as a way to fill a market niche for organic and quality rice and promote the conservation of traditional varieties (DENR, 2008). Such commercialization of *terroir* products has succeeded in several cases to provide income to farmers and conserve heirloom varieties of other crops such as coffee (Linton, 2008), Rooibos tea in Africa (Raynolds and Ngcwangu, 2010) and Mantesoco cheese in Peru (Boucher and Gerz, 2006).

A commercialization project was started in Banaue in 2005 by the American company "Eighth Wonder" and a local NGO "RICE Inc" (Revitalize Indigenous Cordilleran Entrepreneur). The partnership acts as middlemen for producers of six barangays grouped under a cooperative; the Rice Terraces Farmers' Cooperative. *Tinawon* price is nearly twice the price of modern varieties in Banaue market. This means that for one kilogram of *tinawon* sold, the farmers are able to buy twice as much of other varieties. Marketing *tinawon* variety is thus an option to preserve the local variety and improve food security. As opposed to tourism, the marketing of rice provides revenues directly to farmers. Furthermore, the commercialization of *tinawon* rice has given a new value to some cultural (symbolic) and material elements of *tinawon* rice required for its commodification (Sekimoto and Augustin-Jean, 2012), a monetary value, as opposed to the previous spiritual or

[3] 1 Philippine Peso (P) ≈ 0.017 euros (€) or 0.023 US Dollar (USD).

religious value that is declining. Nonetheless, the production potential of *tinawon* is very limited compared to other rice varieties and so are the potential benefits. The initiative has been for now relatively successful, starting with 720 kg sold in 2005 to 24 000kg in 2012 (see Figure 27). The counterpart of this initiative is the commercialization of a once sacred product. Further, it may give an incentive to farmers to neglect and abandon the cultivation of other, less famous, endemic rice varieties.

There are also disagreements between producers and middlemen relative to market prices and product quality (broken grains must be lower than 15%, colour), considering the expectations on the international market (Druguet, 2012; Sekimoto and Augustin-Jean, 2012). Finally, attributing a monetary value to a cultural product may cause further erosion of the spiritual value of the variety, and selling the rice could reduce its availability to farmers themselves, thus forcing them to rely on imported rice.

RICE inc. also offers the possibility to “adopt a terrace”, an inititative that allows Filipinos and foreigners alike to invest in the restoration of abandoned rice terraces. The funds then go to a family affiliated with Rice Inc. and are used to repair colleapsed walls or irrigation systems (RICE Inc., 2012). This is another economic initiative to capture the willingness to pay for the conservation or the restoration of the terraces, in this case mostly from people outside the system. Those economic initiatives are options to adapt to the new reality of the market economy that Banaue is now facing. In an increasingly telecoupled world, farmers in Banaue will be increasingly

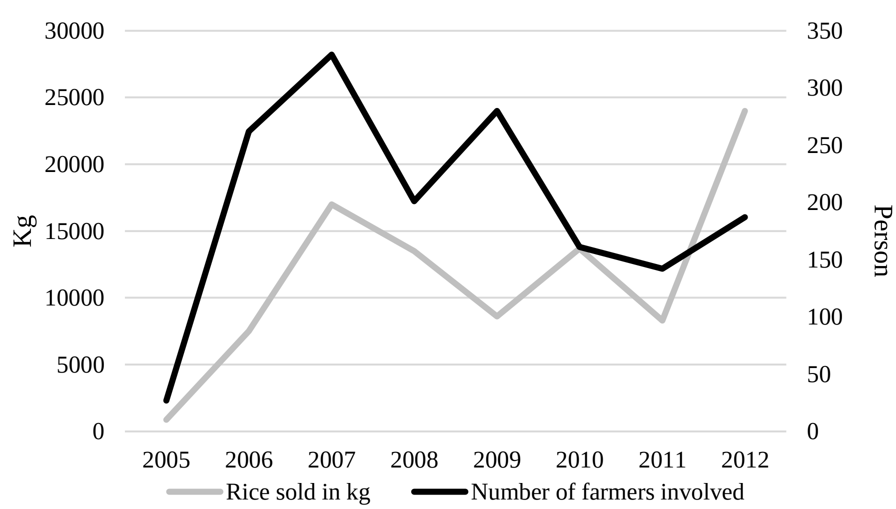


Figure 27 Amount of rice sold and number of farmers involved in the RICE Inc. project (RICE Inc., 2012).

in contact, directly or indirectly, with consumers or tourists from abroad or the rest of the Philippines. Commodification of the traditional rice variety may be an option to take advantage from, and adapt to, the new socioeconomic reality.

5.3.3. Eco-tourism development

Ecotourism based on agriculture and cultural heritage is another possible option to reduce the negative impacts of tourism and provide an additional income that can be used for the maintenance of the terraces. Tourist spots should be extended throughout the province since only Viewpoint and Batad are the main destinations for most tourists at the moment. If tourism activities are concentrated in few areas, this could lead to more migration and inequity of funding.

Tourism brings vulnerability, since it is susceptible to cause some “harm” by increasing the area of sealed surface and reduces the availability of water for irrigation. However, vulnerability, as defined earlier, may not always be a negative attribute of the system. The different actors in the systems have the possibility to reverse the “harm” and find creative ways to diversify their livelihoods and participate in new opportunities from the exposure to tourism by developing the

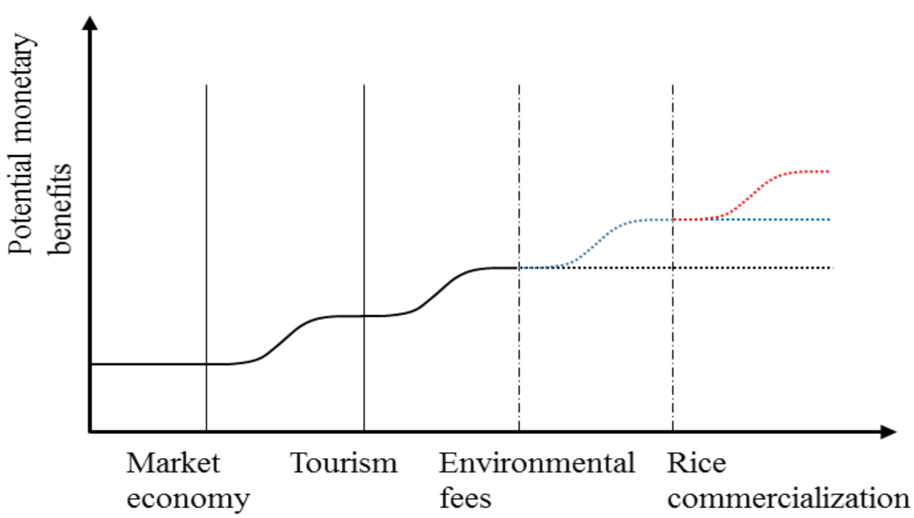


Figure 28 Potential monetary benefits for the social-ecological system in Banaue. The solid black line shows that the integration to the market economy and increasing tourism have increased off-farm job opportunities and monetary income in the area. The system could be resilient and continue on this path, benefiting from tourism through the marketing of handicrafts and vegetables (black dashed line). The collection of environmental fees (dashed blue line) and the commercialization of the traditional rice varieties (dashed red line) are two opportunities to provide supplemental monetary benefits to the farmers.

ecotourism industry, collecting environmental and cultural fees and commercializing the traditional rice (Figure 28).

5.3.4. Adoption of ecosystem-based crop management

As the earthworms represent the main pest in the three areas, research must be concentrated to mitigate their adverse impacts on the structure of the terraces. This can be difficult since most rice is produced in the lowlands in the Philippines, and therefore terrace erosion caused by earthworms is not a major problem in the other provinces.

The most successful method until now has been to apply 150 g of chopped and pounded marigold (*Tagetes erecta*) and 30 g of *Melonoides granifera* shell lime mixed with 500 ml in rice fields (Millare, 2010). The *Melonoides granifera* shell lime is already widely used in Ifugao as ingredients for chewing betel. It is therefore easily available at low cost. A similar experiment by Allig (2013) showed that 100-300 g of powdered rock lime diluted in 8 and 12 liters jars is an effective pesticide against earthworms. All the different concentrations (100, 200 and 300 g) resulted in 100% mortality rate of the earthworms *Pheretima elongate*. Depending on the concentration of the solutions, the worms would die between 6 and 13 minutes. The dust from the powdered lime alters the body water balance of the worms and can be used to raise the pH of soils (Allig, 2013). In previous experiments, it was not perceived as detrimental for rice production or health, but further research would be needed to assess the impact on other aquatic species. At P30 per kilo, powdered rock lime is affordable to farmers, but still represents an additional cost to maintain the rice production at the same level.

Regarding the apple snail, the fruits of *Sandoricum vidalii* or *Bakuwog* in the local dialect, of the Meliaceae family, are thought to be a powerful natural pesticide against golden apple snail. Ngaloy and colleagues (2002) reported that repeated application of the pounded fruit in rice fields were very efficient the kill the snail. However, no scientific experiment have been conducted to determine, for instance, the proper amount of fruits to use or the potential negative effects on other aquatic species. No farmers in this survey indicated using or knowing the efficiency of this natural pesticide. Furthermore, the *Sandoricum vidalii*, endemic to the province of Ifugao, was placed on the list of vulnerable species by the IUCN because of “rates of habitat loss through logging and shifting cultivation”.

Better seed management is another option to improve crop growth without introducing inorganic fertilizer or pesticides. Sigari and colleagues (2005) suggest to cover seedbeds with a plastic cover for the thirty first days to build and maintain a higher temperature inside and therefore offset the cold climate of the region. Their experiment on the Palawan rice variety showed that this method can increase seedling height of 60%, shoot dry weight of 27%, root dry weight of 22% and the number of seedlings per m^2 by 15% compared to traditional nurseries.

5.3.5. Introduction of environmental and cultural impact assessments

The adoption of guidelines for conservation and for procedures of an Environmental Impact Assessment concerning the implementation of major projects was suggested by the UNESCO (2012) for Banaue. Impact assessments allow for the use of the best available knowledge to consider the long-term impact of a development project on the environment and the people. By incorporating local knowledge systems into such assessments, it should be possible to identify the best available mitigation measures that are attuned to the heritage and culture of the community and that minimize the adverse impacts that come with any proposed development (Nozawa et al., 2008).

In principle, the Environmental Management Bureau (EMB), of the Department of Environment and Natural Resources (DENR), administers the environmental impact assessment system in the Philippines (Ingelson et al., 2009). Environmentally critical projects and projects located in environmentally critical areas must go through the impact assessment procedures (DENR, 1996). However, some projects are deemed not "environmentally critical" enough, and therefore can skip the standard procedures. This was the case, for instance, of the Ifugao-Ambangal Mini-hydro Project. The impact assessment, because of the small-scale of the project, was carried out on a voluntary basis by the Tokyo Electric Power Company, the project initiator (E8 general secretariat, 2010).

Impact assessments consider projects of a certain size, but cannot assess the impact of each houses built among rice terraces. There are at the moment no local land use plans that ensure the preservation of the rice terraces and modern structures stand out and often do not blend with the terraced landscape (Nozawa et al., 2008). Houses have already been built on terraces in the town of Banaue, and this process will likely increase if population continues to expand. Therefore, an environmental impact assessment should specifically target urban sprawl in the town of Banaue and road development across the municipality. A good first step in this direction is the environmental risk assessment related to biodiversity loss of the Halsema Highway linking Banaue to Bontoc and Baguio (Untalan et al., 2013). The construction of the highway on an existing smaller road has for objective to infuse economic investments and activity into the rural areas. However, the existing road has already had negative impacts on historical sites, biodiversity, erosion and human health (Untalan et al., 2013).

5.3.6. Instilling values among youth

One major challenge that will face the Ifugao families in the upcoming decades is to convince the next generation to continue rice farming. The loss of cultural traditions and the prospect of jobs outside the province could trigger a faster emigration towards neighboring lowland provinces or Manila. An option suggested to keep the youth in the province is to provide students with incentives such as scholarships and jobs that could rekindle interest in agriculture and forestry-related courses (Calderon et al., 2008; Dizon et al., 2012). In order to conserve both the landscape aesthetics and the cultural heritage, inter-generational transfer of knowledge will be needed to keep, or build on, traditional knowledge and slow down the erosion of, or renew, cultural ecosystem services. The decline in the practice of ritual might be irreversible, but the ecological knowledge embedded into the rituals should be conserved. For instance, biological pesticides should be documented and timeliness taken into account in the rice cultivation. Delays in rice harvest can result in very important pest damage. As an example, a crop development varying by up to 6 weeks compared to the initial cropping season can result in a 330% increase in rodent population (Miller et al., 2008). This could be seen as the “remember” process, by which the reorganized knowledge system draws upon, and is influenced by, previous states of the system. As Folke (2006) states, memory is the accumulated experience and history of the system, and it provides context and sources for renewal, recombination, innovation, novelty and self-organization following disturbance.

5.3.7. Local leadership

Strong leadership might be needed to reverse the trends of abandonment and reliance on the government and UNESCO. Some community traditions such as *baddang* for the maintenance of the terraces and irrigation canals, and *ubbu* for shared work on harvests are not as common as before, while it is still common in other provinces. Rather, the farmers noticed that cooperative community work has been replaced by reliance on government help. The presence of legitimate leaders in small communities has proven in many instances to increase resilience and adaptive governance (Westley et al., 2013), e.g. in wetland cultural landscapes (Olsson et al., 2004) and in coastal fisheries (Gutiérrez et al., 2011). Respected community leaders, when guided by collective interests and not self-benefits, give resilience to changes in governance, influence users' compliance to regulations and enhance conflict resolutions (Gutiérrez et al., 2011). Trusted leaders is of particular relevance in the Philippines, where corruption within the political elite is a rampant issue (Hutchcroft, 2000; Hicken, 2008; Mehta and Jha, 2012).

Leadership would also be beneficial to maintain cohesion between several new actors in the system, e.g. middlemen in handicrafts and rice commercialization, international organizations and non-governmental organizations, tourism sector and the farmers themselves. For instance, broad-minded church groups should be encouraged to recognize the relevance of continuing the rituals and practices (including the survival of the *mumbaki*, the native priests) associated with rice farming (Nozawa et al., 2008).

6. Conclusions

The environment in which the Ifugaos have evolved serves not only as a legacy of the Ifugaos human achievements. In the Philippines, the terraces are commonly known as the “eighth wonder of the world”, showing the importance of the landmark for the whole country. Internationally, the inclusion in the UNESCO World Heritage List and as one of the Globally Important Agricultural Heritage Sites points out the culturally rich legacy of the co-development between human communities and ecosystems. Therefore, the preservation of the terraces and the traditional culture is of utmost importance.

Five key findings can be pointed out from this research:

1) There is a decreasing trend concerning the cultural services provided by the ecosystems to the residents of the five barangays. This comes in the form of declining religious experience related to rice, decreasing ritual practices and dwindling knowledge from ecosystems. Furthermore, this shift in cultural services could be hard to reverse because of the new religion in Ifugao (Calderon et al., 2008). Additionally, the social organization and autonomy became less robust as exposure to modern culture from Manila and foreign countries increased though tourism and telecommunications. As a result, reliance on the government increased, with more farmers awaiting for governmental aid to repair the collapsed walls and fewer farmers practicing the traditional *ubbu* and *baddang*. This erosion of social organization and knowledge was observed by Nozawa et al. (2010) as well. However, cultural services as a whole may not be in decline since services from the landscape are being appreciated by tourists for aesthetics, cultural experience and recreational activities. Also, new ecological knowledge, for instance introduced by famers or scientists from other provinces or abroad, could improve the adaptability of the system to disturbances, to which the local population is not used to cope with, e.g. exotic pest species or climate change.

2) The loss of cultural services (here rituals) impacts not only on the knowledge system but also on the ecosystems. Less rituals, combined with reduction of labor on the rice field,

result in a decreasing synchronization of crops. The consequences of such change are the higher vulnerability to pests, more specifically rodents and rice bugs.

3) This survey reiterates conclusions of previous literature regarding pest species and the lack of knowledge to mitigate their impact on rice cropping. Earthworms, *R. Tanezumi* and *P. caniculata* are new variables that farmers have to cope with, and all increase the labor requirement to maintain the same level of harvest. Farmers have also expressed concerns about a newly introduced eel that is allegedly more damaging to the rice terraces.

4) Evidence shows that forest clearing is not an issue anymore. Forest area is in fact increasing, possibly due to the gradual abandonment of shifting cultivation.

5) There is a noticeable change in climate from the low level of water in the fields, despite harder rains. This climatic change, characterized in the area by longer drought periods and more intense precipitation during typhoons will probably be exacerbated by earthworm and eel pests and by the expansion of the built-up areas and sealed surfaces.

6) The inheritance system specific to Ifugao seems to offset the consequences of high birth and migration rate. From migration also come remittances, which allow the migrant's kin to invest in agricultural production and improve their livelihood (McKay, 2003). At the moment, the study site has not been unsustainably overpopulated, nor is it suffering from high emigration, although the population around Banaue greatly increased in the last 20 years.

This thesis used eight indicators integrating social, economic and ecological components of human-modified ecosystems to assess the state of a rice-based agroecological landscape. From these indicators, vulnerability, resilience and adaptability was inferred, taking into consideration disturbance, exposure and sensitivity. In order to better assess the long-term development of the region, more indicators should be used and more data would be needed. For instance, an exhaustive biodiversity survey similar to the one undertaken by the Cordillera Administrative Region government (DENR, 2011) in the province of Hungduan should be realized in Banaue. Further, data should be available at different intervals to give a better idea of the trajectory of the system, of its resilience and adaptability.

The Ifugao rice terraces are a feat of landscape engineering and in many aspects, a model of sustainability. The traditional knowledge and the ecosystems are a product of long-term co-evolution which has resulted in a unique and complex social-ecological system. This system seemed to be now subject to many pressures, which threaten its durability. This research shows that some pressures are not as serious as previously thought before, since the system has adapted to them. However, some disturbances are continuous and increasing in importance and could cause a regime shift of the system.

References

Acabado, S., 2003. Land use and agricultural intensification: A GIS-based analysis of the Ifugao Landscape, Northern Philippines. MA Thesis, Department of Anthropology, University of Hawaii.

Acabado, S., 2009. A Bayesian approach to dating agricultural terraces: a case from the Philippines. Antiquity 83, 801-814.

Acabado, S., 2012. The Ifugao agricultural landscapes: Agro-cultural complexes and the intensification debate. Journal of Southeast Asian Studies 43(3), 500-522.

Adams, K.M., 1995. Making-up the Toraja? The appropriate of tourism, anthropology, and museums for politics in upland Sulawesi, Indonesia. Ethnology 34 (2), 143-153.

Adger, W.N., 2000. Social and ecological resilience: are they related? Progress in Human Geography 24(3), 347-364.

Adger, W.N., 2006. Vulnerability. Global Environmental Change 16(3), 268-281.

Adger, W.N., Kelly, P.M., Winkels, A., Huy, L.Q. 2002. Migration, remittances, livelihood trajectories, and social resilience. Ambio 31(4), 358-366.

Akama, J.S., Kieti, D. 2007. Tourism and socio-economic development in developing countries: a case study of Mombasa Resort in Kenya. Journal of Sustainable Tourism 15(6), 735-748.

Allig, T.D., 2013. Field evaluation of powdered rock lime to control giant earthworms (*Pheretima elongata*) of the Ifugao Rice Terrace. Open Science Repository Agriculture, e23050419. doi: 10.7392/openaccess.23050419.

Altieri, M.A., 1999. The ecological role of biodiversity in agroecosystems. Agriculture, Ecosystems and Environment 74(1-3), 19-31.

Araral, E., 2009. What can institutional analysis tell us about long lived societies? The case of the 2000 year old Ifugao society. Workshop on Political Theory and Policy Analysis, June 3-5, 2009, Indiana University, United States.

Araral, E., 2013. What makes socio-ecological systems robust? An institutional analysis of the 2,000 year-old Ifugao society. Human Ecology. doi: 10.1007/s10745-013-9617-5.

Bantayan, N.C., Calderon, M.M., Dizon, J.T., Sajise, A.J.U., Salvador, M.G., 2012. Estimating the extent and damage of the UNESCO World Heritage Sites of the Ifugao Rice Terraces, Philippines. Journal of Environmental Science and Management 15(1), 1-5.

Barrion, A.T., Litsinger, J.A., 1997. *Dichogaster* nr. *curgensis* Michaelsen (Annelida: Octochaetidae): An earthworm pest of terraced rice in the Philippine Cordilleras. Crop Protection 16(1), 89-93.

Barthelmes, R., Busemann, C., Heusinger, E., Ochs, C., Trosowski, B., Wellershaus, K., 1998. Banaue-Between yesterday and tomorrow (socioeconomic conditions). In: Settele, J., Plachter, H., Sauerborn, J., Vetterlein, D. (Eds.), Rice terraces of Ifugao (Northern-Luzon, Philippines), conflicts of landuse and environmental conservation – report of a scientific students' excursion. UFZ-Bericht 5/1998, 29-42.

Barton, R., 1919. Ifugao law. University of California Publications in American Archaeology and Ethnology1, 1-186.

Barton, R., 1922. Ifugao Economics. University of California Publication in American Archaeology and Ethnology 15(5), 385-44.

Bennett, E.M., Cumming, G.S., Peterson, G.D., 2005. A systems model approach to determining resilience surrogates for case studies. Ecosystems 8(8), 945-957.

Bergamini, N., Blasiak, R., Eyzaguirre, P., Ichikawa, K., Mijatovic, D., Nakao, F., Subramanian, S.M., 2013. Indicators of resilience in socioecological production landscapes (SEPLs). UNU-IAS Policy Report. United Nations University Institute of Advanced Studies, Yokohama.

Bevan, A., Conolly, J., 2011. Terraced fields and Mediterranean landscape structure: An analytical case study from Antikythera, Greece. Ecological Modelling 222(7), 1303-1314.

Berkes, F., Colding, J., Folke, C. (Eds.), 2003. Navigating social-ecological systems: building resilience for complexity and change. Cambridge University Press, New York.

Beyer, H.O., 1955. The origins and history of the Philippine rice terraces. Proceedings of the Eighth Pacific Science Congress, National Research Council of the Philippines, Quezon City.

Blaikie, P., Brookfield, H., 1987. Land degradation and society. Development Studies, vol. 940, Methuen, London.

Boucher, F., Gerz, A., 2006. Mantecoso cheese in Peru: Organizing to conquer the national market. In: van de Kop, P., Sautier, D., Gerz, A. (Eds.), Origin-based products. Lessons for pro-poor market development, Bulletin 372, Royal Tropical Institute, Amsterdam, CIRAD, Montpellier, p. 41-50.

Bouman, B.A.M., Lampayan, R.M., Tuong, T.P., 2007. Water management in irrigated rice: coping with water scarcity. International Rice Research Institute. Los Baños (Philippines).

Brenkert, A.L., Malone, E.L., 2005. Modeling vulnerability and resilience to climate change: a case study of India and Indian States. Climatic Change 72(1-2), 57-102.

Brosius, J.P., 1988. Significance and social being in Ifugao agricultural production. Ethnology 27(1), 97-110.

Bulilan, C.M.R., 2007. Experiencing cultural heritage and indigenous tourism in Banaue. Philippine Quarterly of Culture and Society 35(1), 100-128.

Bureau of Agricultural Statistics, 2013. CountrySTAT Philippines. Available online at: http://countrystat.bas.gov.ph/?cont=10&pageid=1&ma=A10PNVCP (accessed 27 Jan 2014).

Burkhard, B., Opitz, S., Lenhart, H., Ahrendt, K., Garthe, S., Mendel, B., Windhorst, W., 2011a. Ecosystem based modeling and indication of ecological integrity in the German North Sea—Case study offshore wind parks. Ecological Indicators 11(1), 168-174.

Burkhard, B., Fath, B.D., Müller, F., 2011b. Adapting the adaptive cycle: Hypotheses on the development of ecosystem properties and services. Ecological Modelling, 222 (16), 2878-2890. doi:10.1016/j.ecolmodel.2011.05.016.

Cabell, J.F., Oelofse, M., 2012. An indicator framework for assessing agroecosystem resilience. Ecology and Society 17(1), 18. doi.org/10.5751/ES-04666-170118.

Cagat, A.K., 2013. A site of tensions : negotiating access and autonomy in the Ifugao rice terraces, International Journal of Heritage and Sustainable Development 3(1), 53-61.

Calderon, M.M., Dizon, J.T., Sajise, A.J.U., Andrada II, R.T., Bantayan, N.C., Salvador, M.G., 2008. Towards the Development of a Sustainable Financing Mechanism for the Conservation of the Ifugao Rice Terraces in the Philippines. EEPSEA Research Report No. 2008-RR10. Available online at: http://web.idrc.ca/uploads/user-S/12476447771Marge_2008_RR10.pdf (accessed 02 Feb 2014).

Carpenter, S.R., Walker, M., Anderies, J.M., Abel, N., 2001. From metaphor to measurement: resilience of what to what? Ecosystems 4, 765-781.

Central Cordillera Agricultural Programme, 2003. Catalogue of indigenous forestry species in the Central Cordillera. Central Cordillera Agricultural Programme, Banaue, Philippines.

Clay, K., 2003. Parasites lost. Nature 421, 585-586.

Conklin, H.C., 1967a. Division of anthropology*:* some aspects of ethnographic research in Ifugao. Transactions of the New York Academy of Sciences 30(1) Series II, 99-121.

Conklin, H.C., 1967b. Ifugao Ethnobotany 1905-1965: The 1911 Beyer-Merrill Report in Perspective. Economic Botany 21(3), 243-272.

Conklin, H.C., 1980. Ethnographic Atlas of Ifugao: a study of environment, culture and society in northern Luzon. Yale University Press, New Haven, CT.

Connell, J.H., 1978. Diversity in tropical rain forests and coral reefs. Science 199(4335), 1302-1310.

Crooks, J.A., Soule, M.E., 1999. Lag times in population explosions of invasive species: Causes and implications. In: Sandlund, O.T., Schei, P.J., Viken, Å. (Eds), Invasive Species and Biodiversity Management. Population and Community Biology Series, Vol. 24, Kluwer Academic Publishers, Dordrecht, Netherlands, 103-125.

Cumming, G.S., 2011. Spatial resilience: integrating landscape ecology, resilience, and sustainability. Landscape Ecology 26, 899-909.

Dale, V.H., Beyeler, S.C. 2001. Challenges in the development and use of ecological indicators. Ecological Indicators 1(1), 3-10.

Davidson, M.D., 2013. On the relation between ecosystem services, intrinsic value, existence value and economic valuation. Ecological Economics 95, 171-177.

Department of Environment and Natural Resources (DENR), 1996. Revising DENR Administrative Order No. 21, Series of 1992, to Further Strengthen the Implementation of the Environmental Impact Statement (EIS) System. DENR Administrative Order No. 96-37 December 02, 1996.

Department of Environment and Natural Resources (DENR), 2008. Conservation and adaptive management of Globally Important Agricultural Heritage Systems (GIAHS): The Ifugao Rice Terraces, Philippine Project Framework. Available online at: http://www.fao.org/fileadmin/templates/giahs_assets/Sites_annexes/National_Project_Document_Philippines.pdf (accessed 02 Feb 2014).

Department of Environment and Natural Resources (DENR), 2011. Assessment of agricultural biodiversity of pilot sites of Globally Important Agricultural Heritage Systems, Ifugao Rice Terraces (GIAHS - IRT) at Hungduan, Ifugao, Philippines. Department of Environment and Natural Resources, Cordillera Administrative Region. Available online at: http://www.fao.org/fileadmin/templates/giahs_assets/case_study_annexes/Ifugao_Biodiversity_Assessment.pdf (accessed 27 Jan 2014).

Di Falco, S., Chavas, J.P., 2008. Rainfall shocks, resilience, and the effects of crop biodiversity on agroecosystem productivity. Land Economics 84(1), 83-96.

Dizon, J.T., Calderon, M.M., Sajise, A.J.U., Andrada, R.T., Salvador, M.G., 2012. Youths' perceptions of and attitudes towards the Ifugao Rice Terraces. Journal of Environmental Science and Management 15(1), 52-58.

Douglas, T.D., Kirkby, S.J., Critchley, R.W., Park, G.J., 1994. Agricultural terrace abandonment in the Alpujarra, Andalucia, Spain. Land Degradation & Rehabilitation 5(4), 281-291.

Dozier, E., 1966. Mountain arbiters: the changing life of a Philippine hill people. University of Arizona Press, Tucson.

Druguet, A., 2009. La commercialisation du riz tinawon Ifugao (Philippines): vers une recomposition sociale et territoriale? International symposium, Localizing products: a sustainable approach for natural and cultural diversity in the South? UNESCO, organized by MAB/UNESCO, IRD, CIRAD, MNHN, 9-11 June 2009. Available online at: http://www.mnhn.fr/colloque/localiserlesproduits/12_Paper_DRUGUET_A.pdf (accessed 02 Feb 2014).

Druguet, A., 2012. Les productions locales: une alternative au productivisme mondialisé? Le cas de la valorisation du riz tinawon dans la province Ifugao (Philippines). L'Homme et la société 2012/1n° 183-184, 97-124. doi: 10.3917/lhs.183.0097.

Eder, J.F., 1982. No water in the terraces: agricultural stagnation and social change at Banaue, Ifugao. Philippine Quarterly of Culture and Society 10(3), 101-116.

Evangelista, E.M., 2005. On-farm conservation of traditional rice (*Oryza sativa* L.) varieties in Central Cordillera, Philippines. MA Thesis, University of the Philippines, Los Baños, Laguna, Philippines.

E8 general secretariat, 2010. The Philippine Ifugao-Ambangal Mini-hydro Project. Available online at: http://www.globalelectricity.org/upload/File/ifugao_publication_final.pdf (accessed 29 Jan 2014).

Fisher, B., Turner, R.K., Morling, P., 2009. Defining and classifying ecosystem services for decision making. Ecological Economics 68, 643-653.

Fletcher, C.S., Miller, C., Hilbert, D.W., 2006. Operationalizing resilience in Australian and New Zealand agroecosystems. In: Proceedings of the 50th Annual Meeting of the ISSS, ISSS 2006

Papers. Journals ISSS. Available online at: http://journals.isss.org/index.php/proceedings50th/article/view/355 (accessed 02 Feb 2014).

Fletcher, C.S., Hilbert, D.W., 2007. Resilience in landscape exploitation systems. Ecological Modelling, 201(3-4), 440-452.

Folke, C., 2006. Resilience: The emergence of a perspective for social–ecological systems analyses. Global Environmental Change 16(3), 253-267.

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C.S., Walker, B., 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. Ambio, 31(5), 437-40.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., Holling, C.S., 2004. Regime shifts, resilience, and biodiversity in ecosystem management. Annual Review of Ecology, Evolution, and Systematics 35(1), 557-581.

Gallopín, G.C., 2003. Box 1. A systemic synthesis of the relations between vulnerability, hazard, exposure and impact, aimed at policy identification. In: Economic Commission for Latin American and the Caribbean (ECLAC). Handbook for Estimating the Socio-Economic and Environ-mental Effects of Disasters. ECLAC, LC/MEX/G.S., Mexico, D.F., pp. 2-5. Available online at: http://www.preventionweb.net/files/1099_eclachandbook.pdf (accessed 27 Jan 2014).

Gallopín, G.C., 2006. Linkages between vulnerability, resilience, and adaptive capacity. Global Environmental Change 16(3), 293-303.

Gallopín, G.C., Gutman, P., Maletta, H., 1989. Global impoverishment, sustainable development and the environment. A conceptual approach. International Social Science Journal 121, 375-397.

Gates, G.E., 1972. Burmese earthworms: an introduction to the systematics and biology of megadrile Oligochaetes with special reference to Southeast Asia. Transactions of the American Philosophical Society, New Series 62(7), 1-326.

Grepperud, S., 1996. Population pressure and land degradation: The case of Ethiopia. Journal of Environmental Economics and Management 30(1), 18-33.

Glitzenstein, J.S., Platt, W.J., Streng, D.R., 1995. Effects of fire regime and habitat on tree dynamics in north Florida longleaf pine savannas. Ecological Monographs 65(4), 441-476.

Gomez, R.A., 2003. Environmental management of the Ifugao rice terraces in Kiangan and Banaue, Philippines. Ph.D. Dissertation, University of the Philippines, Los Baños, Laguna, Philippines.

Gomez, R.A., Pacardo, E.P., 2005. Survey of the damage in the Ifugao Rice Terraces and its environmental dynamics. Philippine Agricultural Scientist 88, 133-137.

Gonzalez, R.M., 2000. Platforms and terraces: Bridging participation and GIS in joint-learning for watershed management with the Ifugaos of the Philippines. Doctoral dissertation, Wageningen University, Netherlands.

Guimbatan, R., Baguilat Jr, T., 2006. Misunderstanding the notion of conservation in the Philippine rice terraces – cultural landscapes. International Social Science Journal 58(187), 59-67.

Gunderson, L.H., 2000. Ecological Resilience--In Theory and Application. Annual Review of Ecology and Systematics 31, 425-439.

Gunderson, L.H., Holling, C.S. (Eds.), 2002. Panarchy: Understanding transformations in human and natural systems. Island Press, Washington DC.

Gutiérrez, N.L., Hilborn, R., Defeo, O., 2011. Leadership, social capital and incentives promote successful fisheries. Nature 470, 386-389.

Guy, P., 1995. Agroecosystem analysis and rapid rural appraisal of selected sites in the Central Cordillera, Ifugao, Philippines. Environment and Resource Management Project (ERMP) 15, Halifax.

Haines-Young, R.H., Potschin, M.P., 2010. The links between biodiversity, ecosystem services and human well-being. In: Raffaelli, D., Frid, C. (Eds.), Ecosystem Ecology: A New Synthesis. BES Ecological Reviews Series. Cambridge University Press, Cambridge, 110-139.

Hammad, A.A., Børresen, T., 2006. Socioeconomic factors affecting farmers' perceptions of land degradation and stonewall terraces in central Palestine. Environmental Management 37(3), 380-94.

Harrison, S., Inouye, B.D., Safford, H.D., 2003. Ecological heterogeneity in the effects of grazing and fire on grassland diversity. Conservation Biology 17(3), 837-845.

Hayama, A., 2003. Local forest management in the rice terrace area of Banaue, the Philippines. In: Inoue, M., Isozaki, H. (Eds.): People and Forest - Policy and Local Reality in Southeast Asia, the Russian Far East, and Japan. Institute for Global Environmental Strategies 3, 275-286.

Heal, G., 2000. Nature and the marketplace: capturing the value of ecosystem services. Island Press, Washington D.C.

Herath, S., Liang, L., Kawasaki, J., Jiao, Y., Castro, P.P.M., Wang, Y., 2013. Developing ecosystem-based adaptation strategies to enhance the resilience of rice terrace farming systems against climate change. In: Stevenson, L.A., Shrestha, M.L., Sterin, A. (Eds.), Asia-Pacific Network for Global Change Research Science Bulletin (3), 71-73.

Herzmann, S., Jost, A., Korbun, T., Willerding, C., Settele, J., Plachter, H., 1998. Ifugao Rice Terraces – Landuse changes in a traditional agroecosystem from 1963 to 1997. In: Settele, J., Plachter, H., Sauerborn, J., Vetterlein, D. (Eds.), Rice terraces of Ifugao (Northern-Luzon, Philippines), conflicts of landuse and environmental conservation – report of a scientific students' excursion. UFZ-Bericht 5/1998, 78-90.

Hicken, A., 2008. The Philippines in 2007 ballots, budgets, and bribes. Asian Survey 48(1), 75-81.

Holling, C.S., 1973. Resilience and stability of ecological systems. Annual Review of Ecology and Systematics 4, 1-23.

Holling, C.S., 1996. Engineering resilience versus ecological resilience. In: Schulze, P.C. (Ed.), Engineering within Ecological Constraints. National Academy Press, Washington, DC, 31-43.

Hong, Y., James, S.W., 2008. Nine new species of earthworms (Oligochaeta: Megascolecidae) of the Banaue Rice Terraces, Philippines. Revue Suisse de Zoologie 115(2), 341-354.

Hong, Y., James, S.W., 2010. Six new earthworms of the genus *Pheretima* (Oligochaeta: Megascolecidae) from Balbalan-Balbalasang, Kalinga Province, the Philippines, Zoological Studies 49(4), 523-533.

Hong, Y., James, S.W., 2011. New earthworm species of the genus Pheretima (Clitellata: Megascolecidae) from Mountain Province, Philippines. Journal of Natural History 45(29-30), 1769-1788.

Hutchcroft, P.D., 2000. Obstructive corruption: the politics of privilege in the Philippines. In: Khan, M.H., Jomo, K.S. (Eds.), Rents, rent-seeking and economic development: theory and evidence in Asia. Cambridge University Press, Cambridge, 207-247.

Ingelson, A., Holden, W., Bravante, M., 2009. Philippine environmental impact assessment, mining and genuine development. Law, Environment and Development Journal 5(1), 1-17. Available online at: http://www.lead-journal.org/content/09001.pdf (accessed 29 Jan 2014).

International Union for Conservation of Nature (IUCN), 2013. Pomacea canaliculata (mollusc). Global Invasive Species Database. Available online at:

http://www.issg.org/database/species/ecology.asp?si=135&fr=1&sts=&lang=EN (accessed 20 Sept. 2013).

Jong, G.F. Root, B.D., Gardner, R.W., Fawcett, J.T., Abad, R.G. 1986. Migration intentions and behavior : decision making in a rural Philippine province. Population and Environment 8(1-2), 41–62.

Joshi, R.C., Matchoc, O.R.O., Cabigat, J.C., James, S.W., 1999. Survey of earthworms in the Ifugao Rice Terraces, Philippines. Journal of Environmental Science and Management 2(2), 1-12.

Joshi, R.C., Matchoc, O.R.O., Bahatan, R.G., Dela Pena, F.A., 2000. Farmers' knowledge, attitudes and practices of rice crop and pest management at Ifugao Rice Terraces, Philippines. International Journal of Pest Management 46(1), 43-48

Joshi, R.C., Delacruz, M.S., Martin, E.C., Cabigat, J.C., Bahatan, R.G., Bahatan, A.D., Abayao, E.H., Choy-Awon, J., Chilagan, N.P., Cayong, A.B., 2001. Current status of the golden apple snail in the Ifugao Rice Terraces, Philippines. Journal of Sustainable Agriculture 18(2-3), 71-90.

Joshi, R.C. Martin, E.C., Wada, T., Sebastian, L.S., 2005. Role of golden apple snail in organic rice cultivation and weed management. Paper at: Researching Sustainable Systems - International Scientific Conference on Organic Agriculture September 21-23, 2005, Adelaide, Australia.

Kamau, E.C., Fedder, B., Winter, G., 2010. The Nagoya Protocol on Access to Genetic Resources and Benefit Sharing: what is new and what are the implications for provider and user countries and the scientific community. Law, Environment and Development Journal 6(3), 248-263.

Kassam, K.A., 2009. Viewing change through the prism of indigenous human ecology: Findings from the Afghan and Tajik Pamirs. Human Ecology 37(6), 677-690.

Kasperson, R.E., Dow, K., Archer, E., Caceres, D., Downing, T., Elmqvist, T., Eriksen, S., Folke, C., Han, G., Iyengar, K., Vogel, C., Wilson, K., Ziervogel, G., 2005. Vulnerable people and places. In: Hassan, R., Scholes, R., Ash, N. (Eds.), Ecosystems and Human Well-being: Current State and Trends 1. Island Press, Washington, DC, 143-164.

Kato, T., 1994. The emergence of abandoned paddy fields in Negeri Sembilan, Malaysia. Southeast Asian Studies 32(2), 145-172.

Keesing, F., 1962. The ethnohistory of northern Luzon. Stanford University Press, Stanford.

Kinzig, A.P., Ryan, P., Etienne, M., Allison, H., Elmqvist, T., Walker, B.H., 2006. Resilience and regime shifts: assessing cascading effects. Ecology and Society 11(1), 20. Available online at: http://www.ecologyandsociety.org/vol11/iss1/art20 (accessed 02 Feb 2014).

Koohafkan, P., Jane, M., 2011. Conservation and adaptive management of Globally Important Agricultural Heritage Systems (GIAHS). Journal of Resources and Ecology 2(1), 22-28.

Kurtz, J.C., Jackson, L.E., Fisher, W.S., 2001. Strategies for evaluating indicators based on guidelines from the Environmental Protection Agency's Office of Research and Development. Ecological Indicators 1(1), 49-60.

Kwiatkowski, L., 2013. Globalization, environmental change, and coping strategies among the Ifugao of the Philippine Cordillera Mountains. In: Lozny, L.R. (Ed.), Continuity and Change in Cultural Adaptation to Mountain Environments. Studies in Human Ecology and Adaptation 7, 361-378.

Lambrecht, F., 1967. The hudhud of Dinulawan and Bugan at Gonhadan. Saint Louis Quarterly 5, 527-713.

Lee, K.E., 1985. Earthworms: their ecology and relationships with soils and land use. Academic Press, Sydney.

LEGATO, 2011. Land Luse intensity and Ecological EnGineering – Assessment Tools for risks and Opportunities in irrigated rice based production systems: Description of Work. Contract version 16th May 2011.

Lesschen, J.P., Cammeraat, L.H., Nieman, T., 2008. Erosion and terrace failure due to agricultural land abandonment in a semi-arid environment. Earth Surface Processes and Landforms 33, 1574-1584.

Levin, S., Xepapadeas, T., Crépin, A.S., Norberg, J., Zeeuw, A.D., Folke, C., Hughes, T., Arrow, K., Barrett, S., Daily, G., Ehrlich, P., Kautsky, N., Mäler, K.G., Polasky, S., Troell, M., Vincent, J.R., Walker, B., 2013. Social-ecological systems as complex adaptive systems: modeling and policy implications. Environment and Development Economics 18, 111-132.

Li, H., Reynolds, J.F., 1996. A simulation experiment to quantify spatial heterogeneity in categorical maps. Ecology 75(8), 2446-2455.

Liu, J., Hull, V., Batistella, M., Defries, R., Dietz, T., Fu, F., Hertel, T.W., Izaurralde, R.C., Lambin, E.F., Li, S., Martinelli, L.A., McConnell, W.J., Moran, E.F., Naylor, R., Ouyang, Z., Polenske, K.R., Reenberg, A., Rocha, GdM., Simmons, C.S., Verburg, P.H., Vitousek, P.M., Zhang, F., Zhu, C., 2013. Framing sustainability in a telecoupled world. Ecology and Society 18(2): 26. http://dx.doi.org/10.5751/ES-05873-180226.

Licyayo, D.C.M., 2013. Crop production practices and adaptation to climate change in Ifugao Province. Open Science Repository Agriculture, e23050444. doi:10.7392/openaccess.2305044.

Linton, A., 2008. A niche for sustainability? Fair labor and environmentally sound practices in the specialty coffee industry. Globalizations 5(2), 231-245.

Loreau, M., and Hector, A., 2001. Partitioning selection and complementarity in biodiversity experiments. Nature 412, 72-76.

Lubbers, I.M., van Groenigen, K.J., Fonte, S.J., Six, J., Brussaard, L., van Groenigen, J.W., 2013. Greenhouse-gas emissions from soils increased by earthworms. Nature Climate Change 3, 187-194.

Luis, J.S., Paris, T.R., 2003. Socio-demographic & agricultural factors affecting out-migration in selected rice farming villages in Cagayan province, Philippines. Philippine Journal of Crop Science 28(1), 49-60.

Madulid, D.A., 2010. Plant diversity and conservation of the woodlots of Ifugao UNESCO National Commission of the Philippines, Pasay City, Philippines.

Magcale-Macandog, D.B., Rabena, M.A.F., Edrial, J.D., Manlubatan, M.B.T., Mago, K.S., Bragais, M.A., Marquez Jr, T.L., 2013. Decomposition of sunflower cuttings in payoh rice terrace and leaf litter in muyong forest, Banaue, Ifugao. Presentation at the LEGATO Conference 8-16 April 2013, Hanoi, Vietnam.

Magurran, A.E., 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, NJ.

Maher, R., 1973. Archaeological investigations in central Ifugao. Asian Perspectives 16(1), 39-70.

Margraf, J., Voggesberger, M. 1984. Biological aspects of the traditional agro-ecosystems of Ifugao, Philippines. 5th IFOAM Conference on the Importance of Biological Agriculture in a World of Diminishing Resources, Witzenhausen, Germany.

Martin, K., Grölz, H., Holzhauer, S., 1998. Field studies on the golden apple snail in the Ifugao Rice Terraces. In: Settele, J., Plachter, H., Sauerborn, J., Vetterlein, D. (Eds.), Rice terraces of Ifugao (Northern-Luzon, Philippines), conflicts of landuse and environmental conservation – report of a scientific students’ excursion. UFZ-Bericht 5/1998, 55-62.

Martin, K., Sauerborn, J., 2000. An aquatic wild plant as keystone species in a traditional Philippine rice growing system: agroecological implications. Annals of Tropical Research 22, 1-15.

Mateu-Sbert, J., Ricci-Cabello, I., Villalonga-Olives, E., Cabeza-Irigoyen, E., 2013. The impact of tourism on municipal solid waste generation: the case of Menorca Island (Spain). Waste management 33(12), 2589-2593.

Mbaiwa, J.E., 2003. The socio-economic and environmental impacts of tourism development on the Okavango Delta. Journal of Arid Environments 54(2), 447-467.

McKay, D., 2003. Cultivating new local futures: remittance economies and land-use patterns in Ifugao, Philippines. Journal of Southeast Asian Studies 34(2), 285-306.

Mehta, A., Jha, S., 2012. Corruption, food subsidies, and opacity : Evidence from the Philippines. Economics Letters 117(3), 708-711.

Millare, J.L.D., 2010. Working together to promote agroforestry in rehabilitating the Cordillera region in northern Philippines. Asia-Pacific Agroforestry Newsletter 37, 11-13.

Millennium Ecosystem Assessment (MA), 2005. Ecosystems and Human Well-being: Synthesis. World Resources Institute, Washington, DC, Available online at: www.millenniumassessment.org/documents/document.356.aspx.pdf (accessed 28 Jan 2014).

Miller, R.W., Stuart, A.M., Joshi, R.C., Banks, P.B., Singleton, G.R., 2008. Biology and management of rodent communities in complex agroecosystems - rice terraces. In: Singleton, G.R., Joshi, R.C., Sebastian, L.S. (Eds), Philippine Rats: Ecology & Management, Publisher: Philippine Rice Research Institute. Science City of Muñoz, Nueva Ecija, the Philippines.

Mochida, O., 1987. *Pomacea* snails in the Philippines. International Rice Research Newsletter 12 (4), 48-49.

Morimoto, Y., Maundu, P., Tumbo, D., Eyzaguirre, P., 2010. How farmers in Kitui use wild and agricultural ecosystems to meet their nutritional needs (Kenya). In: Bélair C., Ichikawa K., Wong B.Y.L., Mulongoy K.J. (Eds), Sustainable use of biological diversity in socio-ecological production landscapes. Background to the 'Satoyama Initiative for the benefit of biodiversity and human well-being.' Secretariat of the Convention on Biological Diversity, Technical Series no. 52, Montreal, 67-72.

Morrison, C., Simpkins, C., Castley, J.G., Buckley, R.C., 2012. Tourism and the conservation of critically endangered frogs. PloS one 7(9), e43757.

Müller, F., Burkhard, B., Kroll, F., 2010. Resilience, integrity and ecosystem dynamics: bridging ecosystem theory and management. In: Otto, J.C., Dikau, R. (Eds.), Landform – Structure, Evolution, Process Control. Lecture Notes in Earth Sciences Series. Vol. 115, 221-242.

Müller, F., Burkhard, B., 2012. The indicator side of ecosystem services. Ecosystem Services 1(1), 26-30.

Nair, K.S.S., 2001. Pest outbreaks in tropical forest plantations Is there a greater risk for exotic tree species? CIFOR, Bogor, Indonesia.

Nalliw-Licnachan, E., 2009. Indigenous peoples of Ifugao: Responding to climate change. IOP Conference Series: Earth and Environmental Science 6(57), 572031. doi:10.1088/1755-1307/6/7/572031.

National Statistical Coordination Board (NSCB), 2012. Census of Population and Housing. Population Counts - Cordillera Administrative Region. Available online at: http://www.census.gov.ph/sites/default/files/attachments/hsd/pressrelease/Cordillera%20Administrative%20Region.pdf (accessed 03 Feb 2014).

Ngaloy, I.T., Andrada, M.G., Estigoy, D.A., 2002. The indigenous bakuwog tree: Eradicator of the exotic golden snail. Canopy International 28(2-3), 3. Available online at: http://erdb.denr.gov.ph/publications/canopy/c_v28n2_3.pdf (accessed 28 Jan 2014).

Nozawa, C., Malingan, M., Plantilla, A., Ong, J., 2008. Evolving culture, evolving landscapes: The Philippine rice terraces. In: Amend, T., Brown, J., Kothari, A., Phillips, A., Stolton, S. (Eds.), Protected Landscapes and Agrobiodiversity Values. Protected Landscapes and Seascapes Vol. 1, IUCN & GTZ. Kasparek Verlag, Heidelberg, 71-93.

O'Brien, M., Holland, T.D., 1992. The role of adaptation in archeological explanation. American Antiquity 57(1), 36-69.

Olsson, P., Folke, C., Hahn, T., 2004. Social-ecological transformation for ecosystem management: the development of adaptive co-management of a wetland landscape in southern Sweden. Ecology and Society 9(4), 2. Available online at: http://www.ecologyandsociety.org/vol9/iss4/art2/ (accessed 02 Feb 2014).

Othman, P., 1992. Land Abandonment in the Rice Sector: An Economic Analysis. Jurnal Ekonomi Malaysia 26, 21-45.

Owa, S.O., Oyenusi, A.A., Joda, A.O., Morafa, S.O.A., Yeye, J.A., 2003. Effect of earthworm casting on growth parameters of rice. African Zoology 38(2), 229-233.

Pashanasi, B., Lavelle, P., Alegre, J., Charpentier, F., 1996. Effect of the endogeic earthworm *Pontoscolex corethrurus* on soil chemical characteristics and plant growth in a low-input tropical. Soil Biology & Biochemistry 28(6), 801-810.

Pimm, S.L., 1984. The complexity and stability of ecosystems. Nature 307(26), 321-326.

Plachter, H., Sauerborn, J., Vetterlein, D., Settele, J., 1998. Scenarios for the future development of the Ifugao Rice Terraces (N-Luzon, Philippines) In: Settele, J., Plachter, H., Sauerborn, J., Vetterlein, D. (Eds.), Rice terraces of Ifugao (Northern-Luzon, Philippines), conflicts of landuse and environmental conservation – report of a scientific students' excursion. UFZ-Bericht 5/1998, 91-102.

Platt, W.J., 1999. Southeastern pine savannas. In: Anderson, R.C., Fralish, J.S., Baskin, J.M. (Eds), Savannas, barrens, and rock outcrop plant communities of North America. Cambridge University Press, Cambridge, 23-51.

Qiu, Z., Chen, B., Takemoto, K., 2013. Conservation of terraced paddy fields engaged with multiple stakeholders: the case of the Noto GIAHS site in Japan. Paddy and Water Environment, 1-9. doi:10.1007/s10333-013-0387-x.

R Development Core Team, 2011. R A Language and Environment for Statistical Computing. Vienna, Austria.

Raynolds, L.T., Ngcwangu, S.U., 2010. Fair trade Rooibos tea : Connecting South African producers and American consumer markets. Geoforum 41(1), 74-83.

Resilience Alliance, 2002. Key concepts: Adapative capacity. Available online at: http://www.resalliance.org/index.php/adaptive_capacity (accessed 27 Jan 2014).

RICE Inc., 2012. 2012 Annual report. Available online at: http://www.heirloomrice.com/reports/2012%20RICE%20ANNUAL%20REPORT_final.pdf (accessed 28 Jan 2014).

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III. F.S., Lambin, E., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H., Nykvist, B., De Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley, J., 2009. Planetary boundaries: exploring the safe operating space for humanity. Ecology and Society 14(2), 32. Available online at: http://www.ecologyandsociety.org/vol14/iss2/art32/ (accessed 27 Jan 2014).

Roger, P.A., Voggesberger, M., Margraf, J., 1986. Nitrogen-fixing phototrophs in the Ifugao Rice Terraces (Philippines). Philippine Agriculturist 69, 599-609.

Roxas, J.P., 1996. Isozyme analysis, morpho-agronomic traits and grain quality of traditional rice varieties (Oryza sativa L.) of Ifugao. M.S.Agr. Thesis, Gregorio Araneta University Foundation, Malabon City, Metro Manila, the Philippines.

Sala, O.E., 2001. Price put on biodiversity. Nature 412, 34-36.

Sass, R.L., Fisher, F.M., Wang, Y.B., Turner, F.T., Jund, M.F., 1992. Methane emission from rice fields: The effect of floodwater management. Global Biogeochemical Cycles 6(3), 249-262.

Save the Ifugao Terraces Movement (SITMo), 2008. IMPACT: the effects of tourism on culture and the environment in Asia and the Pacific: sustainable tourism and the preservation of the World Heritage Site of the Ifugao Rice Terraces, Philippines. UNESCO, Bangkok.

Sawey, M., Ngohayon, S., Ngohayon, J., Ildefonso, R., 2010. Climate change adaptation mechanism of the indigenous people's communities in Ifugao-Philippines. Southeast Asian Network for Agroforestry Education (SEANAFE) 2nd international conference on agroforestry education, December 15-17 2010, Chiang Mai, Thailand.

Scheffer, M., Carpenter, S., Foley, J.A., Folke, C., Walker, B., 2001. Catastrophic shifts in ecosystems. Nature 413, 591-596.

Schoon, M.L., Cox, M.E., 2011. Understanding disturbances and responses in social-ecological systems. Society & Natural Resources 25(2), 141-155.

Scott, W.H., 1974. The Discovery of the Igorots. New Day Publishers, Quezon City, the Philippines.

Sekimoto, S., Augustin-Jean, L., 2012. An export niche in the Philippines: the commodification of a specialty rice in Ifugao Province. In: Augustin-Jean, L., Ilbert, H., Saavedra-Rivano, N. (Eds), Geographical Indications and International Agricultural Trade: The Challenge for Asia. Palgrave Macmillan, New York, NY, USA, 181-203.

Serrano, R.C., Cadaweng, E.A., 2005. The Ifugao Muyong: sustaining water, culture and life. In: Durst, P.B., Brown, C., Tacio, H.D., Ishikawa, M. (Eds), In search of excellence: Exemplary Forest Management in Asia and the Pacific. Regional Community Forestry Training Center for Asia and the Pacific, Bangkok, 103-112.

Settele, J., 1998. Land use changes and conservation of natural resources – agroecological research in Philippines rice terraces. PLITS 16(2), 181-204.

Settele, J., 2003. Harvesting of crops in inland wetlands. In: Gherardi, F., Corti, C., Gualtieri, M. (Eds.), Biodiversity Conservation and Habitat Management. Encyclopedia of Life Support Systems (EOLSS; chapter E1-67-04-03), Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford, UK.

Settele, J., Plachter, H., Sauerborn, J., Vetterlein, D. (Eds.), 1998. Rice terraces of Ifugao (Northern-Luzon, Philippines), conflicts of landuse and environmental conservation – report of a scientific students' excursion. UFZ-Bericht 5/1998.

Shannon, C.E., 1948. A mathematical theory of communication. The Bell System Technical Journal 27, 379-423; 623-656.

Sigari, T.A., Desamero, N.V., Cabigat, J.C., Abayao, E.H., Cayong, A.B., 2003. Soil fertility limitations of Ifugao Rice Terraces. Philippine Journal of Crop Science 28(1), 39-48.

Sigari, T.A., Desamero, N.V., Cabigat, J.C., Abayo, E.H., 2005. Seedbed & seedling management in the Ifugao Rice Terraces. Philippine Journal of Crop Science 29(3), 45-50.

Simpson, E.H., 1949. Measurement of diversity. Nature 163, 688.

Smithers, J., Smit, B., 1997. Human adaptation to climatic variability and change. Global Environmental Change 7(2), 129-146.

Spangenberg, J., Rodríguez-Labajos, B., Tekken, V., 2013. Challenges of ecosystem service assessment. Presentation at the LEGATO Conference 8-16 April 2013, Hanoi, Vietnam.

Stanyukovich, M.V., 2003. A living shamanistic oral tradition : Ifugao hudhud, the Philippines. Oral Tradition 18(2), 249-251.

Stuart, A.M., Prescott, C.V., Singleton, G.R., Joshi, R.C., Sebastian, L.S., 2007. The rodent species of the Ifugao Rice Terraces, Philippines – target or non-target species for management? International Journal of Pest Management 53(2), 139-146.

Svensson, J.R., Lindegarth, M., Siccha, M., Lenz, M., Molis, M., Wahl, M., Pavia, H., 2007. Maximum species richness at intermediate frequencies of disturbance: consistency among levels of productivity. Ecology 88(4), 830-838.

Trenbath, B.R., 1999. Multispecies cropping systems in India: Predictions of their productivity, stability, resilience and ecological sustainability. Agroforestry Systems 45(1-3), 81-107.

Turner, B.L., Kasperson, R.E., Matson, P.A, McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L., Polsky, C., Pulsipher, A., Schiller, A., 2003. A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences of the United States of America 100(14), 8074-8079.

Turner, M.G., Bratton, S.P., 1987. Fire, grazing, and the landscape heterogeneity of a Georgia barrier island. In: Turner, M.G. (Ed.), Landscape heterogeneity and disturbance. Ecological Studies Vol. 64, Springer, 85-101.

Turner, M.G., Donato, D.C., Romme, W.H., 2013. Consequences of spatial heterogeneity for ecosystem services in changing forest landscapes: priorities for future research. Landscape Ecology 28(6), 1081-1097.

Tvedten, I., 1990. The difficult transition from subsistence to commercial fishing: the case of the Bijagòs of Guinea-Bissau. Maritime Anthropological Studies 3(1), 119-130.

United Nations Educational, Scientific and Cultural Organization (UNESCO), 1995. World Heritage List: Rice Terraces of the Cordilleras. No 722. Available online at: http://whc.unesco.org/archive/advisory_body_evaluation/722.pdf (accessed 27 Jan 2014).

United Nations Educational, Scientific and Cultural Organization (UNESCO), 1996. Convention Concerning the Protection of the World Cultural and Natural Heritage. WHC-95/CONF.203/16. World Heritage Committee, 19th session, Berlin, Germany. Available online at: http://whc.unesco.org/archive/1995/whc-95-conf203-16e.pdf (accessed 27 Jan 2014).

United Nations Educational, Scientific and Cultural Organization (UNESCO), 2002. Report of the World Heritage Committee WHC-01/CONF.208/24. Rice Terraces of the Philippine Cordilleras (Philippines) VIII.112, p. 32. Available online at: http://whc.unesco.org/archive/repcom01.pdf (accessed 29 Jan 2014).

United Nations Educational, Scientific and Cultural Organization (UNESCO), 2012. Decisions report – 36th session of the World Heritage Committee (Saint-Petersburg, 2012), WHC-12/36.COM/19, Rice Terraces of the Philippine Cordilleras (Philippines) (C 722) Decision: 36 COM 7A.29, p. 40-41. Available online at: http://whc.unesco.org/archive/2012/whc12-36com-19e.pdf (accessed 29 Jan 2014).

Untalan, J.M., Azores, R.P., Palacay, J.P., Anacleto, T., Quibuyen, O., 2013. Infrastructure development vis a vis cultural site preservation, indigenous people protection, biodiversity and the environment of Halsema highway towards safer and greener roads. 14th Conference of Road Engineering Association of Asia and Australasia. Available online at:

http://reaaa.vms.my/images/8/88/%282-07%29Infrastructure_Development_Joy_Untalan_Philippines.pdf (accessed 29 Jan 2014).

Van der Leeuw, S.E., 2001. 'Vulnerability' and the integrated study of socio-natural phenomena. IHDP Update 2/01, art. 2. Available online at: http://www.ihdp.uni-bonn.de/html/publications/update/IHDPUpdate01_02.html (accessed 29 Jan 2014).

Van Oudenhoven, F.J.W., Mijatovic, D., Eyzaguirre, P.B., 2011. Social-ecological indicators of resilience in agrarian and natural landscapes. Management of Environmental Quality 22(2), 154-173.

Van Vliet, N., Mertz, O., Heinimann, A., Langanke, T., Pascual, U., Schmook, B., Adams, C., Vogt, D.S., Messerli, P., Leisz, S., Castella, J.C., Jørgensen, L., Birch-Thomsen, T., Hett, C., Bech-Bruun, T., Ickowitz, A., Vu, K.C., Yasuyuki, K., Fox, J., Padoch, C., Dressler, W., Ziegler, A.D., 2012. Trends, drivers and impacts of changes in swidden cultivation in tropical forest-agriculture frontiers: A global assessment. Global Environmental Change 22(2), 418-429.

Verner, D., 2007. The Haitian People: Demographics, Poverty, and Socioeconomic Outcomes and Risks. In: Verner, D., Egset, W. (Eds.), Social resilience and state fragility in Haiti. World Bank, Washington DC, USA. Available online at: https://openknowledge.worldbank.org/handle/10986/6836 (accessed 31 Jan 2014).

Villalon, A.F., 1995. The cultural landscape of the Rice Terraces of the Philippine Cordilleras. In: von Droste, B., Plachter, H., Rössler, M. (Eds.), Cultural Landscapes of Universal Value – Components of a global strategy, Gustav Fisher Verlag, Jena, 108-113.

Vogel, H., 1988. Impoundment-type bench terracing with underground conduits in Jibal Haraz, Yemen Arab Republic. Transactions of the Institute of British Geographers 13(1), 29-38.

Wackernagel, F.W.H., 1985. Rice for the terraces: cold-tolerant varieties and other strategies for increasing rice production in the mountains of Southeast Asia. Ph.D. Dissertation, Cornell University, Ithaca, N.Y., USA.

Walker, B.H., Holling, C.S., Carpenter, S.C., Kinzig, A.P., 2004. Resilience, adaptability and transformability. Ecology and Society 9(2), 5. Available online at: http://www.ecologyandsociety.org/vol9/iss2/art5/ (accessed 02 Feb 2014).

Walther, P., 1986. Land abandonment in the Swiss Alps: a new understanding of a land-use problem. Mountain Research and Development 6(4), 305-314.

Westley, F.R., Tjornbo, O., Schultz, L., Olsson, P., Folke, C., Crona, B., Bodin. Ö., 2013. A theory of transformative agency in linked social-ecological systems. Ecology and Society 18(3), 27. doi:10.5751/ES-05072-180327.

Wilson, G., 2010. Multifunctional "quality" and rural community resilience. Transactions of the Institute of British Geographers 35(3), 364-381.

World Weather Online, 2014. Banaue Monthly Climate Average, Philippines. Available online at: http://www.worldweatheronline.com/Banaue-weather-averages/Ifugao/PH.aspx (accessed 25 Feb 2014).

Yansaneh, I.S., 2005. Overview of sample design issues for household surveys in developing and transition countries. In: United Nations, Household Sample Surveys in Developing and Transition Countries. ST/ESA/STAT/SER.F/96, United Nations Publications, New York.

Young, O.R., 2010. Institutional dynamics: Resilience, vulnerability and adaptation in environmental and resource regimes. Global Environmental Change 20(3), 378-385.

Yumul Jr., G.P., Dimalanta, C.B., Servando, N.T., Hilario, F.D., 2010. The 2009-2010 El Niño Southern Oscillation in the context of climate uncertainty: the Philippine setting. Philippine Journal of Science 139(1), 119-126.

Zhang, W., Hendrix, P.F., Dame, L.E., Burke, R.A., Wu, J., Neher, D.A., Li, J., Shao, Y., Fu, S., 2013. Earthworms facilitate carbon sequestration through unequal amplification of carbon stabilization compared with mineralization. Nature Communications 4, 1-9.

Appendix I: Household Survey for Banaue

Barangay	HH ID	Date
HH members	Ethnicity	

Household members

	Kin relationship	Name	Sex M,F	Age
1	Respondent			
2	children			
3	parents			
4				
5				
(Adult) child living abroad?	Do you have siblings living abroad?	Do they send remittance?		

1. Economic viability

Rice production by plot

- How many Payo fields do you have? ______
- What is the overall area of your Payo fields? __________ m^2 or __________ha

Field	Rice variety	Do you use pesticides?	Chemical fertilizer?	Best plots/worst plots in production
1				
2				
3				
4				
others				

- Did you sell rice last year? How much (bags, kg)? Income?

Productivity change over the last 10 years		
Increase/decreased	By how much?	Reasons
+/0/-		

2. Self-sufficiency

	0-2 months	2-4 months	5-7 months	8-10 months	11-12 months
For how long can you have rice after a harvest?					
Change in the last 10 years (+/-)					
Note					

Pinugo/Muyung production by plot

Use of trees	**Tree varieties**	**Yield (bags, kg)**	**Sold products**
Firewood			
Food (fruits, wild tea, chewing bettel nuts...)			
Medicine			
Wood carving/tying			
Construction			
Natural pesticide			
Fertilizer			
Other?			
If no longer having Muyung, when did you stop?			

What overall area of Pinugo __________ m²

Habar production by plot

Plant varieties	**Yield (bags, kg)**	**Income**
Kamote		
Ginger		
Pechay		
String beans		
Other?		
If no longer having Swiddens, when did you stopped?		

What overall area of Habal __________ m²

3. Heterogeneity

	Payo	Muyung/Pinugo	Habal/ kaingin	Grassland	Other (garden)
What is the proportion of ... that you own					
How was this proportion 10 years ago?					

4. Redundancy/Multifunctionality

What do you do with rice stalks and residue after harvest?	**Put it back in Payo soil**	**Burn it**	**Other**
Do you make Inago during fallow season? Which vegetables do you grow?			
How many sources of food do you have in Payo?	1. Golden Kuhol 2. Baticol 3. Ginga 4. Aggudong 5. Tilapia 6. Chulog	7. Yuyu 8. Million fish 9. Olippo 10. Allama 11. Te'am 12. Appako	13. Tuyong 14. Uchang 15. Dongla 16. Water criese 17. Gabi 18. Other
Source of food not cultivated anymore?		**Reason**	

5. Honors legacy

Is primogeniture still practised (leave the paddies to the oldest child)? If not, since when?	
Are your children interested in continuing rice farming?	
How many of your children speak your mother tongue?	
How many rituals related to rice do you have?	
From the ones practised by your parents, how many do you practise?	
How many generations interact with the landscape for subsistence and income?	
Are the woman in the household as involved as men in rice cultivation	

6. Demographics

	Not enough	Acceptable	Enough	Not enough money
Are there enough people to help you in busy times of rice growing period? (planting, harvesting)				
Are there enough people to help you in repairing terraces or maintaining irrigation canals?				
Were there more people to help in the past?	Rice growing		Terraces maintenance	
Do you still practice Ububo and Bayanihan				

7. Disturbances

	Almost nothing (0-20%)	Little (20-40%)	Half (40-60%)	Many (60-80%)	Almost all (80-100%)
How many of your terraces are damaged/destroyed					
Change in the last 10 years (+/-)					
Main reason					
How many irrigation canals are damaged/destroyed					
Change in the last 10 years (+/-)					
Main reason					
How much are your rice fields lacking water?					
Change in the last 10 years (+/-)					
Main reason					
What are in order the most damaging pests in your field?	Earthworm Kuhol Grass-Hoppers	Rats Birds Ants	Leaffolder Stem-borers Others, Which ones?		
Do you know natural ways to get rid of pest species? Which ones?					

HH member	Tourism activity	Since when (yrs)	Hours/day or week	Source of material
	Carving, sell, guide, homestay, other			
	Carving, sell, guide, homestay, other			
	Carving, sell, guide, homestay, other			
If not tourism, why?			Share to total HH cash income (%)	
Note				

8. Connectedness

	Tourist in Barangay	Market/shop in Bgy	Shop outside Bgy	Other
How many buyers are there of handicrafts?				
How many buyers are there of the agricultural products				

Declaration

Herewith, I declare that this thesis has been completed independently and unaided and that no other sources other than the ones given here have been used.

The submitted written version of this work is the same as the one electronically saved and submitted on CD.

Furthermore, I declare that this work has never been submitted at any other time and anywhere else as a final thesis.

Date Signature