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Social-ecological Transitions in a Cattle-based Silvopastoral System in Southern Luzon, Philippines

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ABSTRACT

Social-ecological transitions in the silvopastoral system of San Isidro, Rosario, Batangas, Philippines were analyzed using land cover trends and community perceptions. A combination of remote sensing processing, randomized survey, and participatory approaches were conducted. Four of six land cover categories (forests/orchards, grasslands, crop fields and water bodies) were identified to be sources of ecosystem services in the landscape which are essential for cattle farming. In 2000, the landscape became an on-farm research site on cattle farming. Coupled with other social factors such as land privatization and infrastructure development, this has reshaped land cover changes over time. In response, cattle farming dynamics, especially during critical dry periods, have adapted through measures such as switching to greater supplementation of commercial feeds. Despite social-ecological transitions, the cattle-based silvopastoral system in the landscape has persisted by exhibiting key principles of resilience such as diversity, connectivity, and feedback management. However, concerns on further impacts of key issues (e.g., land privatization) should be addressed to sustain the cattle-based silvopastoral system in the landscape. This study provides critical insights on how natural resource management by communities and policies by decision makers should carefully consider their potential impacts in sustaining locally important ecosystem services in the face of rapidly transitioning social-ecological systems.

Keywords: *social-ecological system, agroforestry, cattle farming, ecosystem services, resilience*

INTRODUCTION

Silvopastoral system is an agroforestry system that combines trees or shrubs with livestock and pasture. Trees and shrubs provide ecosystem services traditionally as feedstuff and fodder for the livestock (*Sharrow 1998; Nair 1993; Umrani and Jain, 2010*). Drought tolerance of many of the fodder tree and pasture components make them a critical animal feed resource during dry season when grasses would have dried up (*Le Houerou 1987; Nair et al. 1998*).

Currently, almost 94% or more than 2.3 million heads of cattle are raised under backyard farming in both upland and lowland areas in the Philippines (*Philippine Statistics Authority 2017*). Studies have described smallholder cattle farming to be dependent on a diversity of natural resources and ecosystem services (i.e, nature's benefits) from the surroundings (*Castillo 1997; Sevilla et al. 2005; Victorio and Badayos 2006; Committee on Forage and Pasture Crops 2006; Stanton et al. 2010*). Cattles are usually tethered on trees and fed with cut-and-carried grasses, fodder tree leaves (e.g., *Leucaena leucocephala* (Lam.) De Wit.), crop residues (e.g., cane tops, corn strove, rice straw), and other available plants especially those in and around the raiser's residence.

Communities practicing silvopastoral systems represent social-ecological interdependence where changes in either the environment or actions of humans affect each other (*Moberg and Simonsen 2014; Folke et al. 2010; Gunderson et al. 2010*). As various transitions occur in the environment, humans adapt through actions and other interventions to maintain their current state or sustain the current ecosystem services they obtain for daily subsistence and/or livelihoods. On the other hand, transitions within the human system (e.g., market, demographic changes) also affect the environment. However, systems have thresholds until these transitions and other disturbances could cause the system to have different functions as before (*Walker et al. 2004; Gunderson and Allen 2009; Folke et al. 2010*) such that critically important ecosystem services become scarce or even unavailable. How much systems can absorb transitions and disturbances while retaining its structural and functional properties is known as resilience of social-ecological systems (C*arpenter et al. 2001; Gunderson et al. 2010*).

Using the concept of resilience, social-ecological transitions could be evaluated by looking at how a social-ecological system's structural-functional dynamics, or the system's identity, have changed over time (*Walker and Meyer 2004; Walker et al. 2004*). Such evaluation of the changes of a system's identity could include assessments of its components (*i.e.,* species and people), relationships of these components, sources of continuity (*i.e.,* those that maintain resilience), and sources of innovation (i.e., those that improve resilience) (*Cumming et al. 2005; Andrachuk and Armitage 2015*). Although these transitions could be exhibited at multiple scales (*Walker et al. 2004; Folke et al. 2010*), it is important to specify the focal scale and the temporal boundary in which the changes are being studied (*Carpenter et al. 2001; Gunderson et al. 2010*).

Tracking transitions in social-ecological systems requires mixed methods research to capture both the social and ecological components. One of the most common methods in tracking ecological changes is through the use of remote sensing (*Hill et al. 2009; Kennedy et al. 2009*). This technique shows valuable changes in land covers such as forests, ice caps, and agricultural lands on the Earth's surface (*United States Department of Interior-United States Geological Survey 2016*). On the other hand, tracking of other aspects requires subjective assessments such as the use of perception-based surveys, available secondary information, interviews and participatory group discussions with key informants (*Bieling 2013; Andrachuk and Armitage 2015; de Almeida et al. 2016*).

Grounding on these concepts and rationale, this study was conducted to track social-ecological transitions in a selected landscape of San Isidro, Rosario, Batangas in the Southern Luzon, Philippines and seek insights on its resilience. Specifically, this study aimed to assess components (i.e, land cover and cattle farmers), their relationships within the silvopastoral dynamics, and how various drivers of change affected this cattle farming system) over time. It also examined sources of continuity and innovation by highlighting how the cattle-based silvopastoral system exhibited indicators of social-ecological resilience over a period to adapt or persist with such transitions. Results of this study can guide appropriate interventions towards integrated sustainable management of natural resources while ensuring socio-economic benefits to the community.

MATERIALS AND METHODS

The Study Site

San Isidro (13.7707°N and 121.3132°E) (**Figure 1**) is one of the 48 barangays in the Municipality of Rosario, Province of Batangas in Southern Luzon, Philippines. Its total land area is about 561 ha, which is further subdivided into seven smaller geographical units called *sitios*, which include Tore-Hilirang Kawayan, Compradia-Kapihan, Lipahan, Guinting, Bayanan, Buslot, and Lianganan (*Barangay Local Government Unit 2011*). It has an elevation ranging from 76-350 masl and slopes that are categorized as hilly and steep. Dry season in the area runs from January to May when average monthly rainfall ranges from 94 - 195 mm and temperatures from 25-27°C (*World Bank Group 2020*) Its soil types include Guadalupe Clay Loam in its northern portions and Ibaan Clay Loam in its southern portions. Its main physiographic feature is the Lawaye River as well as its arterial water networks such as the Paliparan and Buho Creeks.

Among the 17 regions of the Philippines, Southern Luzon, where San Isidro is located (i.e., CALABARZON Region) ranks third in backyard cattle production with a national percentage share of 11% or 259,005 heads (*Philippine Statistics Authority 2017*). In particular, communities in Batangas have long established status as important cattle production and trading areas. These cattle-related activities greatly contribute to household income. These also serve as family liquid assets in times of emergencies (*Sevilla et al. 2005; Stanton et al. 2010; Victorio and Badayos 2006*). An earlier socio-economic characterization of San Isidro (*Sevilla et al. 2000*) shows that as much as 90% of the average household income is credited from cattle farming activities. For family subsistence or household consumption, crop (e.g., rice, corn, root) farming is the more prominent form of agriculture. Other income-generating and/or subsistence activities include raising of small livestock such as swine, chicken, and goats, fishing in Lawaye River, and hunting for wild meat and edible native vegetables in the forests.

Cattle farming in San Isidro focuses on beef cattle production. It is further classified as fattening operation or cow-calf operation systems. Households engaging in the fattening operation includes buying of calves and then raising and fattening them before selling. On the other hand, households in the cow-calf operation includes maintaining a breeder cow to produce calves. Calves from this operation are usually sold to fattening operators. However, some cow-calf operators choose to

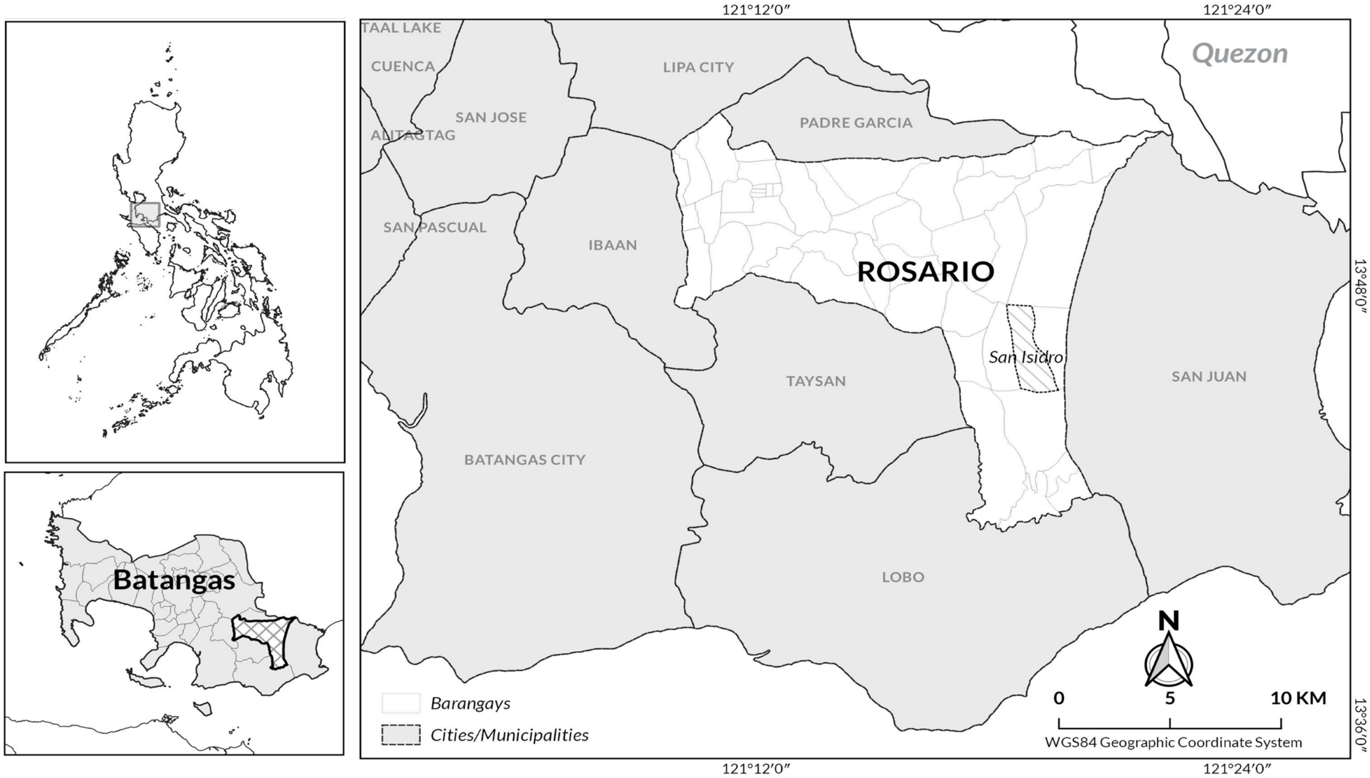

Figure 1. Study site (San Isidro) in the Municipality of Rosario, Batangas, Southern Luzon, Philippines.

raise and fatten the calves by themselves before selling. No slaughtering is done and calves and/or full-grown cattle are the final products in both operation systems.

Cattle farming in San Isidro depends on various ecosystem services from each of the land cover in its landscape. Specifically, tree-based ecosystem services from riparian forests, fruit orchards, and trees scattered across grasslands and home lots have been documented as essential sources of fodder especially during dry season. (*Sevilla et al. 2000; Bejo 2001; Sevilla et al. 2001a*). Hence, with the interdependence on trees and perennial shrubs, such system can be classified as a cattle-based silvopastoral agroforestry system.

In 2000, three *sitios*- Tore-Hilirang Kawayan, Compradia-Kapihan, and Buslot- became study sites of an on-farm research of the University of the Philippines Los Baños (UPLB) on early weaning of cattle in upland areas (*i.e.,* termed as "UPLB Project" in succeeding parts). As part of the above mentioned project, 12 farmers from each of the selected *sitios* were provided with a graded, ready-to-breed heifer while one farmer was assigned a breeder bull (*Sevilla et al. 2000*). Farmers were organized into an association in which improved cattle farming technologies were introduced including establishment of fodder protein banks and supplementation of commercial feeds to early weaned offspring (*Sevilla et al. 2001a; OAS-Rosario 2009*). Because of this major activity in the landscape, the year 2000 was selected as the baseline period for both the analysis of the historical and current land cover and perceptions.

Overall Study Design

To analyze social-ecological transitions in the study site, a mixed method study design (*Creswell and Clark 2011*) was employed. Quantitative techniques included land cover trend analysis using remote sensing and a randomize survey. Land cover trend analysis aims to understand the ecological changes based on changes of the vegetation and provide critical information on how these ecological changes affected cattle farming dynamics in San Isidro. This has also been used by other researchers to understand and evaluate changes in other landscapes including mountains (*Pocas et al. 2011*), river deltas (*El-Kawy et al. 2011*), and nature reserves (*Wan et al. 2015*). On the other hand, the randomized survey aims to capture both ecological and social transitions based on cattle farmers' perception and acquire information that could provide essential narratives and contextualization for land cover trend data. Perceptions are deemed critical to capture landscape-level changes because of its context specificity and integration of strong placed-based, local, and even traditional knowledge (*Bieling 2013; de Almeida et al. 2016*).

In this study, there was a particular interest on a 15-year temporal scale in both land cover trend analysis and randomized survey to match the potential impacts of the UPLB Project. During this period, it is assumed that the landscape has received different disturbances from both the research activities and other internal/external factors that have caused changes. Thus, this study draws on significant quantitative results that show changes from the baseline period, 2000, to the conduct of the study, 2015, to establish social-ecological transitions. To further contextualize results of these quantitative methods, qualitative research techniques were also used including key informant interviews, participatory activities/ appraisals, and review of related documents.

Although it is recognized that social-ecological transitions could occur at multiple scales (*Walker et al. 2004; Folke et al. 2010*) in which the study site is part of (*e.g.,* changes in the municipality or provincial scales), this study only focused on the landscape-level social and ecological dynamics as confined within the administrative boundaries of San Isidro. Hence, succeeding use of the term "landscape" refers to ecosystem units confined within this boundary.

Land Cover Trend Analysis

Representative Landsat images for the periods 2000-2005 or the early-phase of the UPLB Project, 2006-2010 or the peak-phase, and 2011-2015 or the post-project-phase were acquired for free from http://www.earthexplorer.usgs.gov. Specifically, April 2002, April 2007 Landsat ETM+, and May 2015 Landsat8 OLI Level 1 data sets containing the study site were selected after being filtered to have negligible cloud cover. To reduce the potential errors caused by seasonal variation in the landscape, all the images were assured to be within the area's dry month of April. In addition, this month is significant to the annual cattle farming cycle in San Isidro when multiple land covers are maximally utilized to obtain various ecosystem services, especially biomass, to support cattle farming in critical period. This offers a more explicit view of potential social-ecological transitions in the landscape, allowing for a more thorough study of its resilience.

All three images were subjected to a pixel-based, unsupervised land cover classification (*Richards 2013*) using ArcMap™ of ArcGIS®. Composite images for each tile was initially classified using ISO-unsupervised classification (classification=80, standard deviation=10). Using ground truth assessed points, each unique value was then reclassified under 6 land cover categories namely: forest/orchards, grasslands, crop fields, open/ barren lands, built-up structures/ settlements, and water bodies. These land cover classifications were generated after conducting participatory village transects. This transect was participated by leaders of San Isidro's cattle farmers association during which they point and share their local knowledge on the landscape's key features and their respective roles in San Isidro's cattle farming.

Survey on Perceptions of Cattle Farmers

Thirty cattle farmers from the study site were randomly selected using systematic sampling. Since there is no available updated lists of cattle farmers in San Isidro that can be used as a survey frame for a simple random sample, the sample size considered was based on the discussions of *Albacea et al.* (*2015*) which, citing Central Limit Theorem (*Chow and Teicher 1978*), stated that sample size becomes sufficiently large with more than 25 samples. Relative sample sizes were also used by earlier studies in San Isidro (*Sevilla et al. 2000; Sevilla et al. 2001*). To execute the systematic sampling, transects were established along main roads in San Isidro. A randomly selected household in the transect became the starting point and the fourth household after it was selected as the next respondent. This process continued until all 30 respondents were selected.

One-on-one interview with each of the selected cattle farmer was conducted using pretested structured questionnaire with visual aids. Rating questions were asked for their perceptions on different localized social-ecological indicators in their cattle farming (**Table 1**) during three periods coinciding with various phases of the UPLB Project in San Isidro namely: 2000-2005 or early-project phase, 2006-2010 or peak-phase, and 2011-2015 or the post-project-phase. These social-ecological indicators were designed to capture both dimensions of perceived landscape resources and cattle performance under San Isidro's silvopastoral system. These were derived from earlier studies in the same study site by *Sevilla et al.* (*2000*), *Bejo* (*2001*), *Sevilla et al.* (*2001a*), and *Sevilla et al.* (*2001b*). Open-ended follow-up questions on the ratings were asked as well. Probing and referencing techniques were employed to help the respondent recall and assess information.

Data from the survey were analyzed using Statistical Tool for Agricultural Research (STAR, 2013 v. Nebula). Each social-ecological indicator of cattle farming was first subjected to Friedman's Test to determine if there were significant differences across the three periods. Those which tested significant at 90% level of confidence were

Table 1. Perception-based social-ecological indicators on cattle-farming.

Dimension	Indicator
Landscape Resources	• Need for commercial feeds • Accessibility of grasslands for grazing • Availability of cut-and-carry fodder sources • Need for crop residues and other feeding materials from outside the landscape • Availability of drinking water for cattle
Cattle Performance	• Growth performance of cattle • Health status of cattle • Reproductive performance of cattle • Market demand of cattle • Extension services for cattle farming

further subjected to Wilcoxon Signed Rank Test (WSRT). In conducting WSRT, comparisons between shorter periods were first tested namely: 2000-2005 versus 2006-2010 and 2006-2010 versus 2011-2015. If no significant difference was detected in either comparisons, WSRT was then conducted to compare 2000-2005 versus 2011-2015. This further test would assess significance of changes in such cattle-farming aspect over a longer period.

Qualitative and Supplementary Methods

A participatory appraisal was held to obtain information which are not captured through the methods earlier discussed. First, it was held to determine the community-level understanding of the ecosystem services in the landscape and included the use of guided questions and a matrix in which participants discuss the benefits they obtain and the role of each land cover to their cattle farming system. Using other tools such as the trends matrix and resource flow diagram, this appraisal also served as a venue to obtain narrative-based information to supplement quantitative data derived for the various drivers of change, adaptation measures, and social-ecological resilience indicators. It also served as a platform to discuss and acquire consensus on landscape or community-level issues that affect their cattle farming. This appraisal was facilitated in the local language spoken by the farmers (Tagalog).

Earlier studies and characterizations conducted in the study site (*Bejo 2001; Sevilla et al. 2000; Sevilla et al. 2001a; Sevilla et al. 2001b*) during UPLB's Project were reviewed. Researchers involved in the on-farm trials and the Project were also served as key informants and were interviewed for additional insights.

To evaluate the health of the critically important land cover, soil sampling was done on select forests, grasslands/pastures, and crop fields. Soil samples were then analyzed at UPLB's Soil Analytical Laboratory for routine (i.e., pH, organic matter, phosphorus, and potassium) and total N-content analysis.

RESULTS AND DISCUSSION

Socio-economic Profile of Respondents among the 30 cattle farmers in San Isidro randomly selected and interviewed for this study, 57% were females. The youngest was 20 years old while the oldest was 74 years old. Majority of the respondents belonged to the 47-55 years age group (33%). Eighty-seven percent have completed only up to elementary education. Household sizes varied from 2 to 6 persons, averaging to 3.8 members per household. Ninety-three percent are married while the rest are widow/widower.

Eighty-three percent of the respondents had at least 13 years of cattle-farming experience in San Isidro. All have lived in the community throughout their lives; thus, they were able to experience whatever social-ecological changes the landscape has undergone since 2000. In terms of the economic importance of cattle farming, 50% of them credited the income obtained from cattle farming for their children's education (i.e., tuition, daily allowances, school projects) while 30% stated that cattle farming allowed them to build or improve (*e.g.,* concretization) of their houses. In fact, 50% of the respondents stated that they were able to complete their houses between 2000 to 2015 which also corresponds to the implementation of the UPLB Project.

Ecosystem Services from Various Land Covers

While it is acknowledged that variations may exist in the farm or individual level, the silvopastoral system in San Isidro can be generalized as one that revolves on the four land covers in the landscape. Specifically, these were identified to have critical ecosystem services for cattle-farming (**Table 2**). Grasslands are the primary sources of biomass. Cattle farmers allow their cattle to graze around these grasslands all year-round. This biomass is supplemented further by fodder, roughages, and other feedstuff from trees and perennial shrubs interspersed in these grasslands as well as other land covers such as forests (i.e., riparian forests, orchards). On a non-summer period, pumping ground is the main mode of obtaining water for the cattle. All-year round, cattle are tethered and sheltered under trees since most households do not have separate cattle housing.

However, during summer period, these dynamics greatly vary as grasslands dry-up and both quality and quantity of the biomass from such land cover decreases. Hence, cut-and-carry, especially from riparian forests in the Lawaye River, intensifies. Since San Isidro still has minimal irrigation system, cattle farmers leave-out their crop fields from agriculture and temporarily convert them as grasslands where cattle can have additional biomass. Crop residues from the previous cropping are also utilized as additional roughages. Cattle farmers also shift to Lawaye River as the main source of water for cattle as the remaining ground water, if there is any, is used for household purposes only. This change in system dynamics and a more maximal integration of ecosystem services across land covers allow the cattle farmers to bridge the gap until the next rainy season begins when resources for cattle farming are in abundance.

Land Cover Trends and Community Perceptions

Analysis of the land cover revealed that grasslands in San Isidro was reduced from 57% of the total land area in 2002 to only 19% in 2007 (**Table 3**). Between these two periods, the UPLB on-farm research has increased the cattle population, eventually the grazing pressure, in the landscape especially in the *sitios* of Buslot, Torre-Hilirang Kawayan, and Compradia-Kapihan. This period also coincided with the increase in open/barren lands from 67.0 ha in 2002 to 191.7 ha in 2007.

Table 2. Land cover categories that provide ecosystem services for cattle farming.

Land Cover	Ecosystem Services for Cattle Farming
Grasslands	• Grasslands are sources of the primary biomass being grazed by cattle. • Multi-purpose trees scattered across grasslands provide fodder, shade and resting area for the cattle, especially in midnoon.
Forest/ Orchards	• Riparian forests along the Lawaye River, Paliparan Creek, and Buho Creek are year-round sources of "cut-and-carry" fodder. During dry season, this ecosystem service is more pronounced as grasslands dry up. • Orchards are sources of fodder and non-marketable fruits • Orchards provide shade and resting area for grazing cattle
Crop Fields	• Crop residues (*e.g.,* rice hay) from crops in the fields serve as roughages brought to the cattle.
Water Bodies	• Lawaye River and its arterial network of creeks are additional sources of drinking water for the cattle especially during dry season when pumped ground water are reduced.

Between 2009 and 2015, available cattle inventories (*OAS-Rosario 2009*) showed a decreased population of cattle. With reduction of grazing pressure, there was an increase back of grasslands in 2015. However, cattle farmers still perceived more needs for commercial feeds in 2011-2015 than in 2006-2010 (p-value=0.0020). This implies that, although there was an increase from 2009 to 2015, grasslands available in Brgy. San Isidro were still insufficient to support cattle farming without supplementation of commercial feeds. This is unlike the case in 2000-2005 when cattle-farming was primarily dependent on grazing on grasslands with no use of commercial feeds. In fact, in the early 2000, biomass availability (in dry matter content) in the grasslands were 2.8 times more than the requirement for cattle farming in San Isidro (*Sevilla et al. 2001a*).

Moreover, the increase of grasslands from 2009-2015 was negatively affected by social issues particularly on privatization of lands in San Isidro. Cattle farmers perceived less accessible grasslands for grazing in 2011-2015 than in 2000-2005 (p-value=0.0042). It was found out that lands which were owned by family members before have been gradually sold to non-family members. These lands have been eventually fenced and former communal grasslands for grazing became off-limits to cattle farmers. This issue has only transpired recently through this study and has not been documented in the early researches which, in contrast, have emphasized the high communality of grazing and pasture areas in San Isidro (*Bejo 2001; Sevilla et al. 2000; Sevilla et al. 2001a*).

In terms of forest/orchard areas in San Isidro, a slight gradual increase from 2002, 2007, and up to 2015 was observed. Cattle farmers shared that banks of Lawaye River have been sites of tree planting activities by the

Table 3. Land cover distribution in Brgy. San Isidro in 2002, 2007, and 2015.

Land Cover	April 2002		April 2007		May 2015	
	Area (ha)	%[1]	Area (ha)	%[1]	Area (ha)	%[1]
1. Grasslands	294.9	57	108.6	19	199.6	36
2. Forest/ Orchards	28.4	5	34.5	6	55.7	10
3. Crop Fields	168.5	31	216.0	39	264.9	47
4. Water Bodies	0.3	0.05	0	0	0	0
5. Barren/Open Lands	67.0	12	191.7	34	34.6	6
6. Built-up Structures/ Settlements	1.7	0.31	10.4	2	5.9	1

[1]as percentage of total land area of San Isidro

Department of Environment and Natural Resources. Fruit trees and timber trees plantations also started to proliferate in the area, especially for those areas which were sold to and fenced by new owners.

However, despite the increase of vegetation, which are sources of "cut-and-carry" fodder especially during dry season, cattle farmers still perceived lesser available cut-and-carry sources in 2011-2015 than during 2000-2005 (p-value=0.0230). They have attributed this to the change of planted trees to species with no or minimal fodder value such as *Swietenia mahogani* (L.) Jacq. or mahogany which are later sold as wood. In the 2000s, *Sevilla et al.* (*2001a*) even determined that as much as 25% of the cut-and-carry fodder were obtained from and *Leucaena leucocephala* (L.) de Wit and *Gliricidia sepium* (Jacq.) Kunth ex Walp alone. Thus, coupled with the issue on privatization of lands, it became more difficult for cattle farmers to find tree species with good fodder value.

For lack of the usual fodder trees, cattle farmers resorted to feeding parts of available fruit trees such as *Mangifera indica* L. or mango, *Arterocarpus heterophyllus* Lam. or jackfruit, and *Psidium guajava* L. or guava. Native fodder tree species once used by the cattle farmers in San Isidro such as *Albizia saman* (Jacq.) F. Muell. or acacia, *Buauhinia malabrica* Roxb. or *alibangbang*, and *Macaranga tanarius* (L.) Müll. Arg. or *binunga* (*Bejo 2001*) have now become scarce. This is another reason to the perceived increasing trend on the supplementation of commercial feeds to compensate for lack of good fodder.

The impacts of this reduction of traditionally important fodder species has also manifested with the decrease in farmers who practice a traditional force-feeding method called "supak". This originally includes a high concentrate of *L. leucocephala* (L.) de Wit, mixed with water and some forms of salt, then force-fed through a hollowed bamboo or tube to the cattle. Decades before, this was documented to be a major feeding system in San Isidro (*Bejo 2001; Sevilla et al. 2001a*), especially for those involved in cattle-fatterning production system. However, less than 10% of the cattle farmers interviewed in this study indicated that they have not practiced "supak" between 2011-2015 because of insufficient *L. leucocephala* (L.) de Wit.

Steady increase from 2002, 2007, and up to 2015 was also observed in crop fields in . San Isidro. Cattle farmers shared that construction of irrigation systems allowed more farmers to plant crops such as rice and corn during dry season. However, despite this increase in crop fields which provided crop residues for cattle feeding, cattle farmers perceived the need to obtain more crop residues and other feed materials from outside the landscape in 2011-2015 than in 2006-2010 (p-value=0.0708). Cattle farmers are now getting more crop residues from neighboring towns to supplement their landscape-sourced feedstuff for cattle which was not the case previously (*Sevilla et al. 2001a*). Although 2002 had the least area of crop fields, there was less for supplementation because of better accessibility of grasslands and availability of fodder trees species in 2000-2005. It is, however, interesting to note how this study has reevaluated the crop residue conservation effort by San Isidro's cattle farmers. During the early 2000s, because of abundance of biomass, crop residues are usually burnt or dispose by farmers (*Sevilla et al. 2000; Sevilla et al. 2001a*).

These perceived increases in the need to buy rice straw and other feed resources from neighboring towns have also coincided with changes in other social-ecological indicators. Specifically, cattle farmers perceived better growth performance (p-value=0.0230) and health status (p-value=0.0564) of cattle in 2011-2015 than in 2000-2005. Cattle farmers shared that the increasing use and availability of commercial feed mixes/ concentrates in the recent periods has contributed to the improvement of growth and health of cattle. While this study did not conduct physical assessments, this claim is supported by the experiments of *Sevilla et al.* (*2001b*) in San Isidro which showed that mixing concentrates improved greatly the body condition scores of the cattle. On the other hand, there was no significant differences on cattle farmers' perceptions on reproductive performance of cattle.

Studying the role of changing composition of cattle breeds in the landscape should also be explored further. This study did not include changing breed types as a major factor in the social-ecological transition in San Isidro. In the early 2000s, 71% of the cattle being raised in the landscape were of indigenous/native breed (*Sevilla et al. 2000*). However, with the propagation of graded cattle breeds through the UPLB Project, this percentage could have significantly changed. *Sevilla et al.* (*2001b*) even indicated how native cattle tend to consume more fodder but the graded breeds have better metabolic/ nutrition response to concentrates. Thus, it is recognized that the potential change in composition, if there is any, could also influence both transitions and perceptions, especially when it comes to perceived growth and health performance.

Water bodies in San Isidro was detected only in 2002 but were not detected in other years. Since the satellite images were all taken during the dry season, this implies Lawaye River or its arterial networks had no significant water depth from 2007 to 2015. In the early 2000, cattle farmers have been obtaining water for their cattle from the Lawaye River alone (*Sevilla et al. 2000*). However, this later shifted to ground water when water pumps were distributed to households in the barangay by both government and non-government organizations. Thus, this decrease in water volume in Lawaye River was perceived by the cattle farmers to have no significant effects to their cattle farming activities.

Built-up structures/settlements in San Isidro increased more than six times from 2002 to 2007. This can be credited to the construction of cemented roads by the Department of Public Works and Highways in the barangay in mid-2000s. This has also been observed in the current study when cemented roads have now traversed at least six villages in San Isidro. This was unlike the documented case during the early assessments of *Sevilla et al.* (*2000*) when cemented road was only available at the national highway. Reduction in area of this land cover was observed in 2015. However, this reduction did not necessarily reflect the reduction of built-up structures/settlements in 2015. During ground truth assessments of land cover in 2016, large tree canopies along roadsides are partly covering the cemented roads and settlement areas, thus were not fully accounted in the satellite images.

These improvements in built-up structures, particularly of cemented roads, were deemed beneficial by the cattle farmers. Cattle farmers perceived better market demand of cattle in 2011-2015 than in 2000-2005 (p-value= 0.0679). They also perceived improved extension services in 2011-2015 than in 2000-2005 (p-value=0.0000). Cattle farmers shared that the improved roads allowed easier entry by cattle-traders and extension-workers in San Isidro. This also coincides to the farmers' claim on better access to commercial feed mixes/ concentrates during these periods as discussed in earlier paragraphs.

Implications and Issues on Social-Ecological Resilience

The cattle-based silvopastoral system in San Isidro persisted despite various social-ecological changes that were experienced since 2000. This could be attributed to its diversity, connectivity, feedback management, learning, and participation- all of which are principles for social-ecological resilience (*Simonsen et al. 2014*). In terms of diversity, the sourcing of ecosystem services from various land cover for the same ecosystem service (*e.g.,* biomass for feeding) improves its functional diversity. While the use of tree-based ecosystem services instead of depending on grasses or pastures alone has enhanced response diversity since trees have better responses during dry season (*Carpenter 2012; UNU-IAS et al. 2013; Simonsen et al., 2014; van Oudenhoven et al. 2011*). Moreover, the landscape heterogeneity and the presence of more perennials in multiple land cover, in this case, trees on both forests/orchards, grasslands, and even around homesteads, has strengthened overall agro-ecological resilience of the system (*Cabell and Oelofse 2012; van Oudenhoven et al. 2011*).

Landscape connectivity is also apparent as cattle farmers in San Isidro freely traverse multiple land covers (*Janssen et al. 2006*). This allows them to obtain ecosystem services in a variety of spatial points in the landscape. They also demonstrate feedback management of various social-ecological changes through their use of commercial feeds, externally sourced feedstuff, and internally implemented technologies (e.g., protein banks) during times of crises like prolonged dry seasons. By doing so, cattle farming in the landscape could still persist (*Simonsen et al. 2014*). However, this has to be carefully studied further as high dependency on external resources could also be indicators of weakening social-ecological resilience (*Cabell and Oelofse 2012; UNU-IAS et al. 2013*).

The on-farm research of UPLB has contributed to changes in land cover especially with increased grazing pressure and resource use during its implementation. However, one of its contributions is the introduction of various technologies that could improve fodder bank management in the landscape. During implementation, cattle farmers were trained on establishment of high protein fodder banks which they could utilize during dry season or when landscape resources are scarce (*Sevilla et al. 2000; Sevilla et al. 2001a*). They were also trained on husbandry practices which could improve reproductive and growth performances of their cattle given the limiting ecological conditions as an upland community. More than a decade after, many cattle farmers, especially in the sitios of Buslot, Torre-Hilirang Kawayan, and Compradia-Kapihan, continue to practice these technologies. This is important in developing capacity of the cattle farmers to deal with crisis such as resource scarcity (*Gadgil et al. 1993; Folke et al. 2005; Simonsen et al. 2014*).

The UPLB Project has also improved the participation of cattle farmers by organizing the partner farmers into cattle farmers' associations in each of the three partner *sitios*. During the implementation of the project, members of the association were the primary recipients of cattle. Following a traditional sharing system, the offspring of the distributed parental cattle lines were shared alternately by the project and the cattle farmers in the organization. If the offspring was a male calf, it was sold upon weaning and the proceeds were used to purchase a female which was assigned to another cattle raiser. If the offspring was a female calf, this was also assigned to another cattle raiser. Hence, more cattle farmers were encouraged to actively join the association and have since then attended its activities and meetings (*Sevilla et al. 2000*). Participation and a clear system for sharing of the offspring has improved overall resilience in the system through better governance and social equity (*UNU-IAS et al. 2013; van Oudenhoven et al. 2011*), building trusts and shared understanding among cattle farmers, and integration of multiple ideas into actions (*Cabell and Oelofse 2012; Simonsen et al. 2014*).

Soil health of the critical land covers should also be monitored as this is an important indicator for long-term social-ecological resilience (*Cabell and Oelofse 2012*). Degradation of soil will affect ecosystem services in the landscape, especially in both the quantity and quality of feedstuff in San Isidro. This could potentially reshape the system dynamics and further transitioning to a less desired state of cattle farming in the landscape (*Kosmas et al. 2016; Magnuszewski et al. 2015*).

Currently, both the forest and grasslands exhibited good characteristics (**Table 4**). Forested areas benefit from natural recycling from leaf fall and decaying parts of the trees (*Vitousek and Sanford 1986; Pinay et al. 1995*), with the high to very high nutrient contents especially with organic matter. Since these forested areas serve as an essential source of cut-and-carry feedstuff, these could strengthen resilience among cattle farmers especially during dry periods. However, as this is a communal component of the landscape, high possibility of excessive cut-and-carry, which could be driven by prolonged dry periods due to climate variability or increase in stocking rates among farmers, could reduce these natural nutrient cycles within forests and may pose long term sustainability issues.

Grasslands also benefit from the nutrients in the manure and urine of grazing cattle, which contain beneficial microbes as well as decaying parts of the trees scattered across it (*Martinez et al. 2014; Moreno et al. 2014*), as reflected with the very high potassium and phosphorus contents. Such results provide important information on how this multi-component interaction (i.e., trees + cattle + grassland) provides a bundle of ecosystem services (**Table 2**) and serves as beneficial feedback loop for resilience of the system. However, negative activities such as overstocking, overgrazing, and cutting of the trees could adversely impact such valuable dynamics.

On the other hand, the less desired characteristics of crop fields is because of the extractive nature of crop farming and the minimal nutrient recycling happening in it. This poor condition among crop fields are already apparent as cattle farmers start to source external supply of rice hay because of low production in the landscape (see earlier discussions). While crop fields simply provide roughages for San Isidro's cattle production, a further deterioration of the soil fertility in this land cover could have direct impact on the households which depend on these fields for subsistence. Its domino effect could include further transition to livestock raising which would increase stocking rates and dependency to the ecosystem services provided by the other land cover.

However, these principles that have kept the silvopastoral system in San Isidro resilient despite social-ecological transitions are under threat because of various issues uncovered throughout this study. One the major issues is privatization or selling and fencing-off of lands, which has caused massive reduction of accessibility towards various land covers. This is directly impacting landscape connectivity as cattle farmers will have to limit their movements in areas that remain communal or of their own ownership. Communal areas which are well emphasized by earlier assessments

Table 4. Fertility of soil in three of the critical land cover being used for cattle farming in San Isidro.

Land Cover	pH	Remarks[1]	OM %	Remarks	N %	P (ppm)	Remarks	K (cmol kg^{-1})	Remarks
Forest (Riparian Forest)	6.4	Within critical Range	5.76	High	0.28	26[2]	Very High	0.98	High
Grassland (with trees scattered)	6.2	Within critical Range	4.06	Medium	0.23	165[2]	Very High	2.83	Very High
Crop Field (rice farm)	5.6	Within critical Range	2.94	Medium	0.16	2.1[3]	Low	0.38	Medium

[1]Critical range of pH is 5.5-6.5; [2]Bray method; [3]Olsenn method

of *Sevilla et al.* (*2000*) are now less understated in the current situations. During the participatory appraisal, it was found out that large parcels of lands which were owned by older generations were divided and inherited by their family members. Originally, social ties have kept these lands as important communal grasslands for cattle farmers. Unfortunately, some family members who have migrated outside the landscape or who have family members with regular salaries tend to sell these inherited lands. Buyers of these lands are non-family members and outsiders of San Isidro. Eventually, these lands have been fenced by the new land owners; thus, this reduces the extent of grazing for the cattle. Some of the important tree species for fodder are also found in these lands. Hence, privatization of the lands limits the cut-and-carry sources for the cattle raisers.

Moreover, privatized areas have also been credited to trigger homogenization of tree-species by mainly establishing species with higher economic returns such as mahogany for timber and some fruit trees- thereby reducing landscape diversity. These have already started to manifest as cattle farmers perceived less accessible grazing areas and lesser sources of cut-and-carry fodder trees.

Another major issue is the disengagement of younger generations in cattle farming. During the participatory appraisal, one of the recurrent themes is on how the youth is disinterested to continue cattle farming. Their roles were limited to transferring the cattle from the grasslands and tethering them to trees. This is different from what *Sevilla et al.* (*2000*) documented when the whole family, including the children and women, had proactive role in cattle farming in San Isidro.

Interviews with parents also echoed the children's sentiments by sharing parents would rather want their children to go to school. Unfortunately, this has negative implications as this study also found that knowledge on cattle farming, including how to utilize various ecosystem services from trees, are primarily transferred intergenerationally. These could have negative implications on the continuity of learning and participation in the system. Eventually, this could have adverse impacts on how feedbacks from social-ecological transitions are being managed.

Another major issue that should be carefully monitored is climate change or changing climate patterns. While the silvopastoral system of San Isidro has persisted in the climatic conditions and variations between 2000 and 2015, changes in future periods could pose a negative narrative. Under climate change scenario to 2050, it is projected that there could be a rise in annual mean temperature in the Philippines from 1.8 °C to 2.2 °C and a lengthened dry season (*Department of Science and Technology 2011*). Researchers (*Schönhart and Nadeem 2015; Thornton et al. 2010; Nardone et al. 2010*) identify that this increase could have adverse impacts on various aspects of livestock production including increase of water consumption, decrease efficiency of feed conversion, decrease in milk production, decrease in meat production, mortality on grazing cattle, diseases. Studies (*Esmail and Oelbermann 2010; Cailleret et al. 2014*) have also shown that, although trees have been a major factor in keeping the social-ecological resilience of San Isidro's cattle farming, trees could be severely affected future survival, population, and distribution of tree species.

CONCLUSIONS AND RECOMMENDATIONS

Using mixed methods of remote sensing, randomized survey, and participatory approaches, this study provided novel insights on how a cattle-based silvopastoral system has experienced social-ecological transitions over time. In this case, San Isidro's landscape has experienced major changes in its land covers, which provide critical ecosystem services essential for cattle farming. In understanding these changes using farmers' perceptions, significant social-ecological trends were identified that have impacted or continue to impact the system, which culminate to changes on how biomass and feedstuff for cattle are obtained. Despite exhibiting principles of social-ecological resilience, some of these trends indicate major points of concerns including the rise of privatization and reduced access in once communal lands, homogenization of tree species, disinterest among the youths to be involved in cattle activities, and a future with climate change. These should be addressed to ensure continuity of cattle farming in the community even with further social-ecological transitions in years to come.

Thus, even if the context of this study is limited within a single landscape, the information generated could guide communities, local planners and decision-makers, especially in livestock sectors in designing and planning short-and long-term integrated natural resource management systems and policies towards ensuring overall wellbeing of actors in the system without sacrificing the sustainability of the landscape. Specifically, it is recommended that interventions and programs should be implemented to address key issues especially on accessibility and availability of critically important land covers. Regular monitoring of these land

land covers and social-ecological indicators should also be conducted before the overall system crosses thresholds which could later prove challenging for the actors in the system.

This study has also added knowledge on the role of trees in providing critical ecosystem services for livestock production. In this case, tree-based ecosystem services in multiple land cover in San Isidro were proven to be key features in maintaining resilience of cattle farming despite social-ecological transitions experience.

This study has also provided insights on how an on-farm research could contribute to social-ecological transitions in a landscape. Hence, it is important that on-site research should be carefully studied and formulated not only with their promise of improved socio-economic conditions for communities these are implemented on but in their long-term potential impacts in the whole social-ecological system. Sustainable local development requires not only alleviating communities from socio-economic hardships but also assuring that their future generations will have sufficient resources to meet their future needs.

REFERENCES

Albacea, Z.V.J., Reaño, C.E., Collado, R.V., Comia, L.N., Tandang, N.A., Amon, A. and Victoria, J.R.A. 2015. Workbook in Statistics. Institute of Statistics, University of the Philippines Los Baños- College of Arts and Sciences. 130pp.

de Almeida, G. M., Ramos, M. A., Araújo, E. L., Baldauf, C., and Albuquerque, U. P. 2016. "Human perceptions of landscape change: The case of a monodominant forest of *Attalea speciosa* Mart ex. Spreng (Northeast Brazil)". *Ambio* 45(4).

Andrachuk, M. and D. Armitage. 2015. "Understanding social-ecological change and transformation through community perceptions of system identity". *Ecology and Society* 20(4):26.

Barangay Local Government Unit. 2011. Barangay Local Development Plan. Barangay San Isidro Government Unit. 50 pp.

Bejo, M.B. 2001. Ruminal Degradability of Dry Matter, Crude Protein, and Neutral Detergent Fiber in Potential Feed Protein Sources of Different Tannin Content. Unpublished Ph.D. Dissertation. University of the Philippines Los Baños, Laguna, Philippines. 132 pp.

Bieling, C. 2013. "Perceiving and responding to gradual landscape change at the community level: insights from a case study on agricultural abandonment in the Black Forest, Germany". *Ecology and Society* 18(2): 36.

Cabell, J.F. and Oelofse, M. 2012. "An Indicator Framework for Assessing Agroecosystem Resilience" *Ecology and Society* 17(1): 18.

Cailleret., M., Heurich, M., Bugmann, H. 2014. "Reduction in browsing intensity may not compensate climate change effects on tree species composition in the Bavarian Forest National Park". *Forest Ecology and Management* 328: 179-192.

Carpenter, S.R., Walker, B., Anderies, J.M., Abel, N. 2001. "From Metaphor to Measurement: Resilience of What to What?" *Ecosystems* 4(8): 765–781.

Carpenter, S.R., Arrow, K.J., Barrett, S., Biggs, R., Brock, W.A., Crepin, A.S., Engstrom, G., Folke, C., Hughes, T.P., Kautsky, N., Li, C.Z., Mccarney G., Meng, K., Maler, K.G., Polasky, S., Sheffer, M., Shogren, J., Sterner, T., Vincent, J.R., Walker, B., Xepapadeas, A., De Zeeuw, A. 2012. "General Resilience to Cope With Extreme Events" *Sustainability* 4: 3248-3259.

Castillo, A.C. 1997. Backyard Beef Production in the Philippines. FAO Publications Repository. 5pp.

Committee on Forage and Pasture Crops. 2006. Philippine Recommends for Pasture Crops. Philippine Council for Agriculture, Forestry and Natural Resources Research and Development, Los Baños, Philippines. 93 pp.

Cumming, G. S., Barnes, G., Perz, S., Schmink, M., Sieving, K.E., Southworth, J., Binford, M., Holt, R.D., Stickler, C. and Van Holt, T. 2005. "An exploratory framework for the empirical measurement of resilience". *Ecosystems* 8(8):975-987.

Department of Science and Technology. 2011. Climate Change in the Philippines. ADAPTAYO, MDG Achievement Fund, and Philippine Atmospheric, Geophysical and Astronomical Services Administration, Quezon City, Philippines. 91pp.

El-Kawy, O.R.A., Rød, J.K., Ismail, H.A. and Suliman, A.S. 2011. "Land use and land cover change detection in the western Nile delta of Egypt using remote sensing data". *Applied Geography* 31 (2):483-494.

Esmail, S. and Oelbermann, M. 2011. "The impact of climate change on the growth of tropical agroforestry tree seedlings". *Agroforestry Systems* 83(2): 235-244.

Folke, C., Hahn, T., Olsson, P., Norberg J. 2005. "Adaptive Governance of Social-Ecological Systems" *Annual Review of Environment Resources* 30: 441-473.

Folke, C., Carpenter, S.R., Walker, B., Scheffer, M., Chapin, T., Rockstrom, J. 2010. "Resilience Thinking: Integrating Resilience, Adaptability and Transformability" *Ecology and Society* 15(4): 20.

Gadgil, M., Berkes, F., Folke, C. 1993. "Indigenous Knowledge for Biodiversity Conservation" *Ambio* 22(2/3): 151-156.

Gunderson, L.H. and Allen, C. R. 2009. "Why resilience? Why now?". In: Foundations of Ecological Resilience. (ed. C.S. Holling, C.R. Allen, and L.H. Gunderson). Island Press, Washington DC, USA. pp. XIII-XXV.

Gunderson, L., Kinzig, A., Quinlan, A., Walker, B. 2010. "Assessing Resilience in Social-Ecological Systems: Workbook for Practitioners". *Resilience Alliance* 54 pp.

Hill, R.A., Echeverría, E., Golicher, D., Rey, J., Benayas, Cayuela, L., and Hinsley, S.A. 2009. Progress in Physical Geography 2009.

Janssen, M.A., Bodin, O., Anderies, J.M., Elmqvist, T., Ernston, H., Mcallister, R.R.J., Olsson, P., Ryan, P. 2006. "Toward A Network Perspective of the Study of Resilience of Social-Ecological Systems" *Ecology and Society* 11(1): 15.

Kennedy, R.E., Townsend, P.A., Gross, J.E., Cohen, W.B., Bolstad, P., Wang, Y.Q., and Adams, P. 2009. "Remote sensing change detection tools for natural resource managers: Understanding concepts and tradeoffs in the design of landscape monitoring projects". *Remote Sensing of Environment* 113(7):1382-1396.

Kosmas, C., Karamesout, M., Kounalaki, K., Detsis, V., Vassiliou, P., and Salvati, L. 2016. Land degradation and long-term changes in agro-pastoral systems: An empirical analysis of ecological resilience in Asteroussia - Crete (Greece). CATENA 147: 196-204.

Le Houerou, H.N. 1987. "Indigenous Shrubs and Trees in the Silvopastoral Systems of Africa". In: Agroforestry a Decade of Development. (ed. H.A. Steppler and P.K.R. Nair). International Council for Research in Agroforestry, Nairobi, Kenya. pp. 141-156.

Magnuszewski, P., Ostasiewicz, K., Chazdon, R., Salk, C., Pajak, M., Sendzimir, J., and Andersson, K. 2015. "Resilience and alternative stable states of tropical forest landscapes under shifting cultivation regimes". *PLoS ONE* 10(9): e0137497.

Martínez, J., Cajas, Y.S., León, J.D., and Osorio, N.W. 2014. "Silvopastoral Systems Enhance Soil Quality in Grasslands of Colombia". *Applied and Environmental Soil Science* 2014: 1-8.

Moberg, F. and Simonsen, S.H. 2014. What Is Resilience: An Introduction to Social-Ecological Research. Stockholm Resilience Center, Stockholm, Sweden. 20 pp.

Moreno, G., Franca, A., Pinto Correia, M.T. and Godinho, S. 2014. "Multifunctionality and dynamics of silvopastoral systems". *Options Méditerranéennes A*(109): 421-436.

Nair, P.K.R. 1993. An Introduction to Agroforestry. Kluwer Academic Publishers, Dordrecht, The Netherlands. 499 pp.

Nair, P.K.R., Buresh, R.J., Mugendi, D.N., Latt, C.R. 1998. "Nutrient Cycling in Tropical Agroforestry Systems: Myths and Science". In Agroforestry in Sustainable Agricultural Systems (ed. L.E. Buck, J.P. Lassoie, and E.C.M. Fernandes). CSC Press, Boca LLC Raton, Florida. pp. 15-45.

Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M.S., Bernabucci, U. 2010. "Effects of climate changes on animal production and sustainability of livestock systems". *Livestock Science* 130(1-3): 57-69.

OAS- Rosario. 2009. Masterlist of Recipients: Cattle Disperal Project in Barangay San Isidro. Local Government of Rosario- Office of the Agricultural Services, Rosario, Batangas. 10 pp.

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

Philippine Statistics Authority. 2017. Cattle Situation Report: January- December 2016. Philippine Statistics Authority, Quezon City, Philippines. 30 pp.

Pinay, G., Ruffinoni, C. and Fabre, A. 1995. "Nitrogen cycling in two riparian forest soils under different geomorphic conditions". *Biogeochemistry* 30: 9-29.

Pôças, I., Cunha, M., and Pereira, L.S. 2011. "Remote sensing based indicators of changes in a mountain rural landscape of Northeast Portugal". *Applied Geography* 31(3):871-880.

Richards, J.A. 2013. Remote Sensing Digital Image Analysis: An Introduction. Springer, Verlag Berlin Heidelberg, Germany. 494 pp.

Sevilla, C.C., Calub, B.M., Tan, R.L., Bejo, M.B. 2000. Participatory Appraisal and Characterization Of Selected Sitios of Barangay San Isidro, Rosario, Batangas. Institute of Animal Science and Farming Systems and Soil Resources Institute, University of the Philippines Los Baños.

Sevilla, C.C., Calub, B.M., Medalla, L.M., Bejo, M.B., Tan, R.L., Torio, T.M., Almonte, R.C. 2001a. "Cattle Production in the Uplands of Rosario, Batangas III:

Supply and Availability of Feed Resources". Paper presented at the Philippine Society of Animal Scientists 38th Annual Convention. Manila, Philippines. October 2001.

Sevilla, C.C., Calub, B.M., Medalla, L.M., Bejo, M.B., Tan, R.L., Torio, T.M., Almonte, R.C. 2001b. "Cattle Production in the Uplands of Rosario, Batangas IV: Effects of Concentrate Supplementation on the Performance of Cows". Paper presented at the Philippine Society of Animal Scientists 38th Annual Convention. Manila, Philippines. October 2001.

Sevilla, C.C., Solivas, E., Arboleda, C.R., Laude, R.P., Doydora, M., & Reamico, S.B. 2005. "Bionomics of Smallholder Cattle Production in Luzon and Visayas, Philippines". *Philippine Journal of Veterinary and Animal Science* 31(2): 167-177.

Sharow, S.H. 1998. "Silvopastoralism: Competition and Facilitation between Trees, Livestock, And Improved Grass-Clover Pastures On Temperate Rainfed Lands". In Agroforestry in Sustainable Agricultural Systems (ed. L.E. Buck, J.P. Lassoie, and E.C.M. Fernandes). CSC Press, Boca LLC Raton, Florida. pp. 122-141.

Schönhart, M. and Nadeem, I. 2015. "Direct climate change impacts on cattle indicated by THI models". *Advances in Animal Biosciences* 6(1), 17-20.

Simonsen, S.H., Biggs, R., Schlüter, M., Schoon, M., Bohensky, E., Cundill, G., Dakos, V., Daw, T., Kotschy, K. 2014. Applying resilience thinking: Seven principles for building resilience in social-ecological systems. Stockholm Resilience Center, Stockholm, Sweden. 20 pp.

Stanton, Emms, Sia. 2010. The Philippines Beef Cattle Farming Sector: A Briefing For Canadian Livestock Genetic Suppliers. Technical Report. Office of Southeast Asia Regional Agri-Food Trade Commissioner & Agriculture and Agri-food Canada, Singapore. 23 pp.

The World Bank Group. 2020. "to "Average Monthly Temperature and Rainfall for 1901-2016 at Location (121.31,13.77)". Retrieved from http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_historical_climate&ThisRegion=Asia&ThisCCode=PHL on 15 April 2016

Thornton, P. K., and Gerber, P. J. 2010. "Climate change and the growth of the livestock sector in developing countries". *Mitigation and Adaptation Strategies for Global Change* 15(2), 169-184.

Umrani, R., and Jain, C.K. 2010. Agroforestry Systems and Practices: Oxford Book Company, Jaipur, India. 307 pp.

United States Department of Interior and United States Geological Survey. 2016. "Tracking Change Over Time—Understanding Remote Sensing". Retrieved from https://pubs.usgs.gov/gip/133/pdf/RemSens-Student_web.pdf

UNU-IAS, BI, IGES and UNDP,. 2013. Toolkit for indicators of resilience in socio-ecological production landscapes and seascape. United Nations University-Institute of Advanced Studies, Bioversity International, Institute for Global Environmental Strategies, and United Nations Development Program. 38 pp.

Victorio, E.E. and Badayos, R.B. 2006. "Assessment of Backyard Livestock Production in Rosario, Batangas Applying Land Use System Approach". *Journal of Veterinary and Animal Science* 32(1): 99-109.

Vitousek, P. M. and Sanford, Jr., R. L. 1986. "Nutrient recycling in moist tropical forest". *Annual Review of Ecology and Systematics* 17:137-67.

Walker, B. and J. A. Meyers. 2004. "Thresholds in ecological and social–ecological systems: a developing database". *Ecology and Society* 9(2): 3.

Walker, B., Holling, C.S., Carpenter, S.R., and Kinzig, A. 2004. "Resilience, Adaptability, and Transformability in Social-Ecological Systems". *Ecology and Society* 9 (2): 5.

Wan, L., Zhang, Y., Zhang, X., Qi, S., and Na, X. 2014. "Comparison of land use/land cover change and landscape patterns in Honghe National Nature Reserve and the surrounding Jiansanjiang Region, China". *Ecological Indicators* 51:205-214.

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