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The studies on promoting forest carbon sequestration to meet Paris climate agreement targets

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이 도서의 국립중앙도서관 출판예정도서목록(CIP)은 서지정보유통지원시스템 홈페이지(http://seoji.nl.go.kr)와 국가자료공동목록시스템(http://www.nl.go.kr/kolisnet)에서 이용하실 수 있습니다. (CIP제어번호 : CIP2017011167)

Abstract

The new emission standards from the Paris agreement presented us with many challenges. Since the role of developing countries in responding to climate change is becoming more significant, Korea, which has not been obliged to reduce climate change so far, should prepare groundbreaking carbon reduction strategies. In addition, we need to strengthen international cooperation to arrive at global solutions to climate change, since carbon emission will induce climate change regardless of which countries emit it. With this background, KREI in Korea and CATIE in Costa Rica performed joint research to seek effective forest action to mitigate and adapt to climate change. Forests make up the largest terrestrial carbon reservoir, sequestrating 30% of annual global anthropogenic CO_2. Because two countries have abundant forest resources, it would be expected that responding to climate change using forest resources could be an optimal strategy for both countries.

This paper includes details from two different researches. The first research was done by CATIE in Costa Rica with its major objective being to determine the effect of payment for environmental services (PES) as it related to the performance of a silvopastoral (SP) system in Esparaz, Costa Rica. The payment for ecosystem services (PES) has been piloted and implemented in various parts of the world, with an objective of encouraging farmers to engage in environmentally friendly practices to enhance biodiversity. In this strategy, an environmental services index (ESI) is set and farmers are paid for their activities that provide a net increase of the ESI points. A previous study shows that the use of PES initiatives has resulted in increased environmental biodiversity characterized by a reduction in the degraded pastureland and an increase in the portions of pasture with high tree density (Pagiola et al., 2007). The use of PES programs on a silvopastoral (SP) system in Costa Rica also increased the rate of trees' reintroduction and live fences, thereby improving biodiversity habitat and the levels of carbon sequestration. However, the main concern associated with the use of PES initiatives is the long-term sustainability of the programs as a result of the financial resources required to pay the farmers and the continuity of the programs once the payments have stopped. The second research, performed by KREI in Korea, examines efficient forest regulation planning to enhance carbon sinks in forests using linear programming (LP). Forest management has been taken into consideration to increase forest carbon sequestration and sustainability. However, as Duang-sathapon and Prasomsin (2005) argued, forest management can be a challenging and daunting task, calling for the application of scientific methods to ensure proper planning and utilization of environmental resources such as trees in forests. The LP model has been applied to foster proper management of the forest trees. Using the LP model, managers are able to segment forests into cutting units, in which trees that share the same age are segregated, and logging activities are allowed in different segments on a rotation basis to mitigate total deforestation. This model has fostered the maintenance of the tree covers in forests through regulated logging and improved the maintenance of sustainable carbon sequestration in trees. Current unbalanced age structure of Korean forests cannot provide both economic and environmental sustainability. Through harvest prescription from LP, we derived the balanced age-class distribution that constitutes improved conditions for sustainable use of forest resources. Even though there are several limitations, our LP model would provide the forest managers and policy makers with a tool for implementing cost-efficient forest planning.

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Introduction

Chapter 1

At the Paris climate conference (COP21) in December 2015, international governments agreed to phase out fossil fuels by 2050, wherein the agreement will be enforce in 2020. The agreement establishes a global action plan to reduce climate change impacts by limiting greenhouse gas (GHG) emission. Paris' agreement sends a clear signal to all countries to shift away from using fossil fuels and set out a long term goal of keeping the increase in global average temperature to well below 2°C (European Commission 2013). The key elements of the Paris agreement cover the following issues (UNFCCC 2015): 1. Mitigation: reducing emissions rapidly enough to achieve the specific temperature goal (global average temperature to well below 2°C). 2. Taking into account a transparency system for climate action. 3. Providing continuous international support for mitigating/adapting in climate change to developing countries.

Compared with the Kyoto protocol (KP), a major improvement of the Paris agreement is to attract cooperation from developing countries. The KP provided useful guidelines on reducing GHG emission but its impacts on climate change were limited, primarily due to the fact that only developed countries, the EU in particular, could decrease their emission between 1997 and 2012. However, global GHG emission has been gradually increasing, by 30% between 1990 and 2010 while developed countries had decreased their emission (Cheeseman 2015). The lessons we could learn from KP are that climate change is perhaps one of the greatest threats to this planet for both developed and developing countries. Therefore, we would expect that the role of developing countries in climate change will become significant.

The 196 world leaders who convened in Paris recognized the critical role of forests in maintaining a livable climate. With the Paris' agreement in place, forests could be the center of both mitigation and adaptation strategies through various forest action plans. The agreement also calls for enhanced international forest partnership such as REDD+ and other joint approaches. From this background, we are convinced that forest actions for adaptation and mitigation should be crucial and that enhancing international forest partnership imperative to bring about success, in response to ongoing climate change. This research seeks to find effective strategies for enhancing carbon sinks in forests to meet new emission standards in Paris' agreement. This research is a part of the MOU between KREI and CATIE. A rising global concerns about climate change and the forest management had led to a renewed interest in international forest partnership. To respond to this necessity, KREI seeks a new international partnership for joint research in the field of forestry, and for several reasons, we chose Costa Rica as a partner of the joint research. First, forests in the two nations indeed share several aspects, such that both countries once had affluent forest resources but experienced loss of forest resources due to intensive logging at an alarming rate. Second, both countries successfully recovered total forest cover under active governmental drive, but the callow forest plan created new challenges such as an unbalanced forest age-class distribution. For these reasons, the joint research between the two countries will provide an opportunity to share innovative knowledge of new forest action standard and the lessons learned from the joint research will help alleviate climate change that both countries now face. The major objective of this joint research is sharing forest sector innovations in terms of GHG mitigation and climate change adaptation, with the goal of extending the research results to new places and new applications. The outcomes of researches will be present opportunities to disseminate and expand knowledge and depth of understanding in this area, provide new empirical background to reduce emissions and increase carbon stocks in the forest sector, develop a new policy that is more likely to achieve goals and implement a successful policy to improve forests' carbon sequestration.

The overall structure of the paper takes the form of four sections and an appendix. The first section is a general introduction to the paper and the second section is research related to integrated silvopastoral (SP) approaches for ecosystem management in Costa Rica. The major objective of the second section is to determine the effect of payment for environmental service (PES) on livestock farms' environmental performance years after the payment has ceased. The third section introduces the research for enhancing forest carbon sequestration in Korea through controlling forest age distribution. The final section is the overall conclusion of the study During the joint research, the two countries actively exchanged information via online discussion and via in-person meeting. The results of the study were shared through an international conference, held in KREI, 2016. Adequately benchmarking the case of successful forest policy and disseminating our expertise will be a win-win strategy in response to a new greenhouse gas (GHG) emission target.

Intergrated Silvopastoral (SP) Approach for Ecosystem Management in Esparza, Costa Rica

Chapter 2

1. BACKGROUND OF THE RESEARCH

Costa Rica's livestock sector is formed by a great base of small producers, very large in number, with important economic and social incidence, and includes dairy and meat product processing companies. According to the livestock census of 2011, 54.780 farms have been registered and are distributed in all regions of the country. The regions that have more farms are North Huetar (23.3%), Central (20.8%), Brunca (16.2%) and Chorotega (15.8%) (Corfoga, 2012).

Livestock development in each region of the country is managed similarly to the rest of Central America. It is developed under production models that are not very friendly with the environment and lead to a fast degradation of soils, affecting biodiversity significantly and accelerating the loss of ecosystem services, as well as influening ranching families and neighboring communities' livelihoods in a negative way. Kaimowitz (2001) reports that in Central America only, there are 13.6 million hectares of forests that were converted into pastures, and it is estimated that 50% of them are in a critical state of degradation (Szott et al. 2000, Wassenaar et al. 2007). These maneuvers could lead to important economic loss ranging between 8-40% in dairy production and 15-80% in meat production (Benavidez 2013).

In response to this situation, conventional livestock must change their degrading tendency through the implementation of silvopastoral systems (Villanueva et al. 2011). Acknowledging this alternative, the strategy is needed to increase feasibility and productivity while contributing to the reduction of Greenhouse Gas Emissions through Livestock NAMA Costa Rica. The importance of silvopastoral systems is acknowledged with the purpose of achieving carbon neutrality.

The presence of trees in partnership with pastures and animals is known as a silvopastoral system, which provides environmental, economic and social benefits (Pezo e Ibrahim, 1999; Villanueva et al., 2009). The presence of dispersed trees contributes to sequestering between 114 to 143 tons of carbon per hectare (t C ha-1) –in comparison with degraded pastures (Ibrahim et al., 2007). The acquisition of trees in livestock contributes to a series of benefits depending on the goals set by each producer: firewood, timber, fruits, shade, animal feed, windbreaks, nutrient recycling, connectivity and shelter for wild animals. Shade produced by trees is considered the most feasible and efficient alternative to reduce heat stress due to climate change, reducing the temperature by almost 3°C (Pezo e Ibrahim, 1999; García, 2010; García e Ibrahim, 2013).

The above details highlights the importance of silvopastoral systems as an efficient mechanism to recover degraded pastures, and develop production systems that are more sustainable for the environment (Casassola et al. 2008). Nevertheless, although these productive systems have proven to contain optimal technology, the adoption level of these practices is low. This situation is caused by high costs for its initial establishment (Pagiola et al. 2004); for example López (2005) estimates that the cost for the implementation, maintenance and use of fodder banks is between USD 800 and USD 1200 ha^{-1}.

Considering that the initial investment for the establishment of SPS is high and taking into account the environmental benefits they bring, the project "Integrated Silvopastoral Approaches for Ecosystem Management" was implemented between 2002 and 2008. The project was implemented by the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Nitlapán and the Centro Para la Investigación en Sistemas Sostenibles de Producción Agropecuaria (CIPAV) in Costa Rica, Nicaragua and Colombia respectively in collaboration with the World Bank and the FAO, and funded by the GEF. The objective was to encourage livestock farms to adopt silvopastoral practices in these countries through the Payment for Ecosystem Services (PES) (Casasola et al. 2007).

The Payment for Ecosystem Services (PES) as an economic instrument allows market options to be generated for those ecosystem services that provide productive landscapes (Rapidel et al. 2011). Through PES, systems that are friendly for ecosystem services such as silvopastoral systems can be implemented. Costa Rica is an exemplar case, where agroforestry systems have recently been incorporated in the national PES program (Pagiola 2008).

The PES was constituted in part of the base capital aimed for land use change, from those uses with inappropriate management to those that are part of the SPS proposal (enhanced pastures with trees, fodder banks, live fences, among others). An economic compensation was held during 2-4 years in relation to the scheme with which each producer was acknowledged.

During this period, the effects emanating from PES and the adoption of SPS were considerably positive in terms of tree cover augmentation in farms and biodiversity conservation (Saenz et al 2007, Tobar & Ibrahim 2010); organic carbon storage capacity in soils and biomass (Ibrahim et al. 2007); richness, abundance and diversity in butterflies and birds (Enriquez-Lenis et al. 2007, Tobar et al. 2007, Pomareda 2008); decrease in surface runoff and hydric erosion (Ríos et al. 2007). Its socio-economic effects entailed: an increase in the productivity indicators at farms, development of financial tools such as the certification as a strategy to maintain sustainable practices in farms (Sepúlveda et al 2010), among others. The project only lasted five years and as a result, PES, to farmers was not continued after the project ended. There is little information available on whether livestock farmers will revert to conventional practices after the project ends. Some researchers argued that PES resulted in the adoption of silvopastoral practices that are related to increased productivity while, at the same time, provide environmental benefits; this is an incentive for farmers to continue managing these practices.

The objective of this consultancy is to determine the effect of payment for environmental services (PES) in livestock farms' environmental performance, nine years after the payments have ceased as well as in the adoption and permanency of silvopastoral systems implemented during the GEF project. Among the silvopastoral technologies evaluated, improved pastures with trees, fodder banks, live fences and conservation uses, such as riparian forests and secondary forests are found.

2. CONSULTANCY OBJECTIVE

The objective is to determine the effect of payment for environmental services (PES) on livestock farms' environmental performance years after the payments have ceased. Our objective is to focus on three indicators: (i) land use, (ii) environmental performance and (iii) SP practices. This topic is of special interest, now that low emission development is being sought, especially in the livestock sector of Costa Rica and elsewhere; when resources to finance PES schemes are scarcer; and, when decision makers are looking for innovative financial incentives. This project will help answer the question posted by KREI (Korea Rural Economic Institute) in regards to the appropriateness of updating Costa Rica´s PES program to Korean reality to increase the adoption of silvopastoral system (SPS) approaches. A contract was signed between CATIE and KREI to conduct this study and this final report.

3. METHODOLOGY AND METHOD

3.1. Study area

The study area corresponds to the intervention area of the Integrated Silvopastoral Approaches for Ecosystem Management project, financed by GEF with the support of the World Bank and FAO-LEAD, in Esparza, Costa Rica during 2003-2007.

Esparza is located in the Central Pacific region of Costa Rica (Figure 1). The region consists of eight districts: Puntarenas, Esparza, Montes de Oro, Aguirre, Parrita, Garabito, San Mateo and Orotina. It belongs to the Sub-humid Tropical Forest (Holdrige 1970), with an altitude between 50 and 1000 ma. The minimum temperature is 27°C and its relative humidity is between 65 and 80%. The annual precipitation varies between 1500 and 200mm and the dry season is present between December and April. The terrains in the study area present a slope of 0 to 30%. The canton's population is of 23,963; 13,561 of which live in urban areas and 10,492 in rural areas (INEC 2008).

In the study area, 64.2 % of the lands correspond to pastures and 29.3% to forests (secondary forests, riparian forests and forest plantation, fragments) (Table 1). The predominant activity is livestock production, mainly breeding and fattening (63%), followed by the dual purpose systems (dairy and meat 34%) and farms of mixed production, agriculture and livestock (3%). Different cattle breeds are raised in the region, predominantly Brahman, a Brahman and Indo-brasilean crossbreeding in meat and animal production farms like zebu and dairy breeds (Brown Swiss or Holstein) in dual purpose farms; similarly it indicates that *Brachiaria brizantha* e *Hyparrhenia rufa* are the grass species most commonly cultivated (Villanueva et al. 2007).

Figure 2-1. Location of the 130 participant farms in the "Integrated Silvopastoral Approaches for Ecosystem Management Project" - SPS –GEF – Project 2003-2007

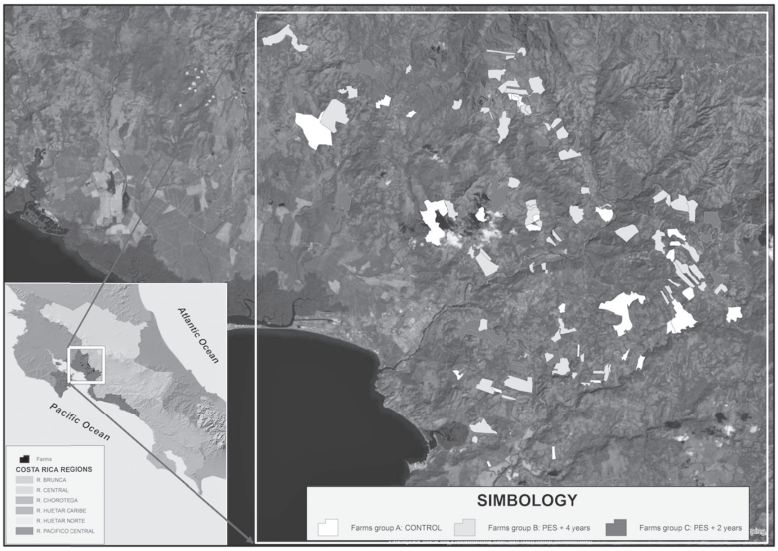


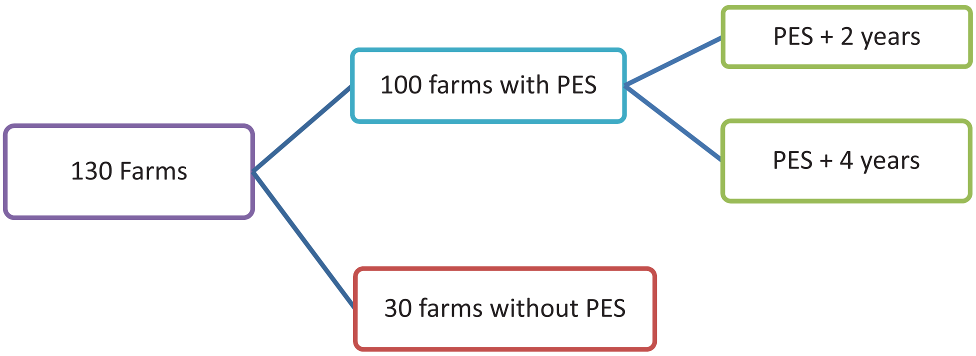
Table 2-1. Distribution of land uses in Esparza, Costa Rica, 2016

Land use	Area (ha)	%
Degraded Pasture	135.9	3.6
Impoved pasture without trees	20.9	0.6
Improved pasture with high tree density	893.6	24.0
Improved pasture with low tree density	1.055.4	28.3
Naturalized pasture with high tree density	130.5	3.5
Naturalized pasture with low tree density	155.5	4.2
Naturalized pasture without trees	1.4	0.0
Fodder bank	46.7	1.3
Intensive SPS	2.4	0.1
Coffee with shade	9.0	0.2
Annual crop	20.2	0.5
Perennial crop	13.3	0.4
Orchad plantation	50.2	1.3
Riparian forest	651.3	17.5
Secondary forest	353.0	9.5
Secondary forest succession	86.8	2.3
Forest Plantation	50.7	1.4
Infraestructure	51.3	1.4
Total general	3,727.99	100

3.2. Methodology

Based on the formulation and development of the Integrated "Silvopastoral Approaches for Ecosystem Management Project", farms were selected to participate in the evaluation of PES, to determine if it was an incentive to increase the adoption of silvopastoral practices; for this reason, farms with PES and without PES were selected (Figure 2). 130 farms were chosen initially to participate in the project, 100 farms as beneficiaries and 30 as a control group (Ibrahim et al. 2003).

Figure 2-2. Distribution of selected farms for the development of "Integrated Silvopastoral Approaches for Ecosystem Management Project", 2003-2007



This consultancy works with the PES group, which consists of 100 farms that provide PES, and have been assigned a specific combination of PES schemes that last between 2 to 4 years with the presence or absence of Technical Assistance (TA) (Zapata et al. 2008). The project coordination team established criteria to be met by aspiring candidates in the selection process: To have a genuine interest in participating in the project, to be small or medium size producers (10-18 ha), to have duly legalized property, to have a positive attitude towards sharing and transferring of experiences, to have resource availability to co-finance land use changes, sign and fulfill the contract, to allow access to their farm, to deliver information to technicians, to have availability to receive capacitation and technical assistance and, to continue operating the silvopastoral systems by the end of the project (Ibrahim et al. 2003). The owners who manifested their interest and met the established criteria were selected upon arrival and depending on their budget availability for beneficiary farms (Pagiola et al. 2010).

The control group consists of 30 farms. The number of farms was established in relation to the cost that monitoring land uses implies. Monitoring was conducted annually as the project progressed. Each farm was given a financial bonus for delivering information to the project technicians. Based on the project's design, PES scheme and control group, the following was established:

Payment scheme 1: A single payment of US$ 10 was made per rate point at the moment of establishing baseline 2 (year 0), also a year's payment was made (calculating annual rates minus the rate of the baseline) throughout the 4 years. The stipend paid for each resulting additional point was US$ 75 (Casasola et al. 2007).

Payment scheme 2: A US$ 10 single payment was made per rate point at the establishment of the baseline, besides making the annual payment for two years. The stipend paid per resulting additional point was US$ 110 (Villanueva et al. 2007).

3.3. Information used for the study

A socioeconomic and productive survey was done to the PES and non-PES farms in 2003. This survey served to establish the baseline and was conducted again in 2016. During the interim period between 2003 and 2007, surveys were not conducted of the participants and non-participants of the PES program (annex 1).

Land use monitoring was conducted in PES and non-PES farms, through the use of Quickbird images from 2002 and 2003, satellite Landsat images and georeferencing with GPS on farms with cloudiness. 16 land uses were identified in the zone in 2003, and on every image of the farm each polygon of use was identified (Murgueitio et al, 2003). The monitoring of land uses was conducted annually from 2003 to 2007 and during the present year (2016), these use changes are being updated by visiting and conducting field trips to the 130 farms.

The Environmental Service Index (ESI) was implemented as a tool to concrete the PES payments. The ESI consisted of establishing a numerical value to each land use according to their contribution in biodiversity conservation services and carbon stock. The index developed an order of uses, from the least contributing ones, such as degraded pastures, scoring 0, to those that contribute the most, such as a secondary forest scoring 1. For each index, the biodiversity conservation score was added to the carbon stock score, reaching a maximum score of 2 (Pagiola et al. 2004). This approach is similar to that of the Environmental Benefits Index (EBI) used in the US Conservation Reserve Program (CRP) (NCEE, 2001).

Separate indices were developed for the biodiversity conservation and carbon sequestration benefits of each land use. These two indices were then aggregated to form an environmental service index to be employed as the basis for calculating payments to participants. A similar index for water benefits was not included, partly because of the lack of data needed to develop it, and partly because improved water flows would be national benefits, thus, providing ineligible for GEF funding. The biodiversity conservation and carbon sequestration indices are presented in Table 2.

3.4. Information update analysis

A survey was applied to collect information; a three-part semi-structured interview is being implemented in the following way:

Family's general information: In which socio-economic aspects are included such as the family's composition by gender and age, education level, participation of each member in the farm's daily activities, land tenure, alternative interests for investment, type of funding, the farm's activities, access to credit, and its market.

Farm's general information: Herd composition, pasture rotation or appliances, records of productive activity, infrastructure, machinery and equipment if any; changes in land use in relation to the last year of monitoring conducted by the project (2007-2016); farm production (incomes); production costs, establishment and management of herd, pastures, fodder banks and live fences.

Farm's management information: If the activities have changed or remain the same, sale of the farm, information related to their perception of PES, perception of silvopastoral systems (comments in economic and ecologic terms), levels of organization and production problems in relation to climate change.

Table 2-2. Environmental service indices used in the SPS-GEF Project – 2003-2007

Land use	Biodiversity index	Carbon sequestration index	Environmental service index[1]
Annual crops (annual, grains, and tubers)	0.0	0.0	0.0
Degraded pasture	0.0	0.0	0.0
Natural pasture without trees	0.1	0.1	0.2
Improved pasture without trees	0.4	0.1	0.5
Semi-permanent crops (plantain, sun coffee)	0.3	0.2	0.5
Natural pasture with low tree density (<30/ha)	0.3	0.3	0.6
Monoculture fruit crops	0.3	0.4	0.7
Fodder bank	0.3	0.5	0.8
Improved pasture with low tree density (< 30/ha)	0.3	0.6	0.9
Natural pasture with high tree density (> 30/ha>	0.5	0.5	1.0
Diversified fruit crops	0.6	0.5	1.1
Monoculture timber plantation	0.4	0.8	1.2
Shade-grown coffee	0.6	0.7	1.3
Improved pasture with high tree density (> 30/ha)	0.6	0.7	1.3
Diversified timber plantation	0.7	0.7	1.4
Scrub habitats (*tacotales*)	0.6	0.8	1.4
Riparian forest	0.8	0.7	1.5
Disturbed secondary forest (> 10 m^2 basal area)	0.8	0.9	1.7
Secondary forest (> 10 m^2 basal area)	0.9	1.0	1.9
Primary forest	1.0	1.0	2.0
New live fence or established live fence with frequent pruning (per km)	0.3	0.3	0.6
Wind breaks or multistrata live fence (per km)	0.6	0.5	1.1

Note: [1]The environmental service index is the sum of the biodiversity and carbon sequestration indices.

For the analysis: An analysis was made based on the state of the farms in 2003, when the project started, and later collected in 2007 and 2016. Based on this information, probabilistic regressions were used to identify farm groups (with PES versus control) that made more changes in land use. Once this analysis was completed using the GOWER distance pairing method, which allows the use of qualitative variables as quantitative variables and the use of mixed linear models, it was possible to show if the changes in the tree cover on of farms by adopting silvopastoral system promoted by technical assistance and PES, favor the conservation of biodiversity in the region of Esparza, Costa Rica.

It is important to consider that the variables of interest are the changes in land use in 2007, compared to 2003 and the changes in the year 2011 compared to year 2003. The dependent variables correspond to the changes in land use between 2003 and 2007 and the changes that occurred in 2011 compared to 2003. The 22 land uses identified during the development of the Silvopastoral Approaches project were grouped into nine categories (Table 3). The categories were defined by making the selection of land uses that have a conceptual relationship and their relationship is linked to the contribution of these land uses to the generation of ecosystem services.
Once all the information was gathered for the analysis of the impact assessment, meant for studying the permanence of the practices, only the farms that allowed the survey were considered. Of 130 farms, 17 farms that were sold did not contribute to the development of the survey; those farms had participated in the project with PES. In the case of the six rented farms (4 PES, 2 Control), surveys were not allowed to be developed in three farms with modality of payment either because the producers were ill. Based on this, 24 farms in control mode and 80 farms with PES mode were established.

3.5. Socioeconomic analysis

To analyze the socioeconomic impacts of the farms, the comparative analysis between 2003 and 2016 was carried out, taking as the baseline of the project and the information compiled in 2016 in the project area. The information could not be compared in 2007 (completion of the project), due to the projection of this information. To evaluate the effect of the changes in land use developed by the producers, the following economic variables were taken into account.

Table 2-3. Grouping of land uses according to importance for the generation of ecosystem services in Esparza, Costa Rica

Category	Land use included
Forest	Riparian forest, disturbed secondary forest (> 10 m2 basal area), secondary forest (> 10 m2 basal area), primary forest, monoculture timber plantation, diversified timber plantation
Secondary forest succession	Scrub habitats (takotals)
Pasture with trees	Improved pasture with low tree density (< 30/ha), Natural pasture with high tree density (> 30/ha).
Pasture without trees	Natural pasture without trees, improved pasture without trees, natural pasture with low tree density (<30/ha), improved pasture with low tree density (< 30/ha)
Perennial crop	Orchad plantation and shade-grown coffee
Fodder bank and SPS	Fodder bank and silvopastoral system intensive
Degraded pasture	Degraded pasture
Annual crop	Annual crops (annual, grains, and tubers)
Simple live fence	New live fence or established live fence with frequent pruning
Multiestrata live fence	Wind breaks or multistrata live fence.

3.6. Cashflow

Cash Flow is a tool that monitors and reports all financial transactions, that is, the input and output values in a given period. For the analysis of the participant farmers, the income from milk and cheese sales, sale of meat, and from other related practices were considered as accounted inflow and the outflow was the sum of all costs incurred by the farmers to perform their operations on the farms. The costs included food and nutrition for livestock, vaccines and health expenses for the animals, contracted farm labor, farm inputs such as herbicides and seeds, electricity and gas, etc. Any capital investments were not considered as an operating cost in this study.

To compare the economic impacts of the project, two financial indicators were used in this study: net income and operating expense ratio. Net income is an important indicator in the analysis of impacts of the project. Net income is gross income or cash inflows minus all expenses i.e. cash outflows. The change in net income, calculated as a percentage, reflects the economic impacts of the project on the farming households. However, net income cannot in itself adequately analyze the economic impacts of the project since it is a highly variable indicator. To this end, the study used another indicator, operating expense ratio, to fill in the gaps of net income analysis. Operating expense ratio adequately compares the economic efficiency of the farms before initiation of the project and the project's impacts after the termination of the project. Operating-Expense ratio is measured as a percentage. The lower the percentage, the better the situation is for the business or farm (Kantrovich, 2012). The percentage form of the ratio helps when comparing economic efficiency of different farms.

3.7. Operating Expense Ratio

The operating expense ratio (OER) is a measure of what it costs to operate on a piece of land compared to the income that same land generates. The OER is calculated by dividing a farm's operating expense by its gross operating income and it is used to compare the cost efficiency of similar farms. The operating costs are costs that help run a farm on a daily basis. Costs such as food for the animals, vaccines, herbicides, and electricity make up operating costs of the farm. A lower OER signifies that the operations of that farms are more profitable and that less of the farm's income is used for covering the operating expenses of the farm, thus, signifying a more efficient management. Calculating and analyzing OER for a number of years will help farmers, donor agencies, project owners and governments to make informed decisions regarding the farm's operations. If the farm's costs increase annually at a greater rate than the rate of income, it results in an increase in OER. This increasing cost makes operations inefficient and not viable, often leading farmers sell their farms. A farmer who is producing at a loss in the long run will attempt to sell his farm and goes into another occupation (Riedl, 2007).

3.8. Cost-benefit Ratio

Another indicator, result of cash flow, was the benefit-cost ratio (B/C). It indicates how much the benefits exceed or stay within the total costs, and the value obtained in this ratio should be greater than or equal to 1 to give feasibility to a project, according to Gonzales (2009). Cost-Benefit Ratio is the ratio of the total revenue on the total costs for the years 2003 and 2016. The formula for calculating the benefit-cost ratio is:

B/C R= (Total Income) / (Total Costs)

4. ANALYSIS OF PES EFFECTS ON FARMS

For the present study, the variables that most influence decision making for the development of changes in land use on farms were identified (Table 3). The age of the producer is a variable that has a negative influence on the decision to participate in the PES program and on the adoption of good livestock practices. That is to say, as the age of producers increases, the probability that the producer makes change on the farm decreases.

Another variable that influences the adoption and permanence of good livestock practices and participation in the project is if the producer resides on the farm. During the PES period the owners who lived on the farm were able to develop changes in land uses in a fast way, due to the fact that with the payment they had a greater security and the technical assistance favored to reduce the risk of the investments.

Farms that have dual-purpose production systems, temporary labor, animal load, land uses related to livestock production (pastures) are related to the intensification of the farm, which is related to the income of the producer and at the same time influences the decision to develop technological changes to improve farm productivity and maintenance of these changes on the farm (Table 4). Farms with larger crop areas have no interest in entering a PES program or improving livestock practices, because the farmer may have other objectives for managing the farm.

Table 2-4. Identified variables that influence the decision making process of the farm in Esparza, Costa Rica

Variable	Description	Effects
Owner's age	Number of years that according to the survey, the farm owners report.	- 0.019*
Farm owner's address	1, if the farmer lives in the farm 0, if the farmer doesn't have a permanent dormitory in the farm	0.035*
% of work outside the farm	Incomes from other activities outside the farm	0.2975
Family labour	% of the working force developed by family members	0.0678
Hired labour	% hired labour (permanent or temporary)	0.3627
Dairy production	Milk production kg milk/cow/year	0.510*
Stocking	Number of animals/hectare	0.446*
Conservation área	Forest area and riverbanks. Measured in proportion to the farm's total size.	0.312*
Pastures without trees	Improved or natural pastures without trees. Measured in relation to the farm's total size.	0.0119*
Pastures with trees	Improved or natural pastures associated with trees that have different density levels. Measured in proportion to the farm's total size.	-0.0534*
Live fences	Lined up trees located in different spots of the farm. Measured as the proportion of living fences in meters in relation to the total area of the farm.	4.456*
Other crops	The proportion of the farm intended for agricultural production systems, fruit crops, coffee, sugar cane, etc. It is measured as the crop proportion in relation to the total area of the farm.	-2.225

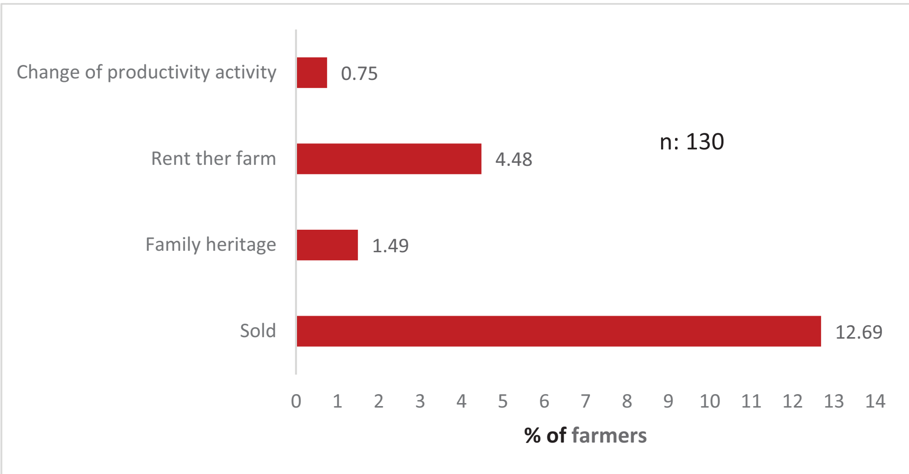
Note: Probit test of fit with significant differences P <0.05

4.1. Analysis of the lack of land in the project farms

During 2016, of the 130 farms participating in the project, but 12% of fams were sold their land. Those farms that were sold, with an average area of 30 ha were at a distance of less than 10 km from the city center of Esparza. According to the interviews, the main reason for the sale was that the farmers no longer had the same energy to continue working the farms (10 farms), and 6 farmers said they saw the opportunity to migrate to other regions of the country. The majority of the farms are located less than 10 kilometers away from Esparza (the nearest town), which favors the urbanization of the farms due to easy access.

4.5% of the producers rented their farms because it was more feasible than to keep managing the milk production, while <1% changed from milk production activities to coffee and fattening activities (Figure 3). 100 owners still live on their farms and maintain their livestock activities.

Figure 2-3. Changes in management and land tenure, in the farms participating in the GEF-SSP project, 2016



4.2. Population distribution

The members of the farming households were classified into age groups to assess the change in demographics from 2003 to 2016 (Table 5).

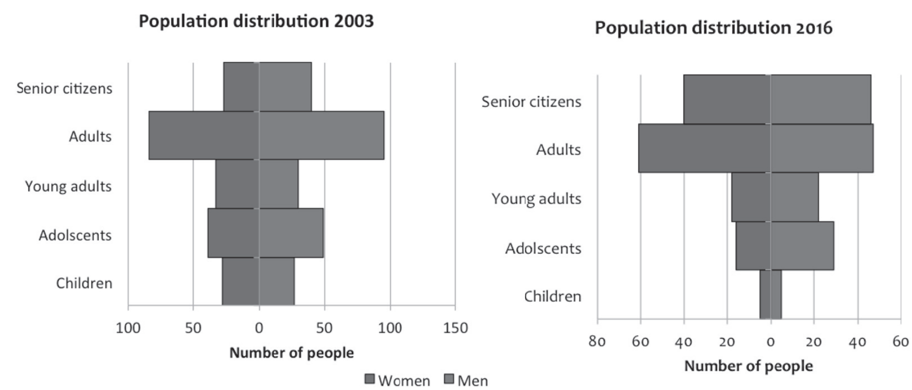
Table 2-5. Classification of years of age into age groups

Years	Age groups
0-9 years	Children
10-19 years	Adolescents
20-30 years	Young adults
31-60 years	Adults
60 + years	Senior citizens

At the beginning of the project, a population between 31-60 years old and a growing population of elderly people prevailed, while the under 30 population on the farms was growing (Figure 4). Unlike in 2016, we can see a change in the age structure of the population living on farms, with in an increase in the adult and elder population and a decrease in the population of people under 30 years.

The young population is sent to other places to continue studying in universities, technical careers or to work as employees in companies, where they can gurantee their economic sustainability once high school is over. The reason for a decrease in the population of young adults could be the rural-urban migration for the educational purpose, mainly to San Jose or the United States. The youth that leave the region for educational reasons study diverse courses, as opposed to only agriculture and livestock-related courses; upon return, they normally find employment in the central valley in countries such as Heredia, Alajuela and San Jose. They are not interested in returning to farms to work, but only to visit their families on the weekends. From the farms whose owners have died, it has been concluded that their heirs prefer to convert the farms into relaxation sites or sell the property.

Figure 2-4. Classification of members of the farming households participating in the study on basis of age in 2003 – 2016



4.3. Economic analysis

This study compares the economic efficiency of the farms before the intervention of the project in 2003 and the permanence of the project in 2016. In 2003, farms in the ‘without PES’ group had a better management system and were more cost effective than farms with PES, as they had a 12% lower OER, which can be seen in Table 6. This signifies that, on average, farms without PES had lower operating expenses and were more economically efficient. It is worth noting that the B/C ratio of farms in the PES group was better than that of farms not in the PES group: 1.2 and 0.9 respectively. Therefore, farms in the PES group had higher operating expenses per hectare, but they also had higher benefits earned per hectare. The average net income for farms with PES was US$ 219.9 per hectare and US$ 160.8 per hectare for farms without PES.

The farms in the PES group on an average had 58% of total cows in lactation with an average daily yield of 3.1 kilograms of milk per cow. At the same time, the farms without PES had an average of 61% of total cows in lactation with an average daily yield of 2.6 kilograms of milk per cow. These variables are important in evaluating the permanence of the activities promoted by the project and level of efficiency of farms. The number of animals sold by the producers in both groups has been decreasing, due to the fact that sales prices of live livestock in the area have declined from US$ 2.5/kg of meat to US$ 2.1/kg of meat, according to information obtained from Asociación de ganaderos del Pacifico (AGAINPA).

The farms have maintained the silvopastoral systems and good management practices implemented by the project in 2003. As shown in Table 6, the average net income of farms with PES is US$ 415.1 per hectare and US$ 453.7 per hectare for farms without PES in 2016. There is an 89% increase in average net income per hectare for PES farms from 2003. There has been a slight increase in average daily milk production as can be seen in Table 4, due to the continued implementation of the practices prioritized by the project. However, it is worth noting that this increase has occurred although the percentage of cows in lactation has reduced from 58% in 2003 to 53% in 2016. This result shines light on the benefits and the efficiency of the implemented practices since farms are producing more milk with fewer cows.

Table 2-6. Means of the variables socioeconomic of farms without PES and with PES for the years 2003 and 2016

Characteristics	Without PES		PES	
Year	2003	2016	2003	2016
Average Farm size (ha)	56.87 ± 16.68		38.9 ± 4.94	
Pastures (ha)	38.1 ± 11.8	39.1 ± 2.39	26 ± 3.43	25.2 ± 3.24
Conserved area (ha)	15.5 ± 4.06	15.6 ± 4.12	11.8 ±1.91	12.2 ± 2.05
Cultivated area (ha)	2.5 ± 1.35	1.5 ± 0.46	0.6 ± 0.14	1.3 ± 0.35
Dairy production (kg/cow/day)	2.6 ± 0.49	2.9 ± 0.76	3.1 ± 0.37	3.3 ± 0.4
% of lactating cows	61 ± 0.06	49 ± 0.1	58 ± 0.03	53 ± 0.05
Number of animals sold	15.11	6.83	13.13	7.9
Animal Stock (AU/has)	1.25 ± 0.13	1.35 ± 0.11	1.24 ± 0.08	1.37 ± 0.08
Cash inflow USD/has	213.8 ± 42.68	655 ± 148.35	315.3 ± 61.46	562 ± 62.06
Cash outflow USD/has	53 ± 10.98	201.3 ± 44.2	94.7 ± 28.46	147.2 ± 22.57
Net income USD/has	160.8 ± 38.44	453.7 ± 120.40	219.9 ± 56.94	415.1 ± 51.96
Operating expense ratio %	33 ± 0.05	42 ± 0.05	45 ± 0.05	32 ± 0.03
Cost benefit ratio	1,2 ± 0.08	0.9 ± 0.03	1.4 ± 0.19	1,1 ± 0.37

Another important result from this economic analysis is that the operating expense ratio for the PES group has decreased from 45% in 2003 to 32% in 2016, whereas the operating expense for the without PES group has increased from 33% in 2003 to 42% in 2016. This is a key result in this analysis, as it shows that the operating expenses have reduced significantly in farms with PES due to the implemented practices and that the farms are being more efficiently managed than farms without PES. The analysis of benefit cost ratios also concludes the effectiveness of the implemented practices, as farms with PES have a B/C ratio of 1.1 compared to 0.9 for farms without PES. This signifies that farms with PES are earning more benefits compared to farms without PES. This result reiterates the results of the OER analysis that the implemented practices have resulted in a more efficient management of farms in the PES group. However, it is also worth noting that the B/C ratio has increased from 1.2 in 2003 to 5.2 in 2016 for farms with PES. The same trend is seen for the farms without PES, whose B/C ratio has decreased from 4.4 in 2003 to 3.7 in 2016. These results point out the decreasing economic viability of the livestock sector, as Table 2 shows that the percentage of lactating cows has reduced by 12% for farms without PES and 6% for PES farms in 2016.

These findings are coherent with the findings of Dass et al. (2016) who confirm that in spite of changing feeding methods, animal populations eventually decline. This decline in the number of lactating cows makes livestock activities less profitable. This is evident from this study, as there were 130 participating farmers in 2003 and during the last five years, 14% have sold their farms, 3% have giften farms as inheritance and the owners are developing new strategies and shifting to more cost efficient activities.

However, it is worth noting that there is an improvement in the management of farms with PES, which have implemented silvopastoral systems and good management practices, as their OER has decreased. This analysis concludes that farms with PES that implemented SPS and good management practices in 2003 are more cost efficient and have a better management system than farms without PES that did not implement SPS and good management practices.

4.4. Land use changes between 2003-2007

The farms both with PES and without PES cover 3728 hectares (Table 7), of which in 2003, 41% belonged to pastures without trees, the area of degraded pastures was 17%. Forest cover was present in 27.5% of the area. In the case of perennial and semi-perennial crops, less than 5% of the area devoted to these uses was found.

Table 2-7. Total area in hectares of land uses on farms with PES and without PES, in the nine categories of land use

Land uses	2003 Baseline (ha)	2003-2007 Period		2007-2016 Period	
		Gain	Loss	Gain	Loss
Annual crop	20.6	2.7			-31
Degraded Pasture	607.5		-433.2		-384
Fodder bank & SPS intensive	18.4	9.7		20.9	
Pasture with tree	331.5	636.8		55.8	
Pasture without tree	1520.3		-231.3		-56.0
Perennial crop	83.0		-17.3	6.8	
Secondary forest succession	67.1	3.8		15.9	
Forest	1024.8	33.9			-3.2
Other	54.8		-5.1	1.3	
Total	3728	687.0	-687.0	99.4	-97.5
Live fences (km)					
Simple	208	29			-4.9
Multiestrata	0	212		12,9	

For the period 2003 to 2007, the most degraded land uses were the untreated and degraded pastures, reducing by 15% and 71%, respectively (Table 7). This reduction resulted in an increase in pastures with trees. The remaining uses increased to a lesser extent. For the period 2007 to 2016, pastures without trees and degraded pastures continued to decline and the area released by this use is converted primarily to pastures with trees and fodder banks as a strategy to improve feeding during the critical period (dry seasons).

For pasture management, farmers have been encouraged to increase the division of paddocks by using live fences, and live fences; live gences mainly multistate living fences, increased during the period of implementation of the project (2003-2007). In the period 2007-2016, producers continued to increase multistate live fences, but at a lower rate than observed during the project.

4.5. Influence of PES for the adoption of good practices friendly to the environment

The payment for environmental services showed a positive influence on the adoption of silvopastoral practices during the payment period (Figure 5). It is evident that the incorporation of trees in the pastures was influenced by the payment of environmental services during the period of the project. At the same time it influenced the other practices developed in the region, such as the increase of live fences on farms (Figure 6). These results are similar to those found in the study of adoption of environmentally friendly land uses, carried out for the same project in Nicaragua (Cerrud 2005; Pagiola et al., 2010).

Figure 2-5. Dynamics of land use change 2007-2003 (%), on farms of livestock producers with PES and control group in Esparza, Costa Rica

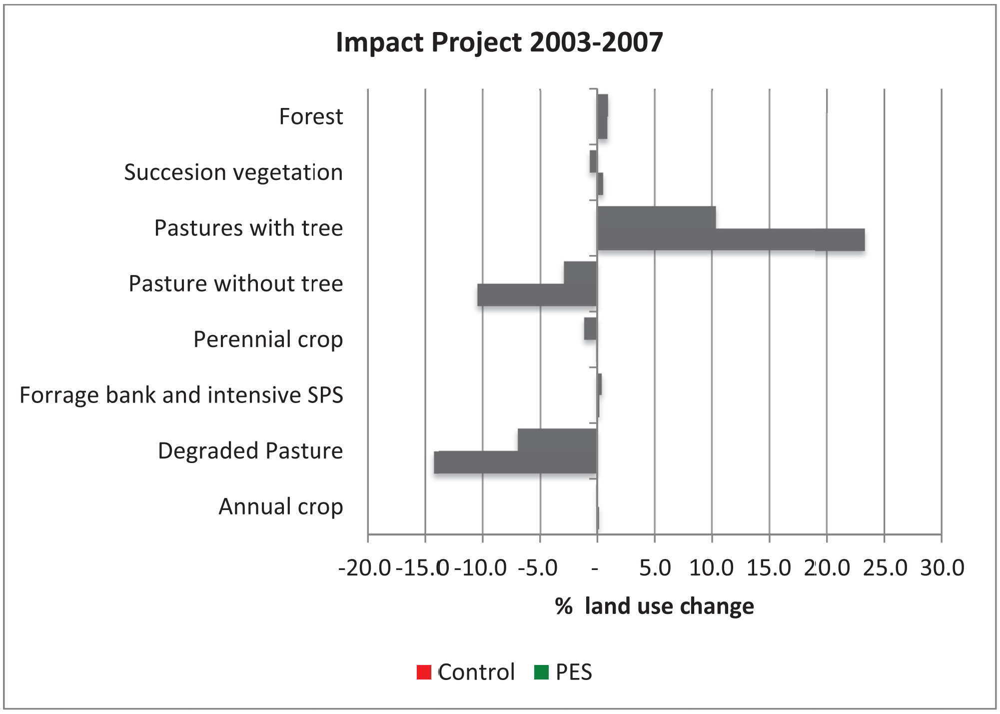
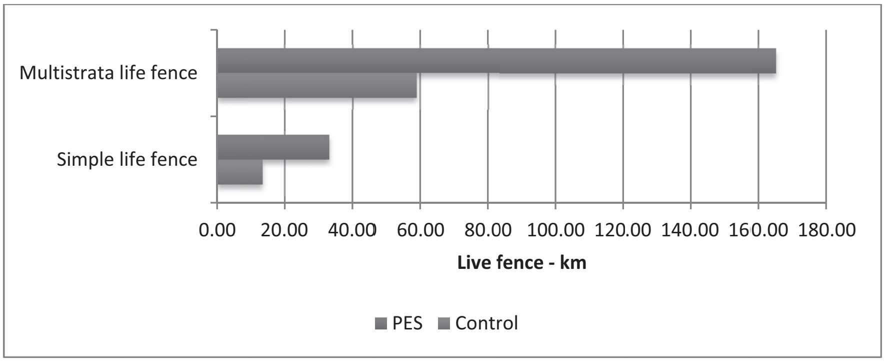
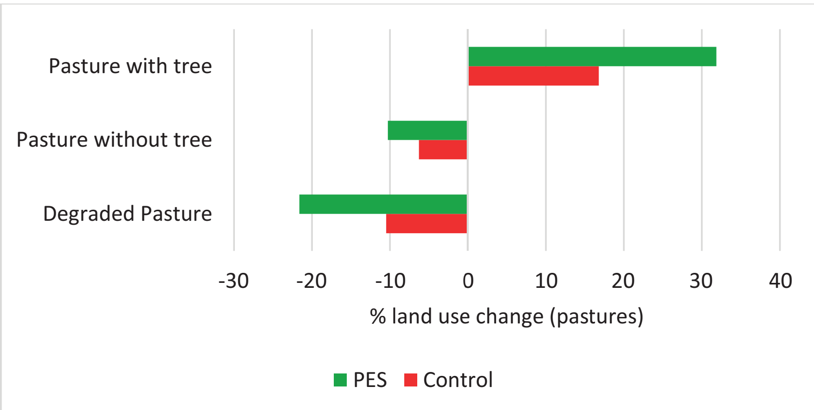


Figure 2-6. Increase of live fences on livestock farms during the project implementation period (2003-2007) in Esparza, Costa Rica



The main changes in land use made by the producers were from degraded pastures and monoculture to pastures with trees dispersed in pasture (Figure 7). This major technological change is due to the fact that pasture change and partnership with silvopastoral technology contribute to improved farm productivity, biodiversity conservation and the generation of ecosystem services, as long as they are well managed and avoid overgrazing (Ibrahim et al. 2011). This positively impacted the PES for the adoption of this silvopastoral technology during the project implementation period ($p < 0.05$).

Figure 2-7. Dynamics of land use change 2007-2003 (%), on farms of livestock producers with PES and control group in Esparza, Costa Rica

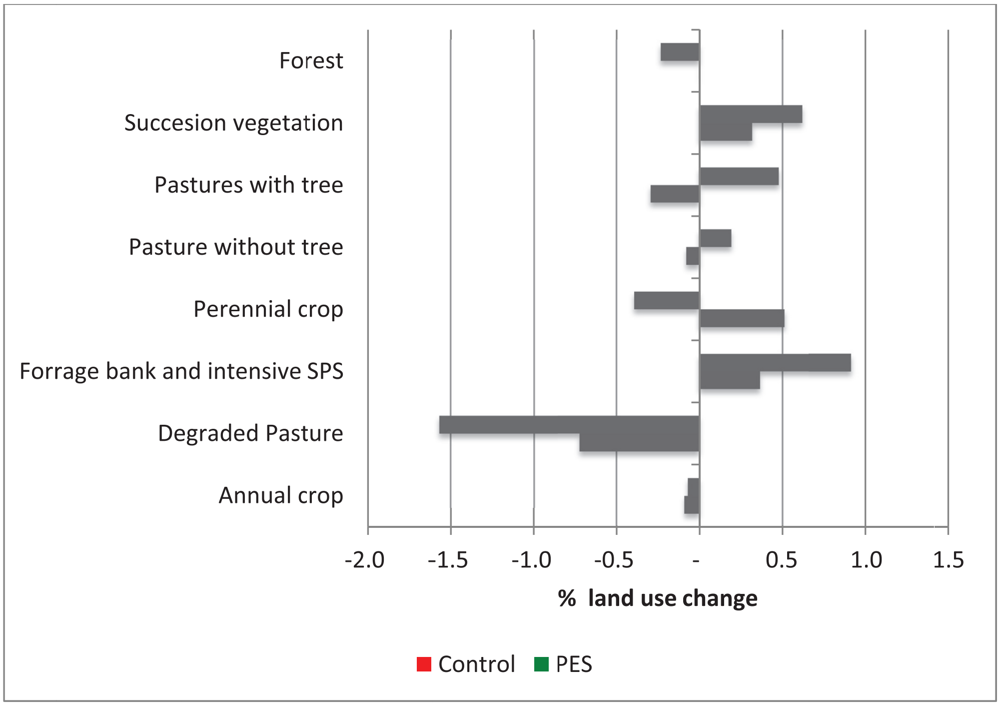


4.6. Land use changes between 2007-2016

The analysis of the permanence of changes in land use on farms shows that during the period 2007-2016, it is evident that the producers maintained the changes in land use that were generated with the project, mainly in the adoption of pastures with dispersed trees and live fences, which were implemented with the support of the PES. These silvopastoral systems have been maintained in the farms, and can be attributed to the PES for its establishment. However, their permanence in the farms can be more related to the benefits of the system for the productivity of the farm; this then improves the well-being of the animals by the shade produced in the systems and, improves the quality of the feeding, which influences the increase of milk and meat production in the farm (Ibrahim et al., 2011).

Thus, if the producers are given an incentive in the first stage of implementing good practices and if the producers show changes in the social and economic benefits, they can be maintained the practices over time and at the same time can continue to generate changes associated to further improve farm productivity (Figure 8).

Figure 2-8. Dynamics of land use change 2016-2007 (%), on farms of livestock producers with PES and control group in Esparza, Costa Rica



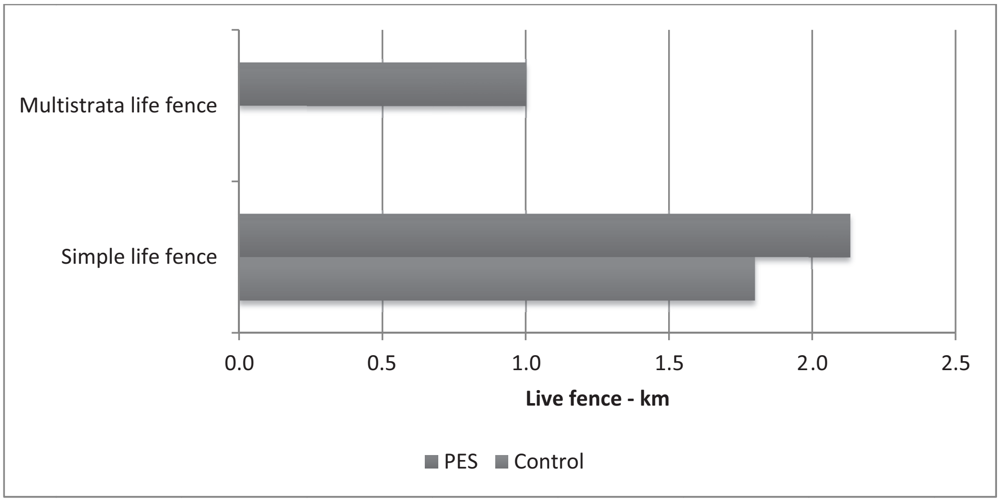
During the period 2007-2016, once the project was completed, the producers maintained the practices and continued reducing the areas of degraded pastures and without trees, at a lower rate of change than when the payment was finalized. This may imply that farmers can improve the investment in the farm to advance the adoption of good livestock practices on the farm whenever they have an incentive.

Likewise, other projects such as CADETI "Sustainable Livestock in the Jesus Maria River Basin" have been introduced in the area once the project was completed, which favored the implementation of other silvopastoral systems such as woody forage banks, which favor the improvement of adaptation strategies to climate change. However, this practice is difficult to adopt when it has short-term projects (<4 years), since the producer prefers to implement practices that do not require much investment and labor, such as the management of perennial banks, a system that increases the labor force by its demands in the establishment and management of the system. The adoption of this type of system is more related to types of incentives other than the PES, such as credit and technical assistance provided by institutions such as the Ministry of Agriculture and Livestock (MAG) in the region. Since 2014, the use of banks woody forage in the region (Ing Carlos Barbosas – MAG comper.) has been promoted. This favors the reduction of economic barriers to the establishment of this SSP, since the establishment costs are very high (Holguín and Ibrahim 2005). It also favors to improve animal productivity and production of milk, thus, generating a greater economic benefit for the farm (Ramírez et al., 2005).

Live fences are the most adopted technology by the producers and the least problem presented in the establishment and maintenance (Figure 9). Producers participating in and receiving PES from the project increased the length of live fences, which contributes to increasing the connectivity of landscapes and generating appropriate environments for the conservation of biodiversity (Tobar and Ibrahim 2010). On the other hand, producers without credit increased fences to a lesser extent (Figure 9).

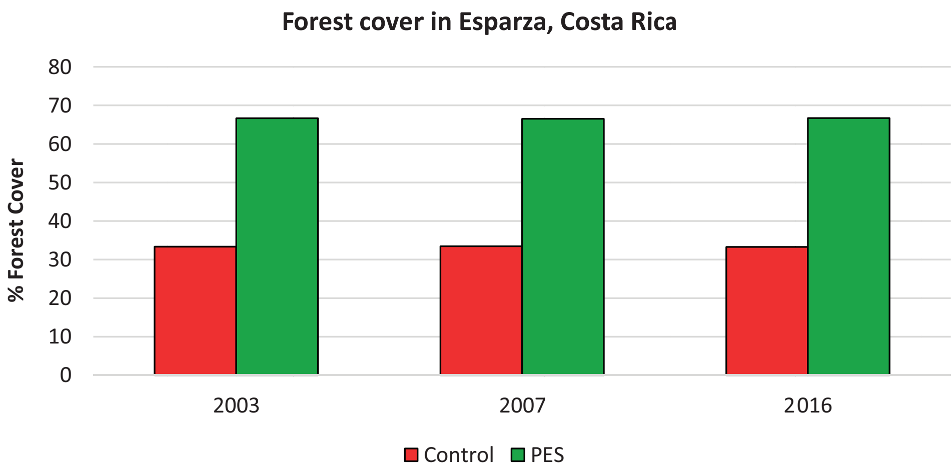
The management of this system in the permanence of these systems (2007-2016) shows that the producers have maintained these systems; further, the establishment or increase of new fences have been in less proportion during this period. Within this period, the simple live fences have pre-dominated in the system, in that, the most appropriate form of establishment is the vegetative form (living post of 2m of act), because the care in the stage of establishment and the losses associated by the damage of the livestock are smaller in comparison to the establishment of seedlings. Therefore, this can influence the adoption and above all the permanence of the system (Figure 9).

Figure 2-9. Increase of live fences on livestock farms during the period of the project (2016-2007) in Esparza, Costa Rica



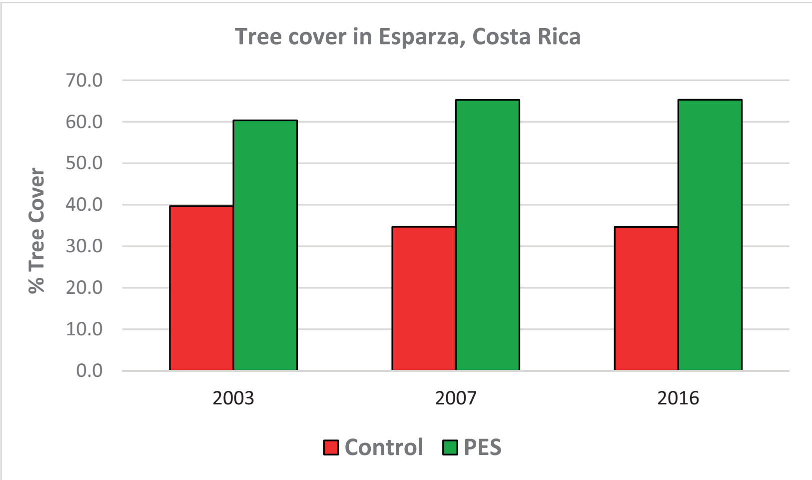
Forest Areas (secondary, riparian, and secondary forests) have remained stable during the beginning of the project, indicating that producers have favored forest protection by preventing the entry of animals and some producers have planted trees in the rivers and streams (Figure 10). Among the benefits of protecting forest remnants on the farm, they are directed as a strategy to adapt to climate change, mainly to help conserve on water sources, to supply water to the animals and to consume water on the farm. However, the analysis did not show an impact of the PES for the protection of forest remnants. It is important to mention that the payment of conservation for this land use was made only once in the year 2003. What has been shown in the analysis is that the PES has favored that the producers maintain the forest areas in the farms.

Figure 2-10. Forest cover during the period 2003-2007 and 2007-2016 on farms of livestock producers with PES and control group in Esparza, Costa Rica



One of the relevant points in this study is that the farms maintain the forest cover, and an impact of PES was evidenced in the increasement of the tree cover (total area of forest and trees in the pastures) on the farms during 2003-2007, whereas the permanence has been positive in the period 2007-2016. Tree cover has remained within the last 10 years in the case of PES farms, while for control farms, during the period 2003-2007, a negative impact on the tree cover was identified (Test Probit: -0.609 $p < 0.05$). A 5% reduction of the tree cover was present in those farms, while in the period of 2007-2016, the tree cover remained stable (Figure 11). This shows that the payment for environmental services is an incentive that promotes the maintenance of the tree cover and the permanence of the same once the payment is finalized.

Figure 2-11. Tree cover during the period 2003-2007 and 2007-2016 on farms of livestock producers with PES and control group in Esparza, Costa Rica



5. EVALUATION OF CHANGES IN LAND USE IN CATTLE FARMS

During the implementation period of the project, it was appreciated that the increase in tree cover in the pasture areas of the farms has been a benefit of the PES during the 2003-3007 period, which favored the increase of tree cover in the farms. It is shown that the incentive provided by the project has contributed to increasing the tree cover in the farms participating in the project; similar results were appreciated by Guzmán (2006). The impact of coverage on each land use is presented in Table 8.

Table 2-8. Changes in the soil uses of PES producers and control between the years 2003-2007 by means of G fit test

	Farm with PES		Control	
Independent Variables	Pr (>Chi)	Impact	Pr (>Chi)	Impact
Live fences	<0.0001	+	0.1236	ND
Degraded pastures	<0.0001	-	<0.0001	-
Improved pastures with trees	<0.0001	+	No-D*	ND
Improved pastures without trees	<0.0001	+	<0.0001	+

Note: No-D: there are no changes in land uses.

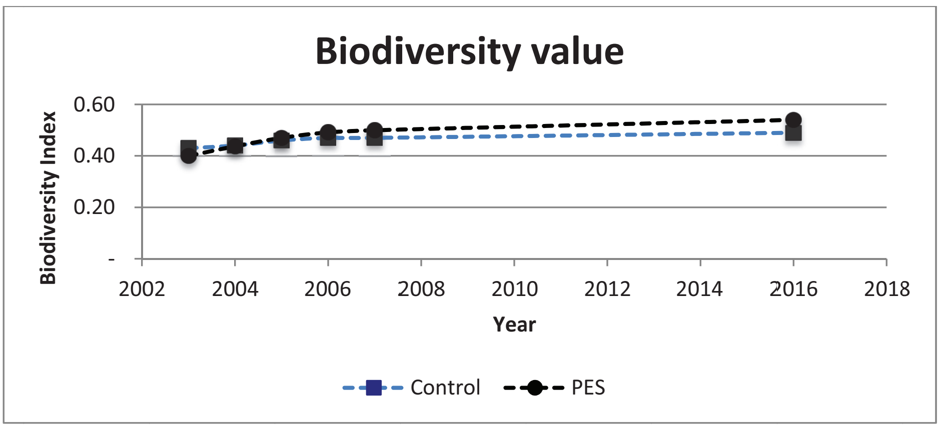
Pastures with dispersed trees had a positive impact on PES farms (Table 7), which contributes to improved farm productivity, animal comfort (shade for livestock), and diversification of farm production (Betancourt 2003). On the other hand, the control group changed at a slower rate.

6. ANALYSIS OF THE GENERATION OF ECOSYSTEM SERVICES

Biodiversity conservation

The farms with PES, with Biodiversity value index presented an increase in the index of biodiversity, which is associated with the increase of tree cover in the production systems; this favors to improve the habitat conditions in these systems, providing a better opportunity for the conservation of the fauna and flora in the region. Mainly, the increase in the biodiversity value index is associated with changes in land use during the period 2003-2007 (Figure 12). The most important changes were the reduction of the percentage of the total area of degraded pastures and pastures without trees. The increase of the improved pasture with trees and the simple and multistate live fences, improves the biological connectivity and the habitat generation for the fauna and wild flora; furthermore, the conservation value has been increased in the farms with PES.

Figure 2-12. Dynamics of biodiversity value index between 2003-2007 - 2016, on PES and non PES farms in Esparza, Costa Rica



Carbon stock

Changes in above-ground biomass carbon stock during 2003-2007 and 2007-2016 were caused by changes in land uses from systems with zero or low tree cover to systems with a higher tree cover. The estimation was carried out considering carbon stocks in the baseline reported in 2003 and an increment of carbon due to land use changes that promote an increase in carbon stock in above-ground biomass stock in 2007 and 2016. This comparison was based on carbon fluxes from registered land uses in each cattle farm in order to estimate the impact of good practices, silvopastoral systems and the payments for environmental services on carbon removals.

The baseline study was developed based on estimations from Ibrahim et al. (2007), who estimated the carbon storage and fixation using the mean age of the components in land uses in the cattle farms (Table 9).

Table 2-9. Above-ground biomass carbon stock and carbon fixation estimated in the different land uses, expressed in CO2e (Ibrahim et al. 2007)

Land use	Average age	Above-ground biomass (MgC02e/ha)	Carbon flow (Mg CO2e/ha/yr)
Degraded Pasture	5	13.9	-0.11
Naturalized pasture without tree	15	16.2	0.15
Impoved pasture without tree	12	18.2	1.47
Naturalized pasture with low tree density	10	29.7	4.33
Improved pasture with low tree density	11	47.8	5.76
Naturalized pasture with high tree density	15	93.2	9.54
Improved pasture with high tree density	10	103.2	10.64
Succesion vegetation	10	172.5	8.84
Forest Plantation	7	348.3	12.48
Riparian forest	50	561.6	5.36
Secondary forest	30	310.1	6.57
Secondary forest (intervened)	30	284.9	7.45
Other use	-	-	-

Changes in carbon stocks during project adoption (2003-2007)

During the period 2003-2007, the changes in carbon stock in above-ground biomass consisted of land use change with little or no tree cover to another land use with greater tree cover (i.e. pastures with trees). The estimation was done in a static model to show how the land use changes reported in 2003 changed the carbon stock in aboveground biomass in 2007. The comparison showed that land uses changes in Esparza generate changes in the carbon stock, based on the removal of CO2e that could be presented during the 4 years that the project lasted. It was appreciated that the greatest increase was due to the changes of degraded pastures and pastures without trees to pastures with trees. In general, the increase in carbon stock was higher in the farms with PES (Table 10).

In 2003, the aboveground carbon stocks were estimated at 218.2 Gg CO_2e and at 363.8 Gg CO_2e in the control and PES farms, respectively; in 2007, it was 226.9 Gg CO_2e and 379.6 Gg CO_2e in the control and PES farms, respectively (Table 10). This represents an increase in the carbon storage between 3.5 and 4.5% caused by PES in farms (Table 9).

It was found that farms with PES have a significant ($p < 0.05$) impact on the carbon storage during the payment period. The increasement is greater in the farms with PES, because the analysis developed by the project showed that the payment for ecosystem services was incremental, in major change is that the monoculture grass to other uses of the soil with diversity of tree covers, where the farms with PES developed more changes than the control farms. The incremental contribution in the carbon stocks was the relationship regarding the increase of the area of the land uses with greater coverage of trees such as pastures with trees of a high tree density (>30 trees/ha) and conservation of forest areas on farms (Villanueva et al. 2011).

Table 2-10. Changes in carbon stock in above-ground biomass in 13 land uses registered in baseline (2003) and 2007 in livestock farms in Esparza, Costa Rica

	2003		**Above-ground carbon stocks (MgCO2e/ha)**		**2007**		**Aboveground carbon stocks (MgCO2e/ha)**		**Dif. 2007-2003 (MgCO2e/ha)**	
Land Uses	Control	PES	Control	PES	Control	PES	Control	PES	Control	PES
Degraded Pasture	166.58	440.93	2.323.17	6.149.24	72.77	101.499	2.315.16	6.138.07	-8.00	-11.16
Naturalized pasture without tree	21.54	221.55	347.86	3.577.59	0.30	2.973	347.91	3.578.04	0.05	0.45
Impoved pasture without tree	27.79	38.94	506.80	710.26	8.97	9.644	519.98	724.44	13.18	14.18
Naturalized pasture with low tree density	179.44	591.94	5.327.48	17.574.82	52.05	181.923	5,552.86	18,362.54	225.39	787.73
Improved pasture with low tree density	306.92	132.23	14.665.54	6.318.59	420.79	612.408	17,089.28	9,846.06	2,423.74	3,527.47
Naturalized pasture with high tree density	62.58	98.72	5.833.86	9.202.76	32.27	110.428	6,141.75	1,.256.24	307.88	1,053.48
Improved pasture with high tree density	133.81	36.40	13.799.01	3.753.41	317.06	508.561	17,172.50	9,164.50	3,373.49	5,411.09
Succesion vegetation	26.63	40.44	4.591.74	6.974.18	18.06	52.829	4,751.37	7,441.19	159.62	467.01
Forest Plantation	18.11	21.73	6.307.41	7.568.54	19.41	29.712	6,549.58	7,939.34	242.17	370.81
Riparian forest	261.74	409.00	146.997.88	229.702.06	263.54	390.167	148,410.46	231,793.35	1,412.57	2,091.30
Secondary forest	0.77	22.85	239.72	7,085.51	8.03	52.026	292.47	7,427.32	52.75	341.81
Secondary forest (inter-vened)	60.62	228.90	17,270.48	65,213.24	62.71	231.013	17,737.63	66,934.28	467.15	1,721.05
Other use	80.52	97.33	-	-	71.09	97.77	-	-	-	-
Total general	1,347.04	2,380.96	218,210.94	363,830.19	1,347.04	2380.956	226,880.94	379,605.38	8,670.00	15,775.19

Changes in carbon stock during project stay (2007-2016)

Changes in carbon stock in above-ground biomass during 2007-2016 were in a lower proportion than those developed during the project adoption or implementation (2003-2007). The farmers switched the pastures without trees to a silvopastoral system because they were paid for the ecosystem services. At the end of the project, the farmers' conversion of pastures without trees and the land uses' changes were emphasized for the improvement of the feeding of cattle (fodder banks) and other systems such as the production of a coffee plantation. By 2016, the carbon stock increases were carried out in pastures with trees and forest cover, and the areas under extension that remains to be a low tree density improved pasture, both for the control farms and PES farms (Table 11). The increasement of carbon stock in the period 2007-2016 was similar to the period 2003-2007. The amounts had been between 3.8 % and 4.1% for control and PES farms, respectively. After PES payment, the positive impact was recorded in the carbon stock for PES farms ($p < 0.05$). This could be related to the fact that the practices that implemented with the project obtained benefits in the maintenance or increasing milk and meat production, as is the case of the increment of the improved pastures with high and low density of trees (Table 11). The same follows suit for the maintenance of the areas of forest cover. With this results, it is evident that the changes in land use made by the farmer play s significant role in the provision of this ecosystem service.

Table 2-11. Changes in carbon stock in above-ground biomass in 13 land uses registered in 2007 and 2016 in livestock farms in Esparza, Costa Rica

	2007		**Aboveground carbon stocks (MgCO2e/ha)**		**2016**		**Aboveground carbon stocks (MgCO2e/ha)**		**Dif. (2007-2016) (MgCO2e/ha)**	
USONAME	Control	PES	Control	PES	Control	PES	Control	PES	Control	PES
Degraded Pasture	72.77	101.499	2,315.16	6,138.07	51.64	84.28	2,309.48	6,128.80	-5.68	-9.27
Naturalized pasture without tree	0.30	2.973	347.91	3,578.04	0.27	1.09	347.95	3,578.20	0.04	0.16
Impoved pasture without tree	8.97	9.644	519.98	724.44	11.59	9.33	537.02	738.15	17.04	13.71
Naturalized pasture with low tree density	52.05	181.923	5,552.86	18,362.54	44.21	111.31	5,744.29	18,844.51	191.43	481.97
Improved pasture with low tree density	420.79	612.408	17,089.28	9,846.06	414.49	640.75	19,476.74	13,536.80	2,387.46	3,690.74
Naturalized pasture with high tree density	32.27	110.428	6,141.75	10,256.24	16.31	114.21	6,297.33	11,345.77	155.59	1,089.53
Improved pasture with high tree density	317.06	508.561	17,172.50	9,164.50	353.58	539.99	20,934.57	14,910.01	3,762.08	5,745.51
Succesion vegeta-tion	18.06	52.829	4,751.37	7,441.19	26.38	60.37	4,984.59	7,974.85	233.22	533.66
Forest Plantation	19.41	29.712	6,549.58	7,939.34	14.77	31.39	6,733.97	8,331.14	184.39	391.79
Riparian forest	263.54	390.167	148,410.46	231,793.35	263.72	387.32	149,823.98	233,869.37	1,413.52	2,076.01
Secondary forest	8.03	52.026	292.47	7,427.32	8.03	52.03	345.22	7,769.13	52.75	341.81
Secondary forest (intervened)	62.71	231.013	17,737.63	66,934.28	62.70	231.01	18,204.78	68,655.31	467.15	1,721.02
Other use	71.09	97.77	-	-	79.34	117.88	-	-	-	-
Total general	1,347.04	2,380.956	226,880.94	379,605.38	1,347.04	2,380.95	235,739.93	395,682.02	8,858.99	16,076.64

7. SUMMARY OF THE RESULTS

The impacts of PES on tree coverage have been very positive; the changes that have been made by producers have been maintained. There is a concern on the part of the producers nowadays for the water resource and the climate that is affecting their production; they are conscious that they must protect their farms' resources. To follow up changes in land use and to encourage them to continue to make changes, farmers have the potential to be able to work with other incentives such as soft loans that will allow them to continue to make changes and improve the productivity of the farm.The PES was important for producers to make changes in their technologies on farms, appreciating that the technology mostly implemented by producers was to disperse trees in pastures, which favors maintenance and increases productivity and profitability on the farm in the 2003-2007 period. In the 2007-2016 period, producers maintained the changes made with the project and started to implement other practices that the sustainability of the farms, such as fodder banks. However, these changes are not associated with the project. These are other initiatives that are currently in the region, including the sustainable livestock project CADETI. The technological changes have favored the increase of productivity on farms. Nonetheless, the increases in the production costs and the low prices of milk in the country have forced farms to invest more, which sometimes hinderss them from retaining enough to maintain their livestock activities.

Forest management practice for enhancing carbon sequestration in national forests of Korea

Chapter 3

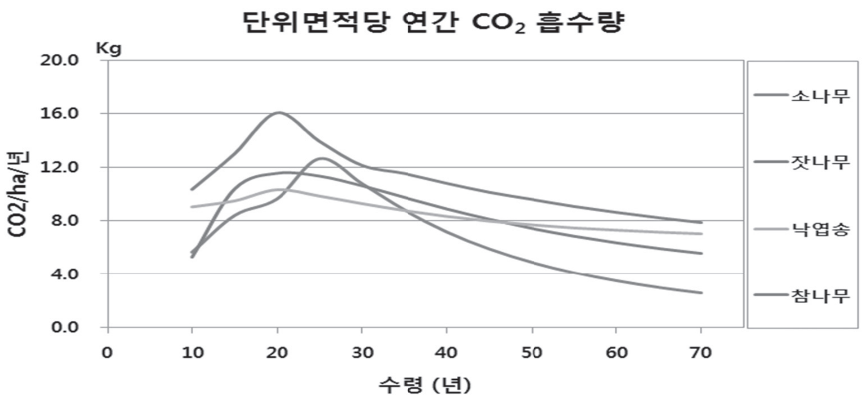
1. RESEARCH BACKGROUND

Recently, climate change has been one of the most urgent and profound issues in Korea. Current development of policy in the field of climate change is evidence of this. In Korea, the new agreement, held in Paris 2015, has sparked renewed interest in climate change. The Paris agreement is a new global climate change regime to correct the limitations of the Kyoto Protocol, which puts binding obligations of GHG emission on developed countries (Sungjin Kim 2015). GHG in the atmosphere such as carbon dioxide has become known as a major cause of climate change. Korea ratified the Paris agreement in 2016, becoming the eighth country to endorse the international agreement on reducing GHG emissions (Yonhap News Agency 2017). The Korean government announced the new roadmap of GHG reduction target on July 20, 2015, to meet new global GHG emission standards of the Paris agreement. Specifically, Korea needs to cut GHG emission by 37 % from BAU (Business as usual) until the year 2030, which is equivalent to the reduction from an estimated BAU of 850.6mtCO_2 in 2030 to 536mtCO_2 (Kim 2015). The Korean government has a plan to fulfill the 37% reduction target through domestic (25.7%) policies and international cooperation systems such as REDD+ (11.3%) (Greenhouse Gas Inventory & Research Center of Korea 2015). Korea is the world's 9th-largest energy consumer, and the heavy dependency on fossil fuels makes Korea the world's 7th largest GHG emitter (Kim 2015). From now on, Korea is no longer free from the obligation of GHG reduction and needs to seek for an efficient way to fulfill these new global standards.

Under the new Paris' agreement, the mechanisms for achieving the new global GHG emission goal are the major subject of policy development for both developing and developed countries. Thus, policy makers are widely concerned about marketable approaches such as cap-and-trade, but there are several challenges at hand, including verification, additionality, and permanence criteria (see Table 1 in Appendix) (Fahey et al. 2010) for stimulating market table approach as carbon offsets. These perspectives have generated new interests in strategies to offset GHG emissions by storing carbon in forests (U.S. Forest Service 1992). Recent evidence suggests that forests are crucial to solving climate change (WWF 2015; van Noordwijk et al. 2008; EPA 2013). The forest carbon pool is the largest terrestrial reservoir, holding more than 3/4 of all above ground terrestrial carbon (IPCC 2000). According to EPA (U.S. Environmental Protection Agency) (2014), the net CO_2 removal from the Land Use, Land-Use Change, and Forestry (LULUCF) sector offset approximately 11 percent of total U.S. GHG emission, in 2014. In the past few decades, the world's forests have sequestrated 30% of annual global anthropogenic CO_2 emission (Bellassen and Luyssaert 2014). Forests can also reduce the amount of GHG in the atmosphere by increasing biomass accumulation (U.S. Forest Service 1992). Forest stand age is a major factor in the carbon sequestration rate (Fahey et al. 2010). Young, growing forests sequestrate CO_2 at high rates, while carbon uptake in mature forests is balanced by CO_2 released from decaying vegetation (U.S. Forest Service 1992). Trees sequestrate CO_2 at a maximum rate between ages 20-30. According to the previous research, forests at age 30 years sequestrate about 200 to 520 tons of CO_2 per ha with productivity ranging from low to high (Australian Government 2008)

This study introduces a forest management scheme to determine efficient way for enhancing carbon sequestration in forests. The relationship between forest and carbon in the atmosphere provides us opportunities to manage forests in ways that would result in storage of additional carbon (U.S. Forest Service 1992). Forests in Korea store approximately 55 million tons of CO_2, which is about 0.08% of all the carbon stored in Asia's forests (Reich 2013). Forest management can increase total carbon sequestration by changing the amount of carbon stored in forests; this is accomplished by managing for optimum tree stocking in forest land (Fahey et al. 2010). Therefore, enhancing carbon sink through appropriate forest management may enable countries to save time until they can develop innovative emission reduction technologies. The role of forests in carbon sequestration might seem straightforward since trees capture carbon as they grow (American Hardwood Expert Council 2012). Forests have multiple roles to play in climate change, and forest management can help to optimize those roles (Bowyer et al. 2011). Many recent studies show that a policy of active and responsible forest management is more effective in enhancing carbon sequestration in forests than a policy of hands-off management that precludes periodic harvests (Fahey et al. 2010; Lippke et al. 2011; Perez-Garcia et al. 2007). Young, healthy trees are important carbon reservoirs. The general rule is that total forest carbon sink is increases with tree volume, while net carbon sink, inferred from changes in storage, sharply decreases with age (Bradford and Kastendick 2010). Although there is variability among species, net carbon storage decline in trees generally occurs between ages 20 and 30 for major Korean tree species (see Figure 1). After this age, if the trees are not harvested, the sequestration rate decreases gradually until maturity at forest age 80 to 100 (Johnson and Coburn 2010). Thus, a harvest strategy focused on increasing forest stocks only works in short-term and misses opportunities for greater carbon mitigation in the long term (American Hardwood Expert Council 2012).

Figure 3-1 Annual CO_2 Sequestration per Unit area (ha)



Source: Korea Forest Service.

To seek for sustainable forest management strategies, the concept of a normal forest provides a good starting point. The term "normal forest" is a concept of an ideal forest that provides an even flow of timber volume harvested in each period (Amacher, Ollikainen, and Koskela 2009). In the history of forest policy, the concept of a normal forest has been sought in order to meet the needs of forest industries supplying wood or ensuring the stability of local communities that depend on wood-based revenues (Amacher, Ollikainen, and Koskela 2009). The objective of this study is to develop forest planning to move toward desired conditions for age class distribution and maximize the revenue and carbon sequestration from unit forest area. Forest age-class distribution has played an important role in achieving long-term sustainability and improving forest health (U.S. Forest Service 2007). To move toward a better distribution of age class across the forestland, this study introduces methods of forest regulation using linear programming (LP); considering both economic profit and environmental benefit from carbon sequestration. In this study, we utilize the concept of a normal forest for managing forest carbon sequestration to answer the following research questions:

1. What is the optimal rotation and forest planning horizon for managing forests to increase carbon storage in them?
2. How could forest management, regulating forest age distribution in particular, could enhance total carbon sequestration in forests?
3. What is the optimal forest management planning process considering financial benefit from wood products and carbon stocks in standing trees?

Attaining the normal forest was the direct or indirect goal of forest management in classical approaches. However, the limitation was that they were only focused on timber-oriented silviculture. Forest management problems are complex due to complicated interaction between different components of the forest and diversity of values associated with natural resources such as carbon sequestration and biodiversity (Buongiorno and Gilless 2003). Thus, considering environmental impacts is mandated for all forest management schemes. Mathematical programming techniques including linear and non-linear programing, integer programing and other alternatives are used for developing complex forest management plans. Applying mathematical approaches on forest management has several advantages, because it allows forest managers to solve complex problems related to hundreds of management areas. Moreover, it will provide scientific evidence to policy makers who would like to develop the long-term national forest outlook. The mathematical approaches are used in a wide range of forest management problems including sustainable yields of products, maintaining optimal habitation mixes, minimizing road-build costs, and even selecting biodiversity reserve locations (McDill E 1999). In this study, we formulate a forest harvest schedule using linear program (LP). The LP is suitable for establishing forest management planning because it can incorporate multiple decision criteria in the model. Therefore, many agencies such as, the Forest Service, U. S. Department of Agriculture in particular, often use the LP package for their timber management planning to calculate the potential yield under forest regulation (Field 1978). The purpose of the LP model in this study is to derive harvest scheduling that maximizes the discounted profits from the forest considering carbon sequestration in trees. Carbon sequestration has become a crucial ecological service that forests provide due to increasing attention to global climate change. The forest owners can gain profits from harvest; however, loss of carbon storage caused by forest cutting activities can generate additional harvesting costs. We hereby introduce a profit maximization formula, which incorporates the benefit and cost of harvest considering cutting-related loss of live trees. The goal of this study maybe to achieve 'sustainable forest management' over one rotation. Sustainable forest management will provide integrated benefits such as providing economic advantage to local livelihood and mitigating some of the effects of climate change (LEDS GP 2016).

The major research area is the national forest in Korea. The target specie is red pine (*Pinus densiflora*), which is one of the major forest types in Korea and covers about 40% of the total forest areas (Table 1). We only concern about national forest to avoid problems related to complicated ownership, but the methodology will be expanded to include private forests in the future research.

Table 3-1. Relative extents of different types of Korean forests

Forest Type	Ownership	Area (ha)	Percent of total forest area
Total Forests	Total	6,165,470	100%
	National	1,248,449	20.25%
	Private	4,917,021	79.75%
Red Pine	Total	2,412,340	39.13%
	National	488,476	7.92%
	Private	1,923,864	31.20%
Korean Pine	Total	235,147	3.81%
	National	47,615	0.77%
	Private	187,532	3.04%
Pitch Pine (Pinus rigida)	Total	312,469	5.07%
	National	63,272	1.03%
	Private	249,197	4.04%
Japanese Larch	Total	281,076	4.56%
	National	56,915	0.92%
	Private	224,161	3.64%
Japanese cedar	Total	17,954	0.29%
	National	3,636	0.06%
	Private	14,318	0.23%
Hinoki cypress	Total	277,873	4.51%
	National	56,267	0.91%
	Private	221,606	3.59%

Oak	Total	1,068,342	17.33%
	National	216,329	3.51%
	Private	852,013	13.82%
Populus	Total	4,418	0.07%
	National	895	0.01%
	Private	3,523	0.06%
Other Broad leaf trees	Total	1,394,741	22.62%
	National	282,422	4.58%
	Private	1,112,319	18.04%
Others	Total	161,110	2.61%
	National	32,623	0.53%
	Private	128,487	2.08%

Source: Korea Forest Service.

2. THE PROFIT MAXIMIZING HARVEST SCHEDULING MODEL

2.1. Harvest planning period

A profit maximizing harvest scheduling model using linear programing developed by McDill (1999) is useful to derive the optimum harvest schedule; as such, this study applied McDill's approach for maximizing the harvest profit but we modified several equations for our objective function. We assume some finite period of forest management schedules including 50 years, 60 years and 70 years planning horizon considering 10 years planning periods since we use ten years age-class in the target forests. To simplify the model, we assume all forest management activities (harvests) are going to take place at the same time during a given planning period. The harvests occur at the midpoint of the period. For example, if they are scheduled for period 1, all harvests are assumed to occur in year 5, in year 15 for period 2… respectively. The general rule to set the length of the planning horizon is that the planning horizon should generally be at least one rotation in length (Buongiorno and Gilless 2003).

2.2. The data description of the target forest

To develop harvest planning for the target forest, we need some forest resource data, economic data and data of current rotation age. Below is a summary of the data.

- The target area: All national forests in South Korea.
- Forest type: Red pine forests
- Rotation ages: 50 years, 60 years, 70 years respectively

In Korea, the government sets the harvest age of trees for national forests and the rotation age of the red pine forests to 60 years. However, this study assumes three different rotation ages, 50 years, 60 years and 70 years, respectively, to calculate various harvest strategies under different rotation ages. From this assumption, we can compare the changes in harvest strategies and forest CO_2 dynamics based on different scenarios. Rotation ages will influence harvest decisions because it affects the harvest volume per unit period.

- Forest data: The initial age-class distribution of the target forests (by area) is shown in the following Table 2. Current data shows that 70% of the target forests are concentrated in a specific age-class (30-50 years). This, however, seems to still remain a favorable condition for carbon uptake since fast growing young growth would be more effective at capturing carbon, as a net carbon sink is the function of trees' growth rate. However, the current age-class distribution cannot guarantee sustainable carbon sequestration since most forest stands will turn into old growth after a few decades without appropriate treatment. The effects of an aging forest also include : 1) an increasing sensitivity to forest mortality from insect and disease outbreaks; 2) a decreasing timber productivity ; 3) an increase in fuel loads, possibly resulting in a higher potential of wild fires (U.S. Forest Service 2007). In combining the production of timber and carbon sink, a more balanced age class distribution is necessary in order to sustain the high carbon sequestration capacity of young trees and high storage capacity of mature trees over time (Garcia-Gonzalo et al. 2007; Routa, Kellomäki, and Peltola 2012).

The initial age-class distribution of the target forests (by volume) is shown in the Table 3. Volumes are measured in m^3. The area and volume data are obtained from data inventory of the Korea Forest Service. To simplify, we assume that the forests only produce wood products. However, more factors can be included in a future study and this is one of the strengths of linear programming compared to other techniques (McDill E 1999).

Table 3-2. Forest areas by age class (unit: ha)

	Forest areas by age class (ha)						
	I	II	III	IV	V	VI	VII
Forest type	(1~10)	(11~20)	(21~30)	(31~40)	(41~50)	(51~60)	(61~70)
Red Pine	0	16503.791	119235.758	199709.355	122277.774	15374.703	7687.352

Source: Korea Forest Service.

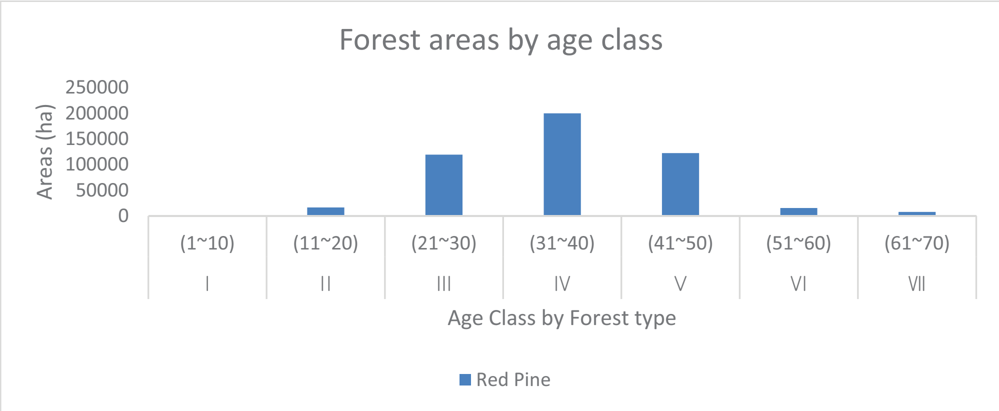
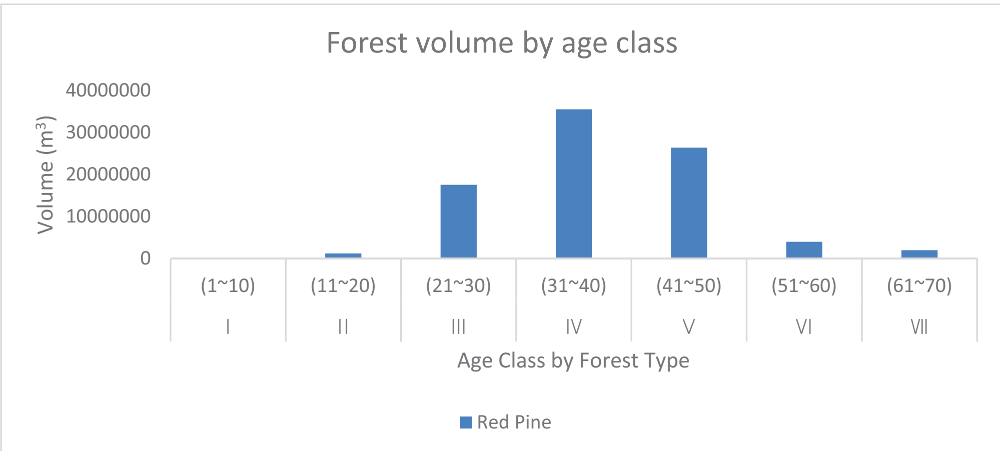


Table 3-3. Forest volume by age class (unit: m^3)

	Forest volume by age class (m^3)						
Forest type	I	II	III	IV	V	VI	VII
	(1~10)	(11~20)	(21~30)	(31~40)	(41~50)	(51~60)	(61~70)
Red Pine	0	1217845	17578924	35526902	26409052	3980941	1990470

Source: Korea Forest Service.



- Economic data: The economic data are used for calculating the profits (cost and return) for each management alternative (McDill E 1999) and Table 4 shows the economic data for the target forests. The regeneration and harvest costs include labor and other management costs and the detailed information of the costs is shown in Table A3 in appendix.

Table 3-4. Basic economic data for the target forests (unit: m^3)

Item	Symbol	Amount
Wood stumpage price	p_w	Statistical year book of forestry from Korea Forest Service[1]
Regeneration cost per ha	e	KRW5,342,000[2]
Harvest cost per ha	h	KRW67,630,000[3]
Interest Rate	r	5%

Source: Korea Forest Service and 구자춘 외(2015).

2.3. The objective function for the model

2.3.1. The profit maximizing objective function

The purpose of the linear programing model is to maximize the discounted profits from the forests. The profit maximization formulation offers flexibility in terms of specifying harvest targets (McDill E 1999). More specifically, the model outlines the harvest levels that would be appropriate for a specific area and planning period. The objective function maximizes the present value of the net revenue, from N years forest management planning horizon. The mathematical form of the objective function is represented as the following equation (1)

(1) $$\text{Max } Z=\sum_{a=1}^{M}\sum_{p=0}^{N} c^{p}{}_{ap} X_{ap}$$

where X_{ap} = the number of areas(ha) cut from initial age-class a (where a= age-class, 1,2,3…M) in period p (where p=1,2,3,..N and p=0 means no harvest during the planning horizon). For example, X_{31} implies the number of assigned areas (ha) to cut from initial age-class 3 in period 1.

[1] The stumpage price data is shown in table A2 in appendix.
[2] 구자춘 외 (2015) .
[3] 구자춘 외 (2015).

c^{p}_{ap} = Objective function coefficient that is the present value of the net revenue of assigning one area (ha) to the variable X_{ap}. The objective function coefficients imply the discounted net profit per hectare for each variable that could be calculated using the following equation (2)[4]

(2)
$$c^{p}_{ap} = \begin{cases} \dfrac{\mathrm{p}_w . v_{ap} - [e+h]}{(1+r)^{(10*p-5)}} & for \quad p > 0 \\ 0 & for \quad p = 0 \end{cases}$$

where p_w = the stumpage price
v_{ap} = the harvest volume per area for hectare assigned to the variable X_{ap}
e = the regeneration cost per ha
h = the harvest cost per ha
r = interest rate

2.3.2. Loss of carbon from timber removal

Forest resource assessments should include expanded analyses of environmental issues such as CO_2 storage in forests (U.S. Forest Service 1992). The rate of carbon sequestration depends on the tree species, basic density of wood, biomass expansion index and carbon fraction (IPCC 2003). The total carbon losses due to harvest can be calculated by following equation (IPCC 2003) (3)

(3) Total Carbon loss (tCO_2)=V×WD×BEF×CF× (1+R)×44/12

where V = Volume of tree removal (m^3);
WD = Wood basic density;
BEF = Biomass expansion factor;
R = Root Ratio (CO_2 in roots);
CF = Carbon Fraction: Biomass⇒Carbon (IPCC =0.5);
44/12 = CO_2 Fraction: Carbon(C)⇒CO_2;

V implies volume of tree removal in forests. The wood basic density is the ratio between the dry weight of wood and the green volume of the same wood which indicates the amount of actual wood substance present in a unit volume of wood (Zobel and Jett 1995). The biomass expansion index (BEF) quantifies carbon stock in forests, which is calculated from the ratio of aboveground biomass and minimum DBH (Sanquetta, Corte, and da Silva 2011). R implies ratio of the below-ground biomass to above-ground biomass, which is 0.26 for red pine. R can be set to zero if no changes of below-ground biomass allocation patterns are assumed. Carbon Fraction factor (CF) is used to convert biomass to carbon by multiplying it. The coefficients for red pine are summarized in Table 5.

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[4] The expression 10*p-5 in equation (2) implies the midpoint of the period P because we assume harvests occur in the midpoint of the period P.

Table 3-5. Conversion Coefficients (IPCC 2006)

Coefficients	WD	R	CF
Red Pine	0.45	0.26	0.5

	Biomass Expansion Index (BEF) By Growing Stock Level (m^3)			
Forest Type	<20	21-50	51-100	>100
Red Pine	1.33	0.75	0.63	0.55

Source: IPCC (2006).

The Korea Forest Service provides a standard forest carbon storage table, which estimates carbon storage in domestic forests by forest type based on equation (3). Table 6 shows the yearly carbon storage of the red pine forest by unit area. As seen in the Table, the forest carbon sequestration by unit area is maximized in forest age 30, and then continuously declines.

Table 3-6. Forest carbon storage by unit area (tCo2/year/ha)

Forest Age	10	20	30	40	50	60
Red Pine	5.7	9.7	10.8	7.2	4.9	3.5
All Forest Types (Average)	6.9	11.5	10.4	8.3	6.7	5.6

Source: Korea Forest Service.

2.3.3. The profit maximizing objective function considering carbon loss by harvest

Equation (4) implies final form of the objective function considering carbon sequestration value in forests. The objective function was generated by incorporating equation (1); economic profit from harvesting and equation (3); carbon loss due to tree removal and additional carbon gain from reforestation.

(4)

$$\text{Max } Z=\sum_{a=1}^{M}\sum_{p=0}^{N}c^{c}{}_{ap}X_{ap}$$

where

$$c^{c}{}_{ap}=\begin{cases}\dfrac{\mathrm{p}_w.v_{ap}-\left[e+h\right]-[D\times BEF\times CF\times 44/12]\cdot v_{ap}\cdot p_c+[D\times BEF\times CF\times 44/12]\cdot v_{1p}\cdot p_c}{(1+r)^{(10*p-5)}} & for\ \ p>0\\ 0 & for\ \ p=0\end{cases}$$

$c^{c}{}_{ap}$ is the objective function coefficient which is the present value of the net revenue of assigning one unit area (ha) to the variable X_{ap} considering carbon value. The term $(D\times BEF\times CF\times 44/12)\cdot v_{ap}$ implies total carbon loss due to timber removal. p_c is carbon cost in market. The term $D\times BEF\times CF\times 44/12$ in the left side of the equation is obtained from equation (3) but set with R=0 since we assume no changes of below-ground biomass allocation patterns. We assume the p_c is 10000 KOW/tc based on the literature review (이상민 외 2010). Equation (4) also considers additional carbon gain from reforestation. When a harvest occurs, the area is reforested and the amount of new forest areas is equal to the harvesting area. Therefore, $[D\times BEF\times CF\times 44/12]\cdot v_{1p}\cdot p_c$ implies additional carbon sequestration from forest age-class one, which is newly generated. The term p_c is necessary to convert carbon value into money term and v_{1p} implies the volume of new trees that are age class 1. Equation (4) simply indicates that economic benefit from cutting tree minus loss from carbon release due to harvesting in monetary terms. This objective function is used to evaluate the optimal amount of harvest area that satisfies maximizing profit from timber, considering carbon loss due to tree removal.

2.4. Constraints for the linear program model

2.4.1. constraints

The area constraints simply imply that we cannot manage more areas (ha) than we have. The restriction for the model is specified by this set of constraints. The N+1 possible prescriptions for each targeted area are: cut in period 1, cut in period 2, cut in period 3, cut in period 4… cut in period N and do not cut the trees in the areas during the planning periods. Therefore, the sum of the areas allocated from the analysis area to each potential prescription must be no more than the total areas that we plan to manage (McDill E 1999). The area constraints for the linear programming model follow equation (5).

(5) $$\sum_{p=0}^{N} X_{ap} \le A_a \quad a=1,2,3,4\ldots M.$$

where A_a = the total number of hectare in initial age *a*

2.4.2. Harvest Fluctuation Constraints

Minimum Harvest Constraints

We set the minimum harvest constraints to meet the government's forest plan. The governmental plan projects that the volume to be harvested from national forests will increase to 1,500,000 m^3 by the year 2020 (산림청 2008). Thus, the minimum harvest constraints could follow equation (6). Equation (6) implies that the harvest level in each period should be more than 105,000 m^3. [5]

(6) $$\sum_{a=1}^{M} v_{ap} \cdot X_{ap} \ge 105000, \quad p = 1, 2 \ldots N$$

Harvest Fluctuation Constraints

The harvest fluctuation constraints are required to widely protect the fluctuating harvest level from one period to the next; furthermore, following constraints will limit harvest level that will be allowed to fluctuate from one period to the next (McDill E 1999). We assume that the harvest level does not fluctuate from one period to the next by more than 15%. For example, we want to ensure that the harvest level in period 2 is not less than 15% below or more than 15% above the harvest level in period 1. Likewise, the harvest level in period 3 should not be less than 15% below or more than 15% above the harvest level in period 2. This can be explained as the following equation (7).

(7) $$\begin{aligned} &H_2 \ge 0.85H_1, H_2 \le 1.15H_1 \\ &H_3 \ge 0.85H_2, H_3 \le 1.15H_2 \\ &\qquad \ldots\ldots \\ &H_N \ge 0.85H_{N-1}, H_N \le 1.15H_{N-1} \end{aligned}$$

The first line in the equation implies that the harvest level in period 2 is at least 85% and at most 115% of the harvest level in period 1. In the second line, we can see that the harvest level in period 3 is at least 85% and at most 115% of the harvest level in period 2 and so on. Here, H_p represents variables rather than parameters. In order to use harvest fluctuation constraints like equation (7), we need to introduce specific harvest accounting constraints. A harvest accounting constraint sums up the harvest level for a period and expresses this sum as a variable including H_1, H_2, H_3… and so on. The harvest accounting constraints for this model can be expressed as the following equation (8) and the

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[5] The number 105,000 is generated by the equation, 1,500,000 ×7%. Based on data from table 1, we assume that the red pine forests cover 7% of the total national forests.

constraint requires that the total harvest is greater than or equal to a minimum harvest target for the period p (McDill E 1999)

(8) $$\sum_{a=1}^{M} v_{ap} \cdot X_{ap} \geq H_p,\ p = 1,2,\ldots \mathrm{N}$$

The constraints from equation (8) can be expressed in terms of the variable H_p, which is the total harvest volume at period p.

2.4.3. Average Ending Age Constraint

We need to design the linear program to leave a specific age-class distribution at the end of the planning horizon. Our purpose is to achieve a "normal forest" through forest management action at the end of the planning horizon. For this, we have an evenly distributed age–class distribution in mind, but this approach is too restrictive. To enhance the potential of the model to achieve other goals, we introduce a set of the ending age constraints for the target forests. To calculate the average age of a forest, we use the following equation (9)

(9) $$\overline{Age} = \sum_{i=1}^{n} \frac{Area_i}{\sum_{j=1}^{n} Area_j} Age_i$$

where $\overline{Age}$ = the average age of the forest
$Area_i$ = the area in the i^{th} unit of the forest, and
Age_i = the age of the i^{th} unit of the forest.

To formulate a constraint for average age of the forest at the end of the planning horizon, the term $Area_j$ in equation (9) can be replaced with the variable X_{ap}, which represents the areas in different blocks of the forest at the end of the planning horizon (McDill E 1999). The following equation represents the average age of the forest at the end of the planning horizon.

(10) $$\overline{Age}^N = \frac{\sum_{a=1}^{M}\sum_{p=0}^{N} Age^N{}_{ap} \times X_{ap}}{\sum_{a=1}^{M}\sum_{p=0}^{N} X_{ap}} = \frac{\sum_{a=1}^{M}\sum_{p=0}^{N} Age^N{}_{ap} \times X_{ap}}{TotalArea}$$

where $\overline{Age}^N$ = the target minimum average age of the forest in N (end of the planning horizon)

$TotalArea$ = the total area of the forest

Age_{ap}^N = the age in year N of areas in initial age-class a, which are planned to be cut in period p.

If we rearrange equation (10), we can generate equation (11), which is the general form of the ending average age constraint for our linear program model.

(11)
$$\sum_{a=1}^{M}\sum_{p=0}^{N} Age^{N}{}_{ap} \times X_{ap} \geq \overline{Age}^{N} \times TotalArea$$

The parameters Age_{ap}^{N} are determined by the following rules. If we consider the age of areas assigned to P=0 (do-not-cut prescription), it will be 60 years older after the end of the planning horizon under a 60 year planning horizon. Thus, the average age of the area (ha) is 5 years old if p=0 and a=1 at the beginning of the planning horizon, and their average age will be 65 years old at the end under the 60 year planning period. Likewise, if p=0 and a=2, the average age of the area is 15 years old at the beginning of the planning horizon, and they will be 75 years old at the end of the planning horizon. Given the areas assigned to cut in period 1 (p=1), they will be 55 years old at the end, regardless of their initial age. Table 7 summarizes the values of the Age_{ap}^{60} parameters.

Table 3-7. Ending age parameters under 60 year planning horizon

	Harvest Period						
Initial Age class	P=0 (no cut)	p=1	p=2	p=3	p=4	p=5	p=6
1	65	55	45	35	25	15	5
2	75	55	45	35	25	15	5
3	85	55	45	35	25	15	5
4	95	55	45	35	25	15	5
5	105	55	45	35	25	15	5
6	115	55	45	35	25	15	5
7	125	55	45	35	25	15	5

The parameter $\overline{Age}^{60}$ (the target minimum average age of the forest in year 60) is related to the ideal forests (normal forests) that we would like to achieve through the LP solution. If the rotation age is 60 years old, the average age of the normal forests will be approximately a 30-year old (half of the rotation) since all age classes are represented in the same quantities in normal forest (Oldeman 2012). Actually, the basic rule of thumb to calculate $\overline{Age}^{N}$ is (rotation age+1)/2 (McDill E 1999).

2.4.4. Non-negative Constraints

The non-negative constraints are necessary in the model because the harvested area cannot have a negative value.

(12) $$X_{ap} \geq 0 \quad a=1,2,\ldots M \;\; p=0,1,2,\ldots N$$

2.4.5. The complete linear program model for profit-maximization

The following equations show the complete linear programming model considering values of carbon sequestration in forests

(13) $$\text{Max } Z = \sum_{a=1}^{M}\sum_{p=0}^{N} c^{c}{}_{ap} \cdot X_{ap}$$

Subject to:

(14) $$\sum_{p=0}^{N} X_{ap} \le A_a \quad \text{(Area constraints)}$$

a=1,2,3,4..M

(15)

$$\sum_{a=1}^{M} v_{ap} \cdot X_{ap} \ge H_p,\ p = 1,2,\ldots\text{N} \quad \text{(Harvest constraints)}$$

$$\begin{aligned} &H_2 \ge 0.85H_1,\ H_2 \le 1.15H_1 \\ &H_3 \ge 0.85H_2,\ H_3 \le 1.15H_2 \\ &\ldots\ldots \\ &H_N \ge 0.85H_{N-1},\ H_N \le 1.15H_{N-1} \end{aligned} \quad \text{(Harvest fluctuation constraints)}$$

(16)

$$\sum_{a=1}^{M}\sum_{p=0}^{N} Age^{N}{}_{ap} \times X_{ap} \ge \overline{Age}^{N} \times TotalArea \quad \text{(Ending age constraints)}$$

(17) $$X_{ap} \ge 0 \qquad a = 1,2,\ldots\text{M} \ \ p = 0,1,2,\ldots\text{N} \quad \text{(Non-negative constraint)}$$

(18) $$\sum_{a=1}^{M} v_{ap} \cdot X_{ap} \ge 105000,\ a = 1,2,\ldots\text{M},\ \ p = 1,2\ldots N \quad \text{(Minimum harvest constraint)}$$

Summary of variables and coefficients

X_{ap} = Variable, the number of areas to be harvested from initial age-class a (a = 1,2,..6) in planning period p (p=0,1,2,…6 and p=0 implies no harvest during the planning horizon)

$C_{ap}^{\ c}$ = Coefficient, the present value of the profit from one unit area (ha) to the variable X_{ap}

A_a = Coefficient, the total number of areas in initial age-class a

v_{ap} = Coefficient, the harvest volume for each area assigned to the variable X_{ap}

H_p = Variable, the minimum harvest target for the planning period p

$\overline{Age}^{N}$ = Coefficient, the average age of the forest in year N

$TotalArea$ = Coefficient, the total area of the forest

$Age_{ap}^{\ N}$ = Coefficient, the age in year N of areas in forest

2.5. Forest regulation Scenarios

The linear programming (LP) harvest scheduling will be affected by various factors such as rotation age and planning horizon. The rotation age is important for managing desired forest structure for seeking optimized commodities and production goals (Bettinger et al. 2010). The rotation age also affects the amount of carbon stock in forests to capture these changes, we assume four different scenarios with single rotation management by rotation age and planning periods:

1. Baseline Scenario
2. Rotation age 50, planning horizon 50
3. Rotation age 60, planning horizon 60
4. Rotation age 70, planning horizon 70

All scenarios assumed single-rotation management and assumed forests are immediately re-established after harvesting. The harvest prescription for the baseline scenario is that forest stands are cut at harvest age (60 years by current law[6]) and immediately re-established by planting, but the harvest prescription would follow the same harvest constraints from the LP model (minimum harvest constraint and harvest fluctuation constraint). Scenarios 2, 3 and 4 are established based on the LP the model, but each scenario reflects rotation age related differences. For example, the rotation age affects the ending age constraints because the basic rule of thumb to calculate the target minimum average age is (rotation age+1)/2.

3. RESULTS FROM THE LP SOLUTIONS

3.1. LP solution

The following Tables and Figures indicate the results of the optimal solution from LP. Figure 2 shows the projected age-class distribution at the end of the planning horizon in various scenarios. The first graph in Figure 2 shows the age-class distribution at the beginning of the planning periods and the other graphs show the final age-class distribution following prescriptions from LP solutions. The age-class distribution at the end of the planning horizon is more balanced than the age-class distribution at the initial stage. The final age-class distribution does not follow complete uniform distribution (normal forest) under all scenarios. However, the results are satisfied with the minimum average ending age requirement. Generally, the LP model prescribes retaining additional areas of young growth rather than achieving normal forest that is composed of an equal area of forestland in each age-class.

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[6] In Korea, rotation ages are regulated by law, 60 years for national red pine forests.

Figure 3-2. The age-class distribution at the end of the planning horizon

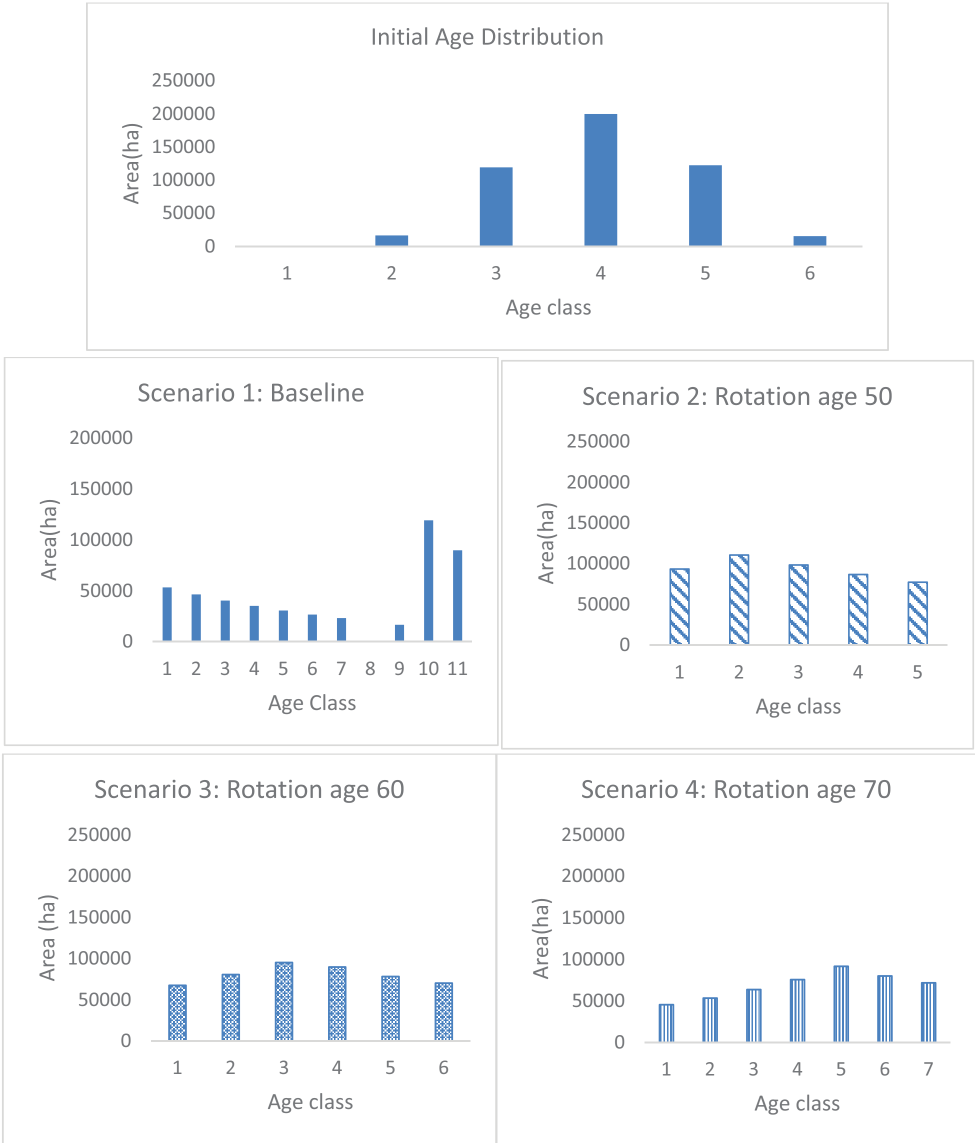
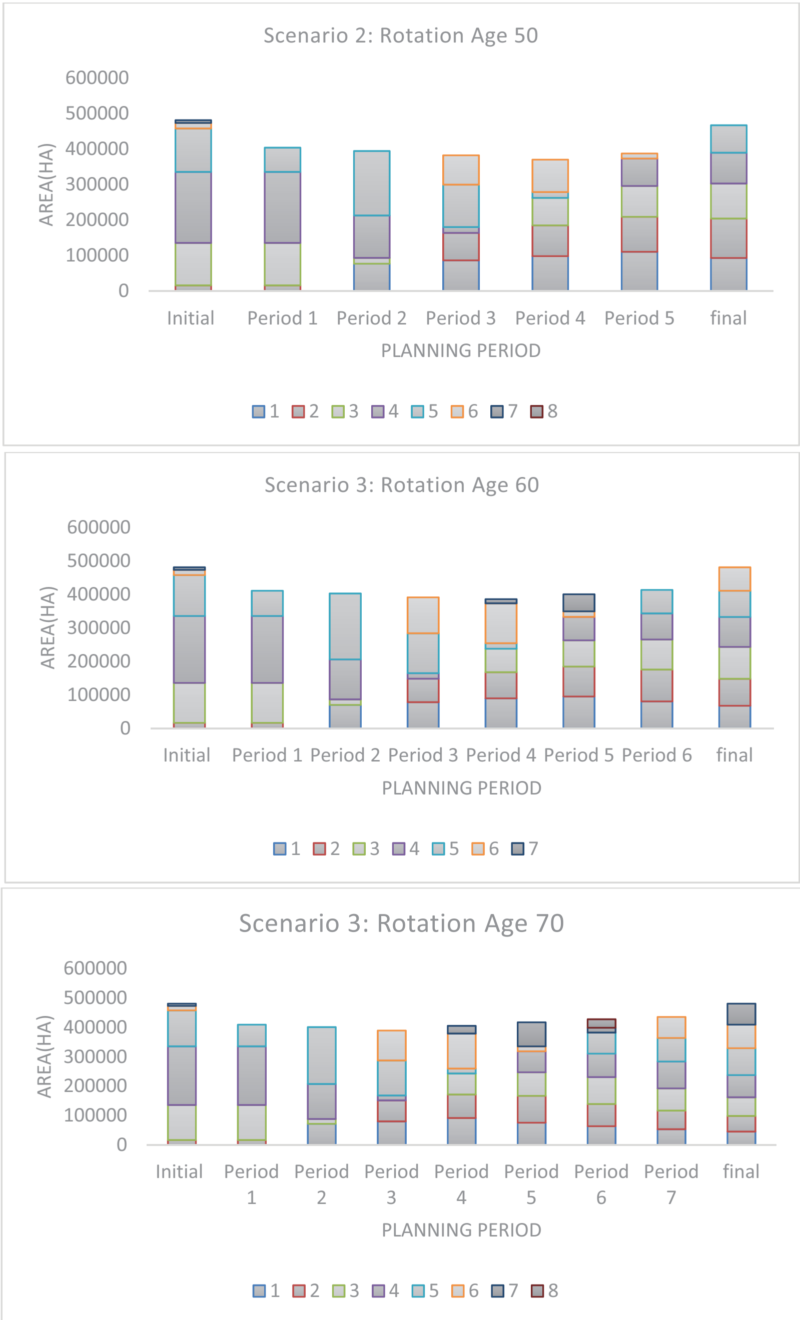


Figure 3 shows the changes in projected age-class distribution at the end of each planning period, under scenario 2, 3, and 4. The age-class distribution of the target forest changes over time, according to harvest prescription, and meets the average ending age requirement at the end of the planning horizon.

Figure 3-3. Changes in age-class distribution for each period by different scenarios



Tables 8 through 10 summarize the results for the optimal harvest prescription by different scenarios. Tables 8-10 would let the forest owners know how many areas (ha) of what age-class will be harvested at a given period. Table 8 informs the harvest schedule in an intuitive way. For example, the forest owner harvests 54140.68ha from age-class 5, 15374.7ha from age-class 6, and 7687.35ha from age-class 7 at the first planning period. We can interpret Tables 9 and 10 in the same way. Table 8 tells us that we need to harvest approximately 9332ha of pine forest each year to meet our management purpose. Under scenario 3, approximately 8013ha will be harvested each year (Table 9). We harvest approximately 6868ha each year under scenario 4 (Table 10).

Table 3-8. Areas (ha) harvested by period and age class (S2: 50 years rotation age)

Planning Period	Age-class	Harvested area
1	5	54140.68
	6	15374.7
	7	7687.35
2	5	18524.74
	6	68137.09
3	6	98496.67
4	6	28064.07
	7	82687.94
5	6	2331.181
	7	91171.69

Table 3-9. Areas (ha) harvested by period and age class (S3: 60 years rotation age)

Planning Period	Age-class	Harvested area
1	5	47005.34
	6	15374.7
	7	7687.35
2	5	2771.185
	6	75272.44
3	6	89575.97
4	6	0
	7	95098.62
5	7	68271.66
	8	12263.58
6	7	16503.79
	8	50964.1

Table 3-10. Areas (ha) harvested by period and age class (S4: 70 years rotation age)

Planning Period	Age-class	Harvested area
1	5	48590.09
	6	15374.7
	7	7687.35
2	5	6270.03
	6	73687.69
3	6	91557.25
4	7	75522.79
5	7	37193.29
	8	26359.29
6	8	53268.25
7	8	16503.79
	9	28774.22

Tables 11-14 show costs and revenues from the forest prescription for each period, by scenario. The costs for each period are from harvest and replanting the harvested areas, which is a function of the area planted and harvested volume.

Table 3-11. The revenues and costs by period for baseline scenario (unit: million KRW)

Value	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Harvested Area (ha)	23,062	26,521	30,500	35,075	40,336	46,386
Volume Harvested (m^3)	5,199,725	6,099,914	7,185,698	8,263,553	9,503,086	10,928,549
Gross Revenues	331,950	389,418	458,735	527,545	606,677	697,679
Costs	291,527	335,257	385,545	443,377	509,883	586,366
Net Revenues	40,423	54,162	73,190	84,168	96,794	111,313
Discounted Factor	1.31[7]	2.23	3.81	6.51	11.13	19.01
Discounted Net Revenue	30,929	24,261	19,193	12,922	8,699	5,857

[7] Discount factors are calculated by $(1+r)^{(10*p-5)}$, where r=5%

Table 3-12. The revenues and costs by period for scenario 2 (unit: million KRW)

Harvest Age	Period 1	Period 2	Period 3	Period 4	Period 5
Harvested Area (ha)	77,203	86,662	98,497	110,752	93,503
Volume Harvested(m^3)	16,623,410	19,116,920	21,984,460	25,282,130	21,489,810
Gross Revenues	1,061,238	1,220,424	1,403,488	1,614,011	1,371,909
Costs	975,920	1,095,492	1,245,096	1,400,016	1,181,970
Net Revenues	85,319	124,932	158,392	213,995	189,940
Discounted Factor	1.31	2.23	3.81	6.51	11.13
Discounted Net Revenue	65,280	55,961	41,536	32,852	17,071

Table 3-13. The revenues and costs by period for scenario 3 (unit: million KRW)

Value	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Harvested Area (ha)	70,067	78,044	89,576	95,099	80,535	67,468
Volume Harvested(m^3)	15,117,850	17,385,530	19,993,360	21,872,680	18,591,780	15,803,010
Gross Revenues	965,124	1,109,892	1,276,376	1,396,352	1,186,899	1,008,864
Costs	885,722	986,549	1,132,330	1,202,142	1,018,046	852,862
Net Revenues	79,402	123,343	144,046	194,210	168,853	156,003
Discounted Factor	1.31	2.23	3.81	6.51	11.13	19.01
Discounted Net Revenue	60,753	55,249	37,774	29,815	15,176	8,208

Table 3-14. The revenues and costs by period for scenario 4 (unit: million KRW)

Value	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7
Harvested Area (ha)	71,652	79,958	91,557	75,523	63,553	53,268	45,278
Volume Harvested (m^3)	15,452,230	17,770,070	20,435,580	17,370,240	14,764,710	12,550,000	10,667,500
Gross Revenues	986,470	1,134,441	1,304,607	1,108,916	942,579	801,192	681,013
Costs	905,755	1,010,746	1,157,375	954,684	803,368	673,364	572,359
Net Revenues	80,716	123,696	147,232	154,233	139,211	127,828	108,654
Discounted Factor	1.31	2.23	3.81	6.51	11.13	19.01	32.46
Discounted Net Revenue	61,758	55,407	38,609	23,678	12,512	6,726	3,347

Table 15 compares overall net revenues for each scenario. Scenario 2 provides the biggest net revenue, while the baseline scenario provides the least revenue among all scenarios. The shorter rotation age and planning periods generate greater net revenue because the total amount of the harvest each year tends to increase, as the rotation period would be shorter. Scenario 2 provides approximately twice as much revenue as the baseline scenario. Based on the LP solution, when comparing scenarios, scenario 2 generates 2.77% more revenue than scenario 3 and 5.28% more revenue than scenario 4. This is because the shorter the rotation periods, the more trees the LP solutions derive to harvested by the unit period to reach the management purpose (balanced age-class distribution). Also, another resons for generating less revenue in the longer rotation is because the objective functions consider the increasing discount rate according to the flow of time.

Table 3-15. The objective function value by scenarios (unit: million KRW)

Scenarios	Objective function value
Scenario 1: Baseline	KRW 101,860
Scenario 2	KRW 212,700
Scenario 3	KRW 206,975
Scenario 4	KRW 202,037

3.2. Changes in CO_2 sequestration performance of forests

Figures 4 through 7 show the changes in yearly CO_2 sequestration in forests under different scenarios. "No treatment" means we keep the forest in its natural state, without any intervention. We can estimate the amount of CO_2 sequestration using equation (3), then divide by the trees' age to get a yearly sequestration rate (Shodor Education Foundation, Inc. 1999). To estimate the yearly CO_2 sequestration rate in trees, we use a standardized yearly forest carbon sequestration table, developed by Korea Forest service. In terms of carbon sequestration, harvesting and replanting scenarios are much superior to no treatment, and forest management scenarios (S2, S3, S4) from LP show a better carbon sequestration performance than the unsystematic forest plan (Baseline). Under no treatment and baseline scenarios, the net carbon sink in the forest would decrease as time progresses. Otherwise, even if the net carbon sink tends to decrease during the short term, it would rebound in the long term under scenarios from LP solutions.

Figure 3-4. Yearly carbon sink (50 years rotation age)

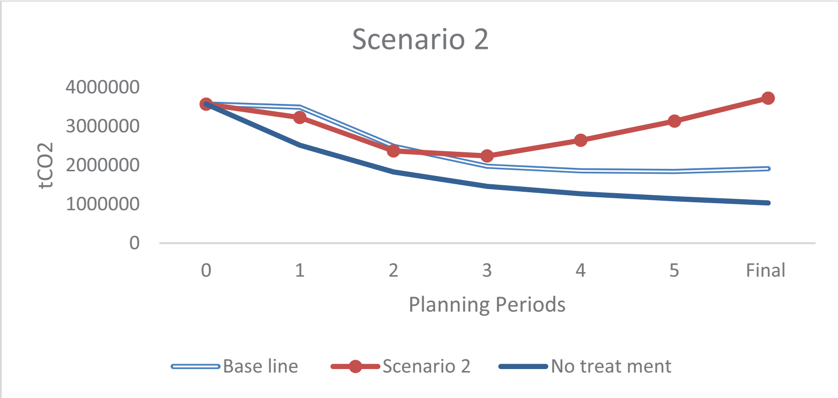


Figure 3-5. Yearly carbon sink (60 years rotation age)

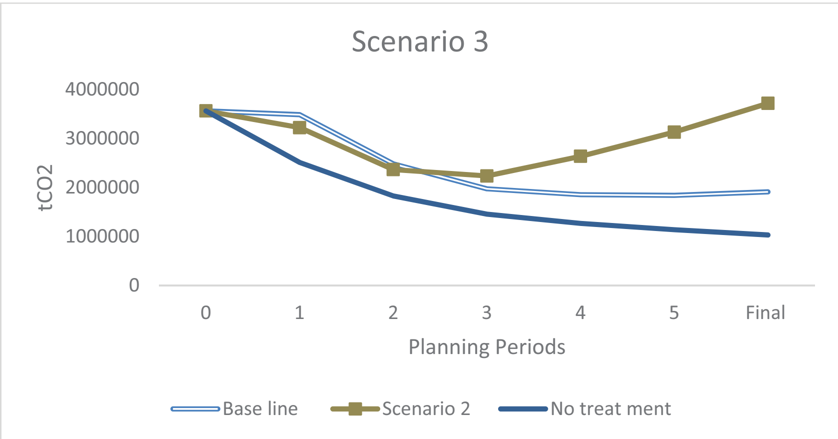


Figure 3-6. Yearly carbon sink (70 years rotation age)

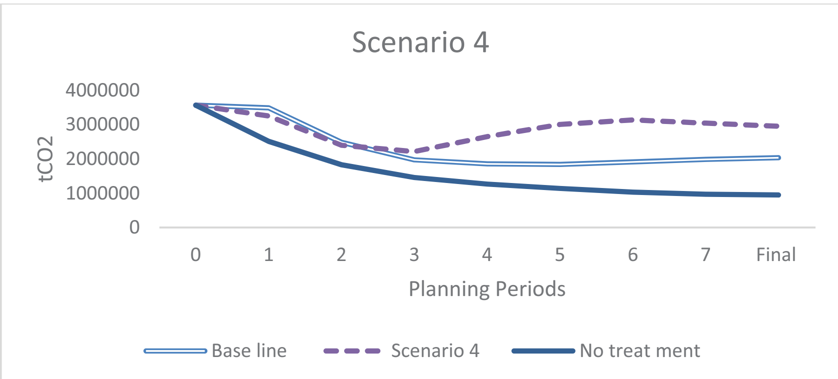


Figure 3-7. Yearly carbon sink (All scenarios)

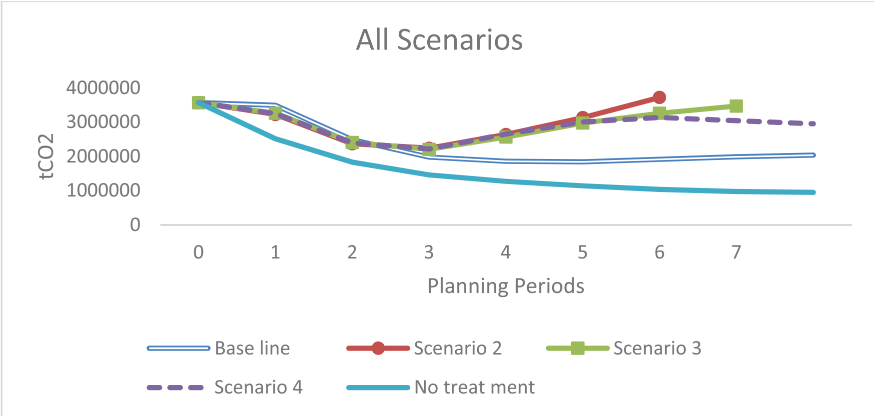


Table 16 shows the summary of the carbon sequestration performance under each scenario. The projected yearly carbon sequestrations in scenario 2 are 95% greater than baseline, 261% greater than no treatment. The projected yearly carbon sequestrations in scenario 3 are 75% greater than baseline, 257% greater than no treatment. The projected yearly carbon sequestrations in scenario 4 are 45% greater than baseline, 215% greater than no treatment. Thus, progress toward a balanced age-class distribution in national forests could enhance forest carbon sequestration by 45% to 95% compared to baseline.

Table 3-16 Increasing carbon sequestered by forests

Scenario	Compared to Baseline	Compared to no treatment
S2	95%	261%
S3	75%	257%
S4	45%	212%

Conclusion

Chapter 4

This paper examines two different researches conducted in Korea and Costa Rica with a common theme of seeking effective actions for enhancing forest carbon sinks. Costa Rica's study in the chapter 2 confirms that the PES was a fundamental instrument to increase tree cover in farms, which has favored the improvement of the value of biodiversity and carbon storage. This proves that the PES helps producers maintain their practices, and that these have been beneficial for the productivity of farms and increasing carbon storage in farmland. Based on the study of Costa Rica, a silvopastoral system is an excellent climate change response strategy that simultaneously holds economic achievement with environmental suitability. However, despite many adventages, Korea's silvopastoral farming is still in its early stages; thus, new policy regime, technology development and management innovation are necessary to develop a suitable silvopastoral system for Korea's actual situation. Additionally, it is necessary to introduce a new system such as product certification that enables consumers to discriminate between traditional forest products and products from silvopastoral farming. We also need to consider introducing governmental incentives such as PES to vitalize domestic silvopastoral farming. In order to introduce PES, it is necessary to evaluate the payment levels and categories, determining the number of pay grades and the monetary range of a position at a particular level within each farm. To be exact, it should be preceded by an accurate estimation of the utilization of the silvopastoral system. However, most domestic researches only focuse on the economic aspect of a silvopastoral system and it is still the early stage in researches that evaluates the value of silvopastoral farming where environmental aspects are concerned. Therefore, improvement is necessary for research reflecting the environmental effects of the silvopastoral system; the study of Costa Rica in this paper may serve as a good guideline.

In chapter 3, we examined efficient forest regulation planning to enhance carbon sinks in forests. In order to meet new international standards of the Paris agreement, innovative carbon reduction measures are necessary. With this background, we developed adequate forest regulation with a single cut cycle in Korean national forests according to: 1) economic benefit from timber and 2) changes in net carbon sequestration regarding age class distribution of target forests. All national red pine forests are studied as an example of developing four different regulation scenarios: 1) baseline, 2) 50 years rotation age and planning horizon, 3) 60 years rotation age and planning horizon and, 4) 70 years rotation age and planning horizon. The harvest prescriptions that optimized the purpose of management are calculated under four different scenarios. Additionally, changes in yearly carbon sequestration from LP solutions are compared with baseline and no-treatment scenarios. The term, forest regulation, is defined as identifying and selecting management alternatives for forested areas, to best meet landowners' objectives (McDill E 1999). Forest regulation is strongly related to sustainable production; thus, calling for a balanced production during planning periods (Buongiorno and Gilless 2003; Davis 1954). To achieve our forest management goal of sustainable carbon storage and timber production, we introduce the concept of "normal forest." The simple definition of normal forest is a forest with an equal number of areas in each age class (Cherokee National Forest (N.F.) 1986). The normal forest provides sustainability to guarantee an even flow of timber products in perpetuity. The current unbalanced age structure of Korean forests cannot provide both economic and environmental sustainability. Through harvest prescription from LP, the forest age structure at the end of the planning period is more balanced compared to the baseline scenarios. However, the solutions from LP did not achieve normal forests with perfectly even aged distribution, but produced a left-skewed age-class distribution curve because cost management rules out the achievement of a normal forest as an optimal solution. This means that achieving a normal forest cannot produce the optimum solution to maximize profit. The results from our LP model also confirm that the forest management activities will enhance yearly carbon sequestration in forests for all scenarios compared to baseline and without treatment. The yearly carbon sequestration and economic benefits are maximized under the shortest rotation age (50 years), primarily due to a shorter rotation and planning horizon, where the LP prescription tends to cut more volume of trees per unit period compared to the longer rotation. From forest management, the forests sequestrate an additional 1.8, 1.5 and 0.9 million tons of CO_2, under scenarios 2, 3, and 4, respectively, compared to baseline. However, it is hard to ensure that 50 years is the optimal rotation age of the target forests, since we do not consider the biodiversity conservation benefit. A previous research showed that inclusion of the biodiversity components such as the minimum viable population for birds into the optimization model led to a longer rotation age compared to the carbon rotation age (Nghiem 2014). Another study from Koskela et al., (2007) also found that promoting biodiversity preservation prolonged rotation age using the simulation model. Also, the longer rotation could improve the soil condition (Wu et al. 2015) and resilience of the forest to disturbance, disease and insect outbreaks (U.S. Fish and Wildlife Service 2008). This study has shown how forest regulation affects net carbon sequestration in the national red pine forests using LP; in addition, harvest prescriptions via specific planning period are provided. The forest resources with which forest managers work, be they land, time or budget, are always limited. Regardless of the course of action, forest managers always face constraint that limits the range of their alternatives (Buongiorno and Gilless 2003). LP is designed to help them find the best alternative among several feasible options, which is a recurring theme in management science (Buongiorno and Gilless 2003). Our LP model provides forest managers and policy makers a tool for establishing sustainable forest management plans considering both economic and carbon sustainability: however, the model has several limitations. First, the objective function does not allow for the possibility of interaction between species since we only considered the one forest type, red pine in particular, as the target species. Second, the objective function needs to reflect more realistic forest practices such as thinning. A thinning will generate additional costs and affect trees' growth and volume. New results will be derived in the event that thinning is included in the model. In addition to carbon sequestration of trees, other factors such as biodiversity should be considered for a more sophisticated model. The model assumes that the carbon price is fixed during the planning horizon, yet, carbon prices could change over time. Thus, carbon price volatility should be taken into account during studies. All in all, there is room to improve or develop better models: 1) expanding target forest species, 2) expanding the target area to private forests, and 3) including other values such as biodiversity in objective function.

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Chapter 5

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APPENDIX

Chapter 6

Annex 1. Survey developed for making information in the field
Proyecto de Analisis del PES en fincas participantes de Esparza, COSTA RICA
¡Muy buenos(as)..! Mi nombre es , soy funcionario del CATIE.
Actualmente estamos realizando un trabajo de investigación para estimar la sostenibilidad del efecto del pago por servicios ambientales en los sistemas tecnológicos que adoptaron en sus fincas entre los años 2003 a 2007, para lo cual la información que se solicitará está relacionada con el manejo gandero y los usos de suelo que mantienen en la actualidad.
En esta entrevista esta diseñada para indagar el manejo de las fincas con las personas que participaron en el Proyecto de Enfoques Silvopastoriles Integrados para el Manejo de Ecosistemas (2003-2007); por ello le solicito respetuosamente pudiera concederme aproximadamente una hora de su tiempo para entrevistarlo. Su participación es totalmente voluntaria y la información que proporcione se manejará con absoluta confidencialidad. Si no desea participar o si existiera alguna pregunta con la que se sienta incómodo o prefiera no responderla me lo puede comunicar sin ningún problema. De la misma manera si usted prefiere finalizar la entrevista, me lo pone de manifiesto y la damos por concluida.
Me gustaría nuevamente dejar en claro que la entrevista es anónima y confidencial y que sus respuestas y las respuestas de las demás personas entrevistadas son muy importantes para el desarrollo de la investigación y éstas se analizarán en conjunto, por lo que no se conocerán cuáles son las suyas en forma particular.
Si mi pregunta no es clara o si desea una explicación adicional, por favor no dude en preguntarme inmediatamente.

I. Información general

Fecha de la entrevista
Hora de inicio: Hora de finalización: Duración: min
N° de encuesta:
Nombre del propietario:
Número Telefónico:
Nombre del entrevistado:
Entrevistador:

II Características del productor y de la familia

1. Es usted el dueño de la finca
   - Sí
   - No
   - Otros:
2. Cuenta con otras fincas si (   ), no (   ), cuantas
3. Vive en la finca o en otro lugar:
4. Cuántos años tiene viviendo en esta finca:
5. Edad del productor/ra:
6. Total de miembros de la familia

Miembros de la familia	Edad	Escolaridad	Parentesco

7. Como es la distribución de las labores de la finca

Descripción	Mano de obra permanente		Mano de obra temporal		Mano de obra familiar	
	Días/año	Cantidad	Días/año	Cantidad	Días/año	Cantidad
Cuidado general ganado						
Ensilado						
Suplementación						
Desparasitación						
Vacunación						
Vitaminación						
Ordeño						
Mantenimiento corrales (aseo)						
Supervisión						
Administración						
Otros						

8. Cuantas personas trabajan permanente en la finca miembros del hogar:
9. Cuantas personas se contratan permanente externas: o temporales: cuantos días al año:
10. Valor del salario

Cargo	Salario/mes	Meses/año

III. Preguntas al mayordomo (Encargado fuera del dueño de la finca)

11. Número de años que tiene trabajando en la finca: Edad:
12. Escolaridad años:
13. Cuantas personas familiares del mayordomo trabajan en la finca:
14. Usted tiene experiencia en sistemas silvopastoriles (árboles dispersos etc.):
15. Usted ha recibido capacitaciones en sistemas silvopastoriles si (   ), no ( ) quien le dio la capacitación:

IV. Información general del Hao

16. Hace 10 años como era su hato ganadero? Mayor ( ) Menor ( ) Igual ( ) Por qué?
17. Cuantos animales tiene en la actualidad
18. Carga animal por hectáreas

Categoría animal	2007	2016
Vacas producción		
Vacas secas		
vacas + 2 años		
Vaquillas 1 - 2 años		
Terneras 0-1 año		
Sementales		
Novillos + 2 años		
Novillos 1 - 2 años		
Terneros 0 - 1 año		
Caballos		
Bueyes		
Otros animales (pollos, cerdos etc).		Total

19. Cuál es la actividad principal de la finca
20. Cuenta con lechería en la Finca si (   ), no (   )
21. Tipo de ordeño en la finca manual   Mecánico

22. Qué tipo de ganadería maneja en su finca

Tipo	2007	2016
Leche		
Carne		
Doble propósito		

23. El cambio de sistema de producción se produjo a:

a. Falta de mano de de obra
b. Problemas de salud
c. Problemas de inversion
d. Otros (Especifique)

24. Hace rotación de los potreros si ( ), no ( )

25. La rotación de los potreros es igual en verano y en época lluviosa

Rotación de potreros	Inviernos		Verano	
	2007	2016	2007	2016
Dias de descanso				
Dias de ocu-pación				

26. Cuál es el promedio de producción de leche por litros por día o por vaca: (kg/Vaca(/Dia)

Descripción Leche en Kg	Inviernos		Verano	
	2007	2016	2007	2016
Total leche L/día (kg)				
Vacas promedio ordeño/día				
Litros promedio vaca/día				
Cantidad de ordeños/día				

27. Cuáles son los productos de comercialización de la finca:

Productos derivados		Leche		Queso	
	Año	2007	2016	2007	2016
Época Seca	Unidad de Venta				
	Cantidad Vendida (lt) o kilos				
	Precio Venta (col/lt)				
Época invierno	Unidad de Venta				
	Cantidad Vendida (lt) o kilos				
	Precio Venta (col/lt)				
	Lugar de venta Comprador				
	Distancia mercado (km)				

28. ¿Engorda y venta de animales?

Categoria animal	Cantidad comprada en el año	Peso promedio (kg)		Tiempo de engorde	Cantida de animales vendido/año	Precio de venta en pie (col/kg)	Muertas
		Inicial	Final				

29. Maneja registros

a. de producción si ( ),no ( )
b. manejo de hato si ( ),no ( )
c. gastos en insumos para la finca si ( ), no ( )
d. Otros

30. Dependen solo de esta actividad si ( ), no ( )

31. Cuál es el aporte de las actividades que realiza al ingreso total de la familia.

Ganadería: % Cultivos: % Otros: %

32. Qué otras actividades se realizan además de la ganadería:

33. Cuenta con cultivos en la finca actualmente

Tipo de cultivo	Área cultivada (ha)

34. Los productos que obtiene son para el autoconsumo? Si ( ) No ( )
35. Donde vende los productos agrícolas que produce, distancia del lugar a la finca:
36. Usos de la tierra presentes en la finca (2016)

Uso de la tierra	Área (ha) 2016	Observaciones**
Pasturas degradadas		
Pasturas naturales		
Pasturas mejoradas		
Bancos forrajeros de gramíneas		
Bancos forrajeros de leñosas		
Cultivos anuales		
Cultivos permanentes		
Plantaciones forestales		
Tacotales o charrales		
Bosques ribereños		
Bosques secundarios		
Otros		
Total (Has)		

** *Anotar información complementaria, por ejemplo especies de pastos predominantes.*

37. Los cambios queha generado en la finca despues del 2007, a nivel de cambios de uso del suelo, que lo ha motivado a desarrollarlos
  a. Incremento en la producción de leche
  b. Incremento en la producción de carno
  c. Estrategia para diversificar los productos (productos diferenes a los generados por la actividad ganadera)
  d. Otros

38. Despues del 2007 usted ha comprado más área de terreno aeldaño a la finca: si No ha
Porqué:
39. Despues del 2007 usted ha vendido terreno de su finca: si no ha
Porqué:
Problemas economicos
Inversion en la finca
Inversión personal : Estudios , Problemas de salud , Construcción ,
Problemas economicos, Falta de mano de obra , Otros

40. Venta de Madera

Año	Producto	Volumen promedio/anual	Unidad de venta	Precio de venta (unidad)	Auto- consumo
2007	Madera en pie				
	Madera aserrada				
	Leña				
	Postes de madera				
2016	Madera en pie				
	Madera aserrada				
	Leña				
	Postes de madera				

41. Insumos utilizados en la alimentación animal (preguntar que insumos en el 2007)

Nombre del producto	Unidad de medida	Cantidad/mes*	Costo (Colones CR)	Categoria animal	Observaciones (ej. función del producto)
2007					
Sal					
Concentrado					
Melaza					
Pacas de heno					
Forraje					
Ensilaje					
2016					
Sal					
Concentrado					
Melaza					
Pacas de heno					
Forraje					
Ensilaje					

42. Insumos para salud animal (hato)

Nombre del producto	Identificación del animal	Unidad de medida	Cantidad/mes*	Costo (Colones CR)	Observaciones (ej. función del producto)
2007					
Antibioticos					
Vacunas					
Desparasitantes					
Desifectantes					
Vitaminas					
2016					
Antibioticos					
Vacunas					
Desparasitantes					
Desifectantes					
Vitaminas					

43. Control de otros gastos en insumos en la finca. Se considera el gasto de combustible, mantenimiento de maquinaria, equipo e infraestructura, energía eléctrica y otros.

Nombre del producto	Unidad de medida	Cantidtidad/mes*	Costo (Colones CR)	Observaciones (ej. función del producto)
2007				
Combustibles				
Energía				
2016				
Combustibles				
Energía				

44. Costos para el establecimiento de bancos forrageros

e. ¿Tiene establecidas nuevas áreas de BF (**después de 2007**)? SI ( ) NO ( )

f. ¿Qué superficie?..ha

g. Especie...

h. Mano de obra

	Frecuencia por año	Mano de obra (jornales)			
		Familiar		Contratada	
		Cantidad	Días/año	Cantidad	Días/año
Aplicación herbicidas					
Preparación terreno					
Siembra del material					
Aplicación de fertilizantes					
Desmalezado manual					
Corte de forraje					
Almacenamiento forraje					

Insumos

Descripción	Unidad	Cantidad	Costo unitario
Fertilizantes			
Abono orgánico			
Insecticidas			
Herbicidas			
Semillas pastos			
Material vegetativo			
Alambre estacas cerca			
Grapas estacas cerca			
Postes estacas cerca			

45. Costos de establecimiento y manejo de pasturas

i. ¿Tiene pasturas de reciente establecimiento (2007)? SI ( ) NO ( )
j. Superficie.........................ha
k. Especie...................................
l. Mano de obra

Actividad	Frecuencia por año	Mano de obra (jornales)			
		Familiar		Contratada	
		Cantidad	Días/año	Cantidad	Días/año
Preparación tierra					
Riego semillas de pasto					
Fertilización					
Control malezas					
Desmonte					
Destroncado					
Chapea					
Fertilización					
Herbicidas					
Reparación caminos					

Insumos

Descripción	Unidad	Cantidad	Costo unitario
Fertilizantes			
Abono orgánico			
Insecticidas			
Herbicidas			
Semillas pastos			
Material vegetativo			
Alambre estacas cerca			
Grapas estacas cerca			
Postes estacas cerca			

46. Costos de establecimiento y mantenimiento de árboles en potrero

m. ¿Tiene establecidos nuevos árboles en potrero (después de 2007)? SI( ) NO( )
n. ¿Qué superficie?..ha
o. Especie..
p. Mano de obra

Actividad	Frecuencia por año	Mano de obra (jornales)			
		Familiar		Contratada	
		Cantidad	Días/año	Cantidad	Días/año
Fertilización					
Control malezas					
Protección de arboles					
Chapea					
Podas					
Herbicidas					

Insumos

Descripción	Unidad	Cantidad	Costo unitario
Fertilizantes			
Abono orgánico			
Insecticidas			
Herbicidas			
Arbolitos			
Alambre			
Grapas estacas			
Postes estacas			

47. Costos de establecimiento y mantenimiento de cercas vivas

a. ¿Tiene establecidos nuevas cercas vivas (después de 2007)? SI( ) NO( )
b. ¿Qué superficie?..km
c. Especie..
d. Mano de obra

Actividad	Frecuencia por año	Mano de obra (jornales)			
		Familiar		Contratada	
		Cantidad	Días/año	Cantidad	Días/año
Fertilización					
Control malezas					
Protección de arboles					
Rparación de cercas					
Podas					
Herbicidas					

Insumos

Descripción	Unidad	Cantidad	Costo unitario
Postes			
Alambre			
Alambre			
Grapas estacas			

48. Nuevas áreas establecidas después del 2007

Actividas	**Si**	**No**	**ha**	**Especie**
Ha continuado protegiendo las riberas de los ríos (después de 2007)				
Ha incrementado las áreas de bosque (después del 2007)				

Costos de actividad de protección de bosques

Actividad	Frecuencia por año	Mano de obra (jornales)			
		Familiar		Contratada	
		Cantidad	Días/año	Cantidad	Días/año

Información de inversiones en la finca

49. Que problemas tiene para el mantenimeinto y manejo de la finca

Problemas	Como esta pensando en solucionarlo
Falta de recursos económicos	
Dificultades en el acceso a mercados	
Falta de capacitación técnica	
Falta de capacitación empresarial	

50. ¿Se encuentra satisfecho con los resultados de las prácticas implementadas con el proyecto en la producción ganadera?

SI ( ) NO ( )

¿Por qué?

51. ¿Considera que los beneficios ambientales generados a partir de las prácticas silvopastoriles implementadas con el proyecto son notorios?

SI ( ) NO ( )

¿Por qué?

52. ¿Considera que valió la pena en términos ecológicos y económicos la implementación de las prácticas silvopastoriles? SI ( ) NO ( )
¿Por qué?

53. ¿Continuaría con la adopción de nuevas prácticas silvopastoriles considerando los resultados que identificó en su finca? SI ( ) NO ( )
¿Por qué?

54. Pertenece a alguna asociación de productores si( ), no ( )

a. Desde que año forma parte de la asociación de productores y el nombre de la asociación:

55. Ha recibido créditos anteriormente para invertir en la finca en sistemas productivos
si ( ), no ( ) y de qué tipo:

56. Conoce usted las modalidades de créditos que pueden acceder para realizar mejoras o compra de animales para la finca?

57. Conoce el programa de créditos para el fomento ganadero si ( ), no ( )

58. Aplico a este programa si ( ), no ( )

59. Qué piensa de estos créditos son: bueno ( ), regular ( ), malo ( )

60. Como se enteró de este crédito?

61. Usted participo en el proyecto en la modalidad de PSA

PES 2 años 4 años Control

62. En la actualidad usted sigue particiando en el programa de PSA de FONAFIFO? si ( ) No ( )

Tiempo (años) Modalidad del PSA

63. Le gustaría volver a participar con un programa de PSA si ( ), no ( ) y el porqué:

64. Recibió o actualmente recibe usted algún tipo de asistencia técnica o beneficio no monetario en su finca? (ONG, o instituciones de gobierno):

Temas	Asistencia Técnica	Capacitación	Frecuencias de visitas o capacitación al año	Institución

65. ¿Las prácticas que se han fortalecido por medio de la capacitación o asistencia técnica las ha puesto en práctica en la finca? Si ( ) No ( )

Si responde **SI**, en que practicas lo ha implementado en la finca

Si Responde **NO**, Que problema ha tenido para implementar las prácticas en la finca

66. ¿Qué tipo de asistencia técnica ó capacitación a usted le gustaría recibir para mejorar su finca?

MÁS DATOS DE ADAPTACION A EVENTOS EXTREMOS DE VARIABILIDAD CLIMATICA

67. Ha realizado acciones de mejora en su ganadería en los últimos 10 años? Si ( ) No ( )

68. ¿Por qué decidió mejorar su ganadería?

q. Variabilidad climática ( )
r. Mejorar sus ingresos ( )
porque otro productor le aconsejó ( )
s. Oportunidad de apoyo ( )
t. Exigencia del mercado ( )
u. Otros:

69. ¿Cómo se preparó(a) para no ser afectado por las sequías alargadas o por el exceso de lluvias?

	ACCIONES	Sequías		Exceso lluvias	
		Antes si/no/=	Ahora si/no/=	Antes si/no/=	Ahora si/no/=
1	Practica conservación de forrajes? Como: ensilaje, pacas, otras	( )Si ( )No	( )Si ( )No	( )Si ( )No	( )Si ( )No
2	Usa suplementos y concentrados (melaza, gallinaza)	( )Si ( )No	( )Si ( )No	( )Si ( )No	( )Si ( )No
3	Compra o alquila pastos en otras fincas: forraje, rastrojo, pacas	( )Si ( )No	( )Si ( )No	( )Si ( )No	( )Si ( )No
4	Usa abrevaderos, represas, pozos	( )Si ( )No	( )Si ( )No	( )Si ( )No	( )Si ( )No
5	Planifica la venta animales para reducir la carga animal	( )Si ( )No	( )Si ( )No	( )Si ( )No	( )Si ( )No
6	Mantiene más árboles en los potreros con diferentes fines: sombra, leña,	( )Si ( )No			
7	Tiene arboles en callejones	( )Si ( )No			
8	Siembra o amplia el área de pastos mejorados con árboles dispersos >30/ha	( )Si ( )No			
9	Tiene bancos forrajeros proteicos	( )Si ( )No			
10	Tiene bancos forrajeros energéticos	( )Si ( )No			
11	Cuenta con galera para cuidar a los animales en verano	( )Si ( )No			
12	Incrementa o mantiene el uso de cercas vivas	( )Si ( )No			
13	Disminuyó el uso de agroquímicos	( )Si ( )No			
14	Protege algunas fuentes de agua	( )Si ( )No			
15	Selecciona especies de ganado más resistentes a las sequías o veranos largos	**Antes**: Si( ) No( )		**Ahora**: Si( ) No( )	
16	Dejó la práctica de las quemas	Si( ) No( )			
17	Drena el exceso de agua en los potreros mediante canales	Si( ) No( )			

70. ¿Cuál es el sistema de manejo ganadero que utilizó(a) por épocas?

Cambios del manejo	Sequías (verano)		Lluvias (invierno)		En que categoría animal (vacas/lactancia/secas, Novillas, terneras, toretes, toretes mayores, sementales)
	Antes si/no/ =	Ahora si/no/ =	Antes si/no/ =	Ahora si/no/ =	
Estabulado del ganado15	( )Si ( )No	( )Si ( )No	( )Si ( )No	( )Si ( )No	
Semi-estabulado del ganado16	( )Si ( )No	( )Si ( )No	( )Si ( )No	( )Si ( )No	
Pastoreo rotacional	( )Si ( )No	( )Si ( )No	( )Si ( )No	( )Si ( )No	
Pastoreo continuo	( )Si ( )No	( )Si ( )No	( )Si ( )No	( )Si ( )No	
Pastoreo rotacion-al-semiestabulado	( )Si ( )No	( )Si ( )No	( )Si ( )No	( )Si ( )No	
Pastoreo continuo – semiestabulado	( )Si ( )No	( )Si ( )No	( )Si ( )No	( )Si ( )No	

71. ¿Qué factores condicionan o limitan a los ganaderos para enfrentar (adaptarse) verano alargado y exceso de lluvias y disminuir sus riesgos? (marcar solo dos factores más importantes)

v. Falta de asistencia técnica ( )
w. Difícil acceso a créditos blandos ( )
x. Altos costos ( )
y. Bajos precios de leche ( )
z. Falta de subsidios insumos ( )
aa. Bajos ingresos ( )
bb. Otros,

72. ¿Cuál cree que es la acción más importante que debería hacer cualquier ganadero para mantener la producción de leche en el verano? Ponga dos acciones, las más importantes.

Acción:

Ideas de apoyo: Tener cercas vivas, Poner arboles dispersos en potrero, Bancos forrajeros, Pasturas mejoradas con o sin árboles, Pasturas en callejones, Reforestación, Protección de fuentes de agua, construir bebederos (cosecha de agua), Uso de registros productivos, Control sanitario de animales, Cambiar la raza de ganado que resista al verano largo.

PERCEPCIONDELCAMBIOCLIMATICO

73. Ha recibido charlas sobre cambio climático, fenómeno del Niño o de la Niña y sus efectos sobre la producción ganadera o agrícola? Si ( ) No ( )

74. Cree Ud. que el clima ha cambiado en los últimos 25 años? Si ( ) No ( ) No sé ( )

75. 5Hace 10 o 25 años, cuantos meses duraba normalmente el verano (sequía) y el invierno (lluvias) en esta zona?

76. Verano (sequía) meses, indicar:

Hace 25 años (1990)

□Ene □Feb □Mar □Abr □May □Jun □Jul □Ago □Sep □Oct □Nov □Dic

Comportamiento del verano
Adelantado Prolongado Corto Intendificaco
Comportamiento del Lluvia
Adelantado Prolongado Corto Intendificaco

Hace 10 años (2000) número de meses

□Ene □Feb □Mar □Abr □May □Jun □Jul □Ago □Sep □Oct □Nov □Dic

Actualmente (2016) número de meses

□Ene □Feb □Mar □Abr □May □Jun □Jul □Ago □Sep □Oct □Nov □Dic

77. Cuál es la disponibilidad de agua en las fuentes naturales actualmente o en los últimos 10 años en la zona? Mayor ( ) Menor ( ) Igual ( ) N/S ( )

78. ¿Sabe cuántas fuentes de agua (ríos, quebradas, manantiales, pozos naturales) se secan en verano (sequía)? Número Ninguna Nose

79. En los últimos 10 años, en las quebradas, ojo de agua u otra fuente, ha notado que el nivel de agua ha cambiado?

Disminuido ( ) Aumentado ( ) Está igual que años anteriores ( ) se ha secado ( )

80. Cuáles son los dos grandes problemas que le genera el verano (sequías) prolongado, sobre su hato ganadero? Marcar (√) solo los dos más importantes

	Pérdida de cultivos	Reducción de área de pasturas	
	Siembra tardía	Desadaptación de especies de forraje	
	Pérdida de cosechas	Potreros erosionados	
	Retraso en el crecimiento de los pastos	Muerte arboles	
	Baja producción de pastos	Presencia de plagas	
	Desaparición de fuentes de agua	Otros:	

81. Cuáles son los dos problemas urgentes por excesos de lluvias, sobre la finca? Marcar (√)

	Arrastre de sedimentos en grandes volúmenes	Suelos erosionados	
	Enfermedades respiratorias	Enfermedades en pezuñas	
	Inundaciones en potreros y otras áreas	Otros:	

82. Recuerda haber experimentado algún evento, fenómeno natural, sequía o verano largo/ intenso en los últimos 25 años? En qué años y en qué época del año fue, en el verano o invierno (seca o lluviosa)?

Evento Climático	Año	Comentario
Frentes fríos		
Lluvias intensas; chaparrón o aguacero poca duración (algunos días con lluvias fuertes y varios días sin lluvia)		
Tormentas eléctricas (vientos fuertes, lluvias torrenciales y truenos)		
Sequías o verano prolongado		
Otros:		

<Table A1: Criteria for carbon cap-and-trade offset projects, elaborated for the context of forestry (Faheyetal.2010)>

Real	Means that quantified GHG reductions represent actual reductions and not accounting artifacts.
Additional	Refers to the need to ensure that a forestry offset project does not take credit for some forest management activity that would have happened anyway. Similarly, in the case of protection of C in newly created forest preserves, additionality would not be achieved if wood harvest consequently occurred in a different forest tract (ie “leakage”).
Verifiable	The need for accurate monitoring programs; although C storage in forests usually changes so slowly that frequent (< 5 yr) remeasurements are pointless, the importance of periodic data collection, in tandem with the awarding of credits, is emphasized by this criterion.
Permanent	Specifies that the sequestered carbon is not re-emitted to the atmosphere, or that some guarantees against this risk are provided. The time scale of “permanence” remains a controversial issue. Mechanisms to address this criterion include risk pooling and banking a percentage of credits as risk insurance. Also, schemes have been proposed to guarantee forest C storage for limited time periods, long enough for alternative technologies to reduce C emissions in other sectors
Enforceable	The need for contracts or other legal instruments to back the forest offset project and ensure exclusive ownership

<Table A2: Stumpage price for major forest type in Korea (per m^3)>

Forest type	Red Pine	Korean Pine	Japanese Larch	Other needle leaf trees	Other Broad leaf trees
Stumpate price	63,840	28,720	31,440	14,160	9,200

Source: Korea Forest Service

<Table A3: Regeneration cost breakdown (per m^3)>

Category	Cost
1. Tree planting cost	1,856,726
A. Seedling cost	1,554,000
B. Other	302,726
2. Labor cost	2,032,316
A. Direst labor cost	1,849,242
B. Indirect labor cost	183,074
3. Operation cost	323,589
A.Transportation cost	34,980
B. Equipment cost	24,989
C. Insurance fee	195,101
4. Management cost	321,311
5. Profit	391,288
6. Tax	458,668
Total	5,342,000

Source: 구자춘 외(2015).