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PRIORITY AREAS FOR PAYMENT FOR ENVIRONMENTAL SERVICES (PES) IN COSTA RICA

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PABLO ANDRES IMBACH BARTOL

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MAGISTER SCIENTIAE

FIRMANTES:

Lucio Pedroni, Ph.D.
Consejero Principal.

Sergio Velázquez , M. Sc.
Miembro Comité Consejero

Francisco Alpízar, Ph.D.
Miembro Comité Consejero

Thomas Koellner, Ph.D.
Miembro Comité Consejero

Glenn Galloway, Ph.D.
Director Programa de Educación y
Decano de la Escuela de Posgrado

Pablo A. Imbach.

Pablo Andrés Imbach Bartol
Candidato

Dedication

A mis padres…

A todos los que me aguantaron y con los que complete todas las facetas de estos tiempos…

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A Lucio por la confianza y la guía…

A las personas y las instituciones que me apoyaron…

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Imbach, P. 2005. Priority areas for payment for environmental services (PES) in Costa Rica. Tesis Mag. Sc., CATIE, Turrialba, Costa Rica. 106 p.

Key-words: environmental services, GIS, biodiversity, carbon, scenic beauty, potable water, irrigation, hydro-energy.

SUMMARY

A methodology was developed to give priorities to areas in Costa Rica to receive Payment for Environmental Services (PES). Priorities are given according to the provision of environmental services of the areas and the risk of the society of loosing the benefits of such services. The methodology approach is based on providing priorities spatially and therefore it was developed using Geographical Information Systems. A Multicriteria Decision Analysis (MCDA) framework was used to combine the different criteria in the form of maps. The study is framed on the 1996 Forest Law of Costa Rica that dictates the services that are to be compensated, the land use activities that ensure them and a financial mechanism to make the payment sustainable. The eligible activities under the scheme are forest conservation, forest plantations and agroforestry systems. Environmental services (ES) provision was evaluated for biodiversity, carbon, scenic beauty and water for human consumption, irrigation and hydro-electric generation. The risk of loosing the ES provision was evaluated as the risk of deforestation for forest covered areas and as land use change to intensive management crops for non forested areas (or as the risk of the above mentioned activities of being implemented). The resulting methodology is flexible as it can be adapted for different objectives since the ES provision and its risk can be evaluated separately for each service. It also allows being adapted to different societal or institutional preferences or changing scientific evidence since it integrates expert knowledge and variable weights to differentiate the importance of the criteria evaluated. Further work has to be developed in order to test the methodology robustness as well as autocorrelation among the biophysical variables used.

Imbach, P. 2005. Priorización de áreas para el pago por servicios ambientales (PSA) en Costa Rica. Tesis Mag. Sc., CATIE, Turrialba, Costa Rica. 106 p.

Palabras clave: servicios ambientales, SIG, biodiversidad, carbono, belleza escénica, agua potable, riego, hidro-energía.

RESUMEN

Se desarrolló una metodología para dar prioridades a las áreas en Costa Rica para recibir Pago por Servicios Ambientales (PSA). Las prioridades son otorgadas de acuerdo a la provisión de servicios ambientales de las áreas y el riesgo que tiene la sociedad de perder los beneficios percibidos por estos servicios. La metodología se basa en la asignación de prioridades en el espacio y por lo tanto se desarrolló con ayuda de Sistemas de Información Geográfica (SIG). Los diferentes criterios utilizados, bajo la forma de mapas, fueron combinados sobre el marco metodológico del Análisis para la Decisión Multicriterio (ADMC). El estudio se sustenta en la Ley Forestal de Costa Rica de 1996, que dictamina los servicios ambientales que se deben compensar, las actividades de uso del suelo que aseguran su provisión así como el mecanismo financiero para la sostenibilidad del pago. Las actividades elegibles en este esquema para recibir PSA son conservación de bosque, plantaciones forestales y sistemas agroforestales. La provisión de servicios ambientales (SA) se evaluó para biodiversidad, carbono, belleza escénica y agua para consumo humano, riego y generación eléctrica. El riesgo de perder la provisión de los SA se evaluó como el riesgo de deforestación para áreas con cobertura forestal y el riesgo del cambio de uso del suelo a actividades de agricultura intensiva para las áreas sin cobertura forestal (o el riesgo de implementación de las actividades mencionadas anteriormente). La metodología resultante es flexible ya que se puede adaptadar a diferentes objetivos debido a que la provisión de SA y su riesgo se puede evaluar separadamente para cada servicio. Permite también adaptarse a diferentes preferencias institucionales y sociales ó a cambios en la evidencia científica ya que integra conocimiento experto y diferentes pesos para diferenciar la importancia de los criterios evaluados. Se recomienda en trabajos futuros evaluar la robustez de la metodología así como la autocorrelación de las variables biofísicas utilizadas.

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Abbreviation and acronym list

ACCVC: Central Volcanic Mountain Range Conservation Area
AyA: Aqueducts and Sewers Institute
CANATUR: National Tourism Board
CCT: Tropical Scientific Center
DEM: Digital Elevation Model
ES: Environmental Service
FUNDECOR: Foundation for the Conservation of the Central Volcanic Mountain Range
FONAFIFO: National Forestry Financing Fundation
GAP: GAP Analysis
GEF: Global Environmental Facility
GHG: Green House Gases
GIS: Geographical Information Systems
IDA: Agrarian Development Institute
ICE: National Institute of Electricity
ICT: National Institute of Tourism
INEC: National Institute of Statistics and Census
IPCC: Intergovernmental Panel on Climate Change
MADM: Multi-attribute decision making
MAG: Livestock and Agriculture Ministry
MAUT: Multi-attribute utility theory
MCDA: Multi-criteria decision analysis
MINAE: Energy and Environment Ministry
MODM: Multi-objective decision making
PES: Payment for environmental services
PROARCA: Regional Environmental Program for Central America
SINAC: National System of Conservation Areas
UNDP: United Nations Development Program
UNEP: United Nations Environment Program

1. Introduction

1.1 The problem and its importance

Costa Rica is one of the very few countries in the world where the government has established a program for payments of environmental services (PES) to private land owners that voluntarily commit their lands to certain forms of land use. The program was created in 1996 with the new Forest Law (Law No. 7575) and since then, the number of land owner demanding PES has grown above the capacity of the Costa Rican government to pay. . This has created the need to prioritize among the areas offering such services, so that the government budget available for PES can be spent where the return to the Costa Rican society is the highest. . This prioritization should be based on a set of clearly stated criteria that will justify the allocation of public and private resources for PES and ensure their proper and efficient use.

1.2 Payment for Environmental Services (PES) in Costa Rica

1.2.1 History of forest incentives in Costa Rica

Barrantes (2000) distinguishes two historical periods regarding the use of forest conservation incentives in Costa Rica. The first one is defined from 1969 to 1995, and involved mainly the development of a legal framework for fiscal and economical incentives aimed to stop deforestation. At the time, the forest value was limited to its wood products only. This was later on modified during the second period, which starts in 1996. Based on Costa Rica's commitment to the Rio 1992 Conference –specifically the Climate Change and Biological Diversity Conventions- a broader variety of services from forest and forest plantations was acknowledged and stated in the 1996 Forest Law (Law No. 7575) (Barrantes, 2000; Chaves and Lobo, 2000; FONAFIFO, 2005).

The 1996 Forest Law and its regulations provide guidelines for protection and sustainable forest management, as well as for the recovery of forest on suitable lands by regeneration or forest plantations (FONAFIFO, 2002). The value given to forests in the 1996 Forest Law is used on mechanisms such as forest certification, a re-definition of the "forest management plan", as well as in the payment for environmental services.

These mechanisms are also accounted for in the Biodiversity Law, The Environment Organic Law and the Water Law (FUNDECOR, 2004). The Biodiversity Law specifically strengthens the PES concept by the regulation of the offer and demand of hydrological services (Castro and Barrantes, 1999).

1.2.2 PES in Costa Rica

The 1996 Forest Law No.7575 (in the following "1996 Forest Law") decrees the payment to land owners for their provision of environmental services (ES) to the society. Specifically the following environmental services are recognized (Asamblea Legislativa de la República de Costa Rica, 1996):

- "Mitigation of greenhouse gas emissions (fixation, reduction, sequestration, sinks and absorption)",
- "Water protection for urban, rural or hydro-energy uses",
- "Biodiversity protection for conservation and its sustainable use for science, pharmacological, research, genetic engineering, ecosystems and life forms protection",
- "Scenic beauty for tourist and scientific uses".

The 1996 Forest Law defines forest conservation, agroforestry and forest plantations as the eligible activities for PES, therefore the only activities that generate the environmental services mentioned above.

The Forest Financing Fund (FONAFIFO) was created along with the 1996 Forest Law as a dependence of the National System of Conservation Areas (SINAC). It provides administration and fundraising for the PES (Chaves and Lobo, 2000), and strengthens activities related to forest management, reforestation, forestation, land restoration, agroforestry systems, etc. FONAFIFO also processes applications, makes payments and defines priority areas for PES (Navarro, 2004[1]).

The funds used by FONAFIFO to finance the PES have different sources (FONAFIFO, 2005):

- Oil and other fuels taxes transferred through the Finance Ministry

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[1] Navarro, G. 2004. Activities compensated by FONAFIFO (personal communication). Turrialba, CR, CATIE.

- Private agreements for national or international sales of environmental services (4 agreements at the time)
- Projects (actually one with the World Bank/GEF and a national program for Environmental Services Certificates)
- Donations.

1.2.3 Study Justification

The 1996 Forest Law defines de foundations for a legal and institutional framework that integrates ecosystem generated services into a market system. Within this context, an economic and ecological assessment tool for ES would be extremely useful, since it would place a value on the areas assigned for protection and the costs of their preservation. This in turn, would improve the understanding of the impact of human activities on the provision of ecosystem services (Costanza and Farber, 2002).

Currently FONAFIFO gives priority regarding PES to counties with low Social Development Index, biological corridors, areas for water resources protection, and lands with high soil or biodiversity degradation (FONAFIFO, 2005). Although this priority is aligned with current development needs, it does not ensure a sustained provision of environmental services to society, which is the main objective of the PES program in the 1996 Forest Law. The main problem arises because some areas receiving payment could be providing high amounts of ES but without any risk of losing this provision under a scenario lacking PES (*i.e.* forests in areas that provide large amounts of ES without any threat of deforestation because of its inaccessibility).

The tool developed in this research contributes to this objective by providing information useful to the prioritization of areas suitable for PES. The varying importance and usefulness of these areas are identified, based on the quality of the services offered by their ecosystems and the risk of implementation or failure of the activities that generate these, both defined by the 1996 Forest Law.

1.2.4 Analysis approach

The general research objective is to develop a method to identify priority areas for the payment of environmental services in Costa Rica.

Priority areas are those which, by implementing an eligible activity, present a relatively higher ES provision as well as a high risk of implementation or failure of the activity generating the services, so that society is at risk of a high ES reduction or loss in the without PES scenario.

This implies the analysis of two main components: the spatial variability of the relative provision of ES, and the spatial variability of the threats to the activities generating the ES.

The relative provision of ES means that services will not always be spatially evaluated in terms of concrete units (i.e. tons of carbon or number of people drinking water). In some cases, the importance of an area regarding its provision of ES will not depend on a specific measure unit, but of its ranking in relation to other areas according to a set of criteria (as in biodiversity conservation priorities). The methodology accounts for ordinal properties of the results (ES provision or risk maps) but not for cardinality. In other words, this methodology shows which area is a priority for PES compared to another but not in which measure it is more important. This is because the improvement in terms of the final outcome (ES provision to the society) is unknown.

The relative provision of ES will be disaggregated in the four services contemplated in the Forest Law and over which FONAFIFO offers compensation: biodiversity, water, carbon and scenic beauty.

Threats to environmental services will be modeled as the risk of implementation or failure of the eligible activities for compensation under the current PES scheme: - forest conservation, - forest plantations and agroforestry systems. Risk of implementation or failure is defined in this study as the risk of an activity of being replaced by another land use or as the probability of an activity of being implemented without PES.

Activities not eligible for PES are supposed not to generate ES (according to the Forest Law) which might not be entirely true, although this is assumed because the current study intends to fit in the current legal framework. The current framework pays for certain land uses or land use changes without considering a quantification of ES provision neither for an economic valuation of the ES provided.

Therefore, the specific objectives are:

1. To develop a method that spatially quantifies the relative provision of the environmental services in Costa Rica: carbon, water, scenic beauty and biodiversity.

2. Develop a method that spatially quantifies the relative threat to each activity eligible for PES: forest conservation, forest plantations and agroforestry.
3. Develop a method that identifies priority areas for PES based on its contribution of environmental services and the threat to the activity that generates them.

The problem context requires the integration of environmental management concepts as well as spatial planning, in which the combination of Geographic Information Systems (GIS) and Multi-criteria Analysis, have proved useful (Malczewski, 1999).

Others issues should be addressed in order to further extend this methodology (besides its own improvement), among them: the variability of the costs to provide ES, the administrative and institutional needs in order to use the methodology, opportunity costs of the activities being implemented in priority areas, etc.

2. Literature review

2.1 Environmental services

2.1.1 Ecosystems functions and valuation of environmental services

The 1996 Forest Law defines a set of activities eligible for PES. The payment supposes a direct relation between ecosystem management activities and the generation of environmental services.

Goods and services provided by ecosystems are the direct or indirect benefits perceived by the population, produced by ecosystem functions, and are known in general as environmental services. These services consist of a combination of a flow of materials, energy and information of the natural capital stock with manufacture services or human capital (Costanza *et al.*, 1997). The human actions that threaten the environment, its resources and ecosystems can raise the cost of maintaining the flow of environmental services and/or reduce potential human well-being (Costanza y Farber, 2002).

The value of nature is linked to the environmental service and defined in different ways. One definition refers to the contribution that something does to keep the state or condition of a system, for example the value of a species in maintaining the condition of a forest (Costanza y Farber, 2002). Another definition is focused on the contribution of a system to a purpose, in this case the purpose can be human well-being, its equitable distribution (Costanza y Farber, 2002), and its survival (Farber *et al.*, 2002).

The sources of values mentioned above are used as guides for ecosystems management, where a key element is quantifying the probability of losing environmental services by the effect of human activities on ecosystems functions. The fragility of ecosystems is then important when referred to the services humans are dependent on, and not when referred to the natural system itself. Therefore, it is necessary for ecosystems management policies not only to measure the magnitude of the provision of environmental services but also ecosystems fragility (Costanza y Farber, 2002).

Synthesizing, observed ecosystem functions are redefined as “environmental goods and services” when considering human values (de Groot *et al.*, 2002). In this study, the value of an ecosystem is defined in terms of a goal, for example, certain quality and quantity in the provision of drinking water for the population (Farber *et al.*, 2002; de Groot *et al.*, 2002).

2.1.2 Giving a value to the environment

A value system must be defined after the valuation object. This value system delineates the rules and moral criteria that people use to give importance or necessity to their beliefs and actions, implying objectives and practical actions (Farber *et al.*, 2002). "Environmental service" is then used to understand that the function and structure of nature has a value for humans (Limburg *et al.*, 2002).

Generally, environmental policies are based on mixed value systems. These value systems consider an intrinsic value in nature (so it is kept in a sustainable way) and an instrumental value (in the measure they satisfy human preferences) (Farber *et al.*, 2002).

Usually the relationship between the effects of specific environmental policies and the satisfaction of human preferences is not fully understood. Although the "dose-response" relationship between land use management and the provision of environmental services is not fully known (measurable) its estimation is necessary in order to put a PES system in place (Campos *et al*, 2005).

2.2 Biodiversity

The 1996 Forest Law defines biodiversity as an environmental service. It legislates its conservation and sustainable use for scientific, pharmaceutical, research, genetic engineering, ecosystems and life forms protection purposes.

Biodiversity on earth declines rapidly as a consequence of certain human activities (Convention on Biological Diversity, 2004). Therefore, an effective evaluation of the actions taken to suppress the process of biodiversity degradation is necessary (Rousseau y Van Hecke, 1999). On the other hand, Mesoamerica is considered one of the biodiversity "hotspots" at global level (areas with at least 1500 endemic species of vascular plants and 70% of habitat loss) (Conservation International, 2004). Considering this, two questions arise: - What should we preserve? and – How to implement measures efficiently?

2.2.1 What should we preserve?

Conservation of biodiversity has evolved from focusing in conservation of species with particular importance (social or economic) to a broader meaning, aimed at keeping ecosystems functions and services, trying to preserve the variety of species, genes and ecosystems (Sierra *et al.*, 2002; Lathrop y Bognar, 1998; Ferrier, 2002; Moore, 2003).

Rousseau and Van Hecke (1999) value biodiversity by considering two components: species richness and its uniformity. The first provides the number of species while the second component explains the relative abundance of species. The combination of both leads to a measure of "heterogeneity" that can be understood as a measure of biodiversity (Rousseau and Van Hecke, 1999). Justus and Sarkar (2002) add the concept that conservation of biodiversity efforts should not only maximize the number of species but also keep the representation of biomes and ecosystems in a region (known as the complementary principle).

The problem of conserving species representativeness with a broader focus involves measuring factors such as persistence, vulnerability to threats, size and reserves connectivity, evolution role, minimum population viability, juxtaposition of areas, protection gradients, disturbances, large scale processes and climate change (further details in Sierra *et al.*, 2002; Ferrier, 2002; Moore, 2003).

The Mesoamerican Biological Corridor is a large scale conservation effort in Central America, which aims to preserve areas important for biodiversity conservation in the area between southern Mexico and Panama, through a network of protected areas, their buffer zones and biological corridors (UNDP and UNEP, 2005).

2.2.2 How conservation efforts should be implemented?

Biodiversity conservation requires among others the identification of areas that should be included in a national or regional system of protected areas.

Ferrier (2002) points out that to achieve this identification, the spatial distribution of biodiversity components should be known. Because this task is usually complex and incomplete, biodiversity conservation efforts resort to entities for which we know the distributional information as surrogates for the spatial pattern of biodiversity (or "biodiversity surrogates").

2.2.3 Species and taxons as biodiversity surrogates

The most common surrogates used are particular species and higher taxa (genus or families), which include species with a particular social or ecological importance or all species within an indicator group (Ferrier, 2002). Various problems arise with the use of selected species as surrogate of the total biodiversity distribution. The first problem is that these indicators are not always related to biodiversity distribution on its totality (Andelman y Fagan, 2000). In addition the data sources are not always exhaustive and random; therefore the use of interpolation techniques is needed to fill information gaps (Ferrier, 2002).

Interpolation related problems are magnified at detailed scales, for example when giving priorities to areas within a "region" instead of between "regions" based on its species richness. The problem is centered in locating species in places where they are not or in predicting species absence in places where they exist (Ferrier, 2002).

2.2.4 Discrete terrestrial classes as surrogates

A different approach is the use of environmental maps originated from remotely sensed data. It counteracts the drawbacks of the previous method by dealing with discrete terrestrial classes (for example: ecosystems, vegetation types, etc.) supposing the characterization agrees with the distribution of biodiversity patterns. Hence, maintaining representation for all the classes would preserve most of the present species. The advantage of this method is that mapping of all the units managed is fast and affordable. This is attained through analysis of remotely sensed data from space or airborne sensors such as multi-spectral scanners or radar which should be complemented by fieldwork whenever possible (Ferrier, 2002).

The assumption in this approach is an existing correlation between species distribution and the classes generated on the map. This correlation has been rarely confirmed and it is possible that the results would be poor in many cases. This is due to variables such as competition, depredation, local extinction, barriers, etc. that generate a patchy distribution of species distribution, particularly when analyzed at a more detailed scale than the one used to map terrestrial classes (Ferrier, 2002).

There are different methods to map discrete terrestrial classes as surrogates of biodiversity distribution, among them (Honnay *et al.*, 2002):

1) Mapping of Habitat Heterogeneousness: Habitats with heterogeneous abiotic conditions have more diverse potential niches. For example, physical structure variations can be used to map the distribution of plant species richness (i.e. appearance, drainage and/or texture).
2) Isolation and Patch shapes: In fragmented landscapes the distance between potential habitats determines species composition and richness. In this same venue, irregular patches possess more environmental gradients, hence more plant species.
3) Scenery Heterogeneousness: Landscape composition, combined with different size/shape patches under human or natural management, have a considerable effect on biodiversity distribution.

Biodiversity landscape indexes and their response to landscape structures and scale have been studied, however, little is known regarding their relationship with biotic or plant diversity distribution (Honnay *et al.*, 2002).

2.2.5 Combined surrogates

The combinations of both strategies originate a third approach, which is known as “fine filter/coarse filter”. This approach somewhat mitigates the flaw in the scope range of the “species and taxons” surrogate and the low correlation with real biodiversity distribution of the “discrete terrestrial classes” surrogate. In a combined approach, conservation areas that consider all terrestrial classes is developed, and known information on the distribution of particularly important species distribution is considered in its design (Ferrier, 2002).

The Gap Analysis Program (GAP), developed under the Natural Resources Division of the US Geological Survey, is an example of an application of the “fine filter/coarse filter” approach (Scott y Jennings, 1998).

The GAP aims to identify biodiversity elements that do not have an adequate representation in protected areas, so that it provides feedback for the design of new conservation areas (Crist, 2000; Scott and Jennings, 1998). Initially, the identification of species rich areas was utilized within this context, however this emphasis was later changed into and analysis that would represent all the elements (Crist, 2000; Scott and

Jennings, 1998). The method basically comprises the combination of maps of vegetation coverage and animal species distribution with maps from the protected areas system. Following this, a representation of biotic elements on different management categories is calculated (Crist, 2000; Scott y Jennings, 1998).

Some limitations of this method are due to the lack of consideration to the following elements (Crist, 2000; Scott y Jennings, 1998):

- Precision analysis, for example, due to mapping errors that might reduce the precision of the results when integrating errors from the different map sources;
- Analysis of the historic distribution of the analyzed elements, for example, a well represented species may have had a great reduction in the occupied area for other causes than a recent perturbation being studied;
- Element viability, for example, a population may not survive due to habitat quality loss.

2.3 Water

The focus of this research is based on the environmental services receiving incentives from the 1996 Forest Law. This Law specifies that hydrological resources will be valued for human consumption, irrigation and hydro-energy production. The resource will be evaluated based on its current use.

In the following paragraphs, the variables that grossly affect the resource are detailed, as a parameter to determine areas upon which PES might signify a better environmental service.

2.3.1 Contaminants

Contaminants can be released into the atmosphere, soil or water either dissolved or in gaseous form. Pollution sources are divided in two categories: point and non-point sources. There is not a clear distinction between the two types of sources, because one source type can fall into the other category when the scale of analysis is changed. One difference between the two of them is that point source pollution can be collected, controlled or treated; in the case of non-point sources this could only be achieved if all point sources of contamination that belong to it are found (Meybeck and Helmer, 1996).

Most of the point source pollution affecting water comes from the discharge of domestic or industrial wastes and from agricultural practices such as cattle raising. Other agricultural practices such as agrochemical use are considered non-point source pollution (Meybeck and Helmer, 1996).

Point source pollution is related by definition to an outlet. Waste waters without treatment, for example, are the biggest point source of pollutants worldwide. Other sources are mines and industrial wastes (Meybeck and Helmer, 1996).

Non-point sources do not have a single point outlet; instead they consist of many outlets over a large area. Typical examples include: - runoff water in agricultural areas, including surface and sub-surface erosion with the transfer of organic and inorganic particles, nutrients, pesticides and herbicides to water bodies; - runoff from urban areas that do not flow to a main drainage, transferring oil derivates, bacteria, metals, inorganic industrial contaminants as well as agrochemicals from the management of green areas; - municipal and industrial waste sites, liquid waste sites or sediments; - navigation wastes from ports, marinas or lakes resources exploitation (oil or natural gas) (Meybeck and Helmer, 1996).

2.3.2 Water environmental services

Water for human consumption, irrigation and transportation has always had priority over other long term services that water provides to society. These other services have only recently acquired importance. It is now understood that aquatic ecosystems provide goods and services in the short term (potable water provision, food support, flood control, waste purification and habitat for plants and animals) and long term (sustained provision of the mentioned goods and services as well as adaptive capacity to environmental disturbances) (Baron *et al.*, 2002; Baron *et al.*, 2003).

Baron *et al.* (2002) made an inventory of useful activities for ecosystems restoration in order to ensure water ES provision, including: management of the water flow variability, identification and control of point source and non point source pollution, use of improved agricultural practices and management of the maximum total load of the contaminant.

2.3.3 Water for drinking

Identification of specific points (point source pollution) and its effect on water quality is the most common method used to solve contamination problems (Harrison, 1998) and therefore the first step in mapping polluted areas. The analysis of other pollution sources is complex and presents some flaws. For example, the effect of habitat degradation, non point source pollution and cumulative effects of sub-lethal levels of contaminants on water quality is still unsolved (Griffith, 2002). There is also a deficient monitoring of water quality related to use and land use change on regional scales where the use of data from remote sensors can be very helpful (Harrison, 1998; Griffith, 2002), as well as traditional information from streams monitoring (Harrison, 1998).

The sources of pollution that are less understood (mentioned above) have an important impact in agricultural lands due to the physical changes occurring in streams and the effect that the runoff surface has on the water quality. There are many approaches to understand the processes relating water quality and land use and its characteristics. Some studies are oriented to the effect of different land uses on water quality while others evaluate the influence on a watershed level considering the spatial arrangement of land uses and landscape pattern indexes on water quality. The use of digital elevation models combined with these techniques has been also evaluated to explain the relationship between land use and water quality (Griffith, 2002).

In spite of the mentioned approaches there is still a need to efficiently analyze medium and large watersheds throughout large areas. This seems to be the reason to perform water quality studies on a watershed level with a landscape approach. Some difficulties arise, as explained before, because of the complex relationships between landscape metrics and water quality. To provide a landscape approach to these studies, efforts should concentrate on field work linked to geographic information systems (GIS) and data from remote sensing sources (Griffith, 2002).

2.3.4 Hydroelectric energy

Sedimentation rate is variable between land uses and agricultural practices and has a direct effect on the production of hydroelectric energy; the life span of dam reservoirs is determined throughout the world by the sedimentation rate that reduces the capacity of water storage and the production of energy. The production of sediments in the watershed is related to the erosion rate and sediments transport (Rodney, 2000). Globally, the average annual reduction of the water storage capacity due to sediments in dam reservoirs is between 0.5 – 1% (Rodney, 2000 and Palmieri *et al*., 2003). Sediments also degrade the infrastructure by abrasion and blocking of water outlets, which affects activities located downstream and increases the load on the dam (Palmieri *et al*., 2003).

In most cases, dams are designed for their projected lifespan only, without consideration to sediments management and end of activities after the project's intended lifetime (Palmieri *et al*., 2003). Therefore sediment management is a problem that should be solved during the dam's lifespan given that otherwise it will be left to coming generations.

The existing techniques for sediment management can be categorized as:

- reduction of the sediments intake (watershed management among others),
- sediment management inside the reservoir,
- replacement of the lost storage capacity ,
- sediment evacuation,
- project closure.

In the watershed management context erosion control is one of the viable options to reduce sediment transport, although erosion control measures must be implemented for many decades before they take effect (Palmieri *et al*., 2003),. In many cases the time lag between the start of control activities and their effect may have caused for the activities to appear ineffective. This situation is common when the recharge area is large, due to the long time required for sediments to arrive at the reservoir. The contrary has been demonstrated when sediments are fine and arrive quickly to the rivers (Palmieri *et al*., 2003).

A bad correlation between sediment production and erosion rates makes it difficult to estimate the sediment load that enters the reservoir (Rodney, 2000). It has been discovered that the rate diminishes when the recharge area increases (Rodney, 2000 and Palmieri *et al*., 2003). The problem is due to the diversity of factors involved in the erosion rate, among them: climate (precipitation, runoff, speed and direction of the wind), geotectonic (geology, soils and tectonic activity), topography (slope, watershed orientation, drainage area and density), vegetation, land use and human impacts.

In areas where the land use in the watershed is stable, the storage capacity loss is constant and increases when deforestation processes exist (Rodney, 2000).

The relationship between sediment transportation in rivers and the processes in the recharge area is poorly understood; therefore the impact of human activities on watershed management cannot be predicted. A field assessment by experts is recommended for specific cases (Palmieri *et al.*, 2003). An example of such a specific assessment has been published by Pallaris (2000), which used GIS to find areas with high erosion risk and then validated the results with field work by interviewing local people.

2.3.5 Irrigation

According to Meybeck and Helmer (1996), some type of water contamination produce benefits to irrigated fields (such as the presence of organic matter, algae or nitrates), while other can have minor effects (pathogens, organic micro-contaminants and trace elements). The only significant problem could be the presence of salts on irrigation water, although this problem has not been identified on such projects in Costa Rica (personal communication Schweizer[2], 2005).

2.4 Scenic beauty

The 1996 Forest Law defines scenic beauty as one of the environmental services compensated in the PES. It is therefore necessary to identify the components of this service, as well as the way of evaluating it throughout the landscape.

2.4.1 General concepts

Scenery is defined as the general appearance of one place along with its view or landscape characteristics (the arrangement of the dominant natural characteristics observed in one place). It is composed of biophysical (water, vegetation, land forms) and cultural elements (resulting from the human activities on the landscape) (Galliano and Loeffler, 2000).

High quality scenarios bring benefits to individuals, communities and society (Harmer, 2000) on a psychological and physiological level (Galliano and Leffler, 2000). In this way the visual quality of the landscape is recognized as a unique and valuable natural resource, and is therefore included in environmental management plans (Crawford, 1994; Germino *et al.*, 2001).

Scenery evaluation consists of an inventory of landscape components and their analysis, so it may contribute to decision making in planning by considering the criteria above and

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[2] Soils Department, National Institute of Agrarian Technology (INTA)

the way people value the environment (Galliano and Loeffler, 2000). Galliano and Loeffler (2000) found that although cultural attributes are positive to scenic beauty, a basic premise for landscape management systems is that in public areas, people have come to expect a view dominated by nature instead of cultural alterations.

2.4.2 Landscape evaluation

Scenery evaluation of large geographical areas use two basic elements: *landscape character* and *scenic integrity*. Landscape character is the general impression of the scenery resulting from natural processes and human influences and can be described by using attributes such as landforms, vegetation, water forms and cultural forms. Scenic integrity is the degree in which the landscape is intact and complete and it is used as an indicator of its scenic condition, considering the degree of visual deviation from the landscape character.

Thematic landscapes are a component of landscape character applied in large geographical areas and it can be used to identify purposes or goals of the landscape character. It is a way of identifying and describing the visual and cultural impressions created by landscape arrangement and its land use patterns (Harmer, 2000 y Galliano y Loeffler, 2000).

Scenic integrity is used as base line to measure, in relative terms, potential changes in the landscape. A high scenic integrity landscape has no discordant elements and human alterations are positive, providing a good visual condition. The opposite would be discordant elements such as contrasting geometric figures that do not mix with the surroundings, for example, treatments to the vegetation, roads, etc. (Galliano y Loeffler, 2000).

There are four methods to evaluate the way people react to the landscape (Preston, 2001):

- expert techniques: are performed by landscape architects and are based on experience and formal landscape theory, taking into account characteristics such as line, form, color and texture. The method has the advantage that it does not always relies on the assessment of the community preferences and thus can be used when the budget is restricted,

- quantitative polls: using social research techniques to measure the reaction of people to landscape characteristics (usually shown in photographs) an involves a complex task when people's preferences have to be transferred to maps,
- focal groups: using social research techniques to describe the response of groups of people interacting with the landscape (the method *per se* cannot be used to generate maps),
- contact with individual experiences: based on the understanding of the on-site individual experience in the interaction between the person and the landscape (subjective sensations, expectations and interpretations of the encounter with landscape).

In spatial modeling, the most common method in the mapping of preferences of the community for a scenario is based on expert input. The expert assigns a value to the units in the map according to an observation. Another approach is to statistically model the preferences and locate them according to information collected from remote sensors. A third approach consists of assigning preferences to units in the terrain based on predictions from valuation of photos of representative points in the landscape (Preston, 2001). Most of the quantitative approaches are based on simulations of visibility lines making planimetric or perspective maps (simulating the landscape viewed from any point in the surface) (Germino *et al.*, 2001).

2.5 Carbon

Carbon sequestration is considered a global environmental service due to its role in relation to global warming. This is described in the following pages, along with the political context of global warming mitigation, to justify its inclusion into the PES scheme. Methods used in the quantification of carbon sequestration are also explained.

2.5.1 Global warming and its mitigation: a global context

Climate changes occur due to climate variability and to natural and anthropogenic external factors. The effect of these factors on the surface temperature of the earth is known as "*radiative forcing*", and when its value is negative the earth temperature decreases and vice versa (IPCC, 2001a).

The concentration of atmospheric carbon dioxide (CO_2) has increased 31% since 1750 Around three quarters of the (CO_2) emissions in the last 20 years come from the burning of fossil fuels, while the remaining quarter comes from land use change activities, predominantly deforestation. Other greenhouse gases (those with an effect on radiative forcing) such as methane, nitrous oxide and halocarbons present a similar situation. In general, there is evidence that global warming in the last 50 years has been caused by the concentration increase of greenhouse gases (IPCC, 2001a).

Technological options for reducing GHG emissions include the increase of renewable energy sources, more efficient production, distribution and use of energy, substitution of fossil fuels with fuels generated from renewable biomass, capture of fugitive GHG from waste disposals and industrial processes and carbon removal and storage by biological means, among others (IPCC, 2001b). GHG emission reductions on the biological field can be faced with three strategies: conservation of existing carbon sinks, increase or creation of new carbon sinks and substitution of synthetic products with biological products produced in a sustainable way. Sinks conservation is the combination of leaks preservation with the control of deforestation and other losses (Trexler and Haugen, 1995; IPCC, 2001b) in order to avoid future emissions. Also, the conservation and increase of sinks, though not a permanent solution, can provide a longer timeframe to implement permanent measures.

Annex 1[3] countries which ratified the Kyoto protocol consider land use change activities in their carbon accounting such as forestation, reforestation and deforestation among others. New plantations or forest regeneration areas will keep fixing carbon after their establishment if no major disturbance occurs at a rate that depends on species and site conditions (IPCC, 2000), therefore a large scale effort could considerably reduce carbon contents in the atmosphere (Trexler y Haugen, 1995).

Potentially, around 12 – 15% of all emissions from fossil fuel burning between 1995 and 2050 could be sequestered by forestry practices on a global scale. The estimation is based on the preservation of forest at risk of deforestation, natural forest regeneration, forest plantations and agro-forestry practices (Butcher *et al.*, 1998).

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[3] Annex 1 countries include developed countries belonging to the Organization for Economic Cooperation and Development (OECD) as well as 12 "economies in transition" (countries in Central and Eastern Europe, including some states formerly belonging to the Soviet Union)

There are complexities inside the context of the Kyoto protocol regarding the definition of forest, land use and land use change activities, as well as for carbon accounting methods, leaks and permanence of the sequestered carbon (further details in IPCC, 2000). Although there are some unsolved issues in the global discussion, the concept behind the PES for carbon sequestration is a measure for climate change mitigation (Asamblea Legislativa de Costa Rica, 1996).

2.5.2 Quantification of carbon

The contribution of land use change to the increase of atmospheric carbon concentration has been quantified in global scales (Detwiler y Hall, 1988; Houghton, 1999; Houghton *et al.*, 1983), as well as its carbon sequestration potential (Butcher *et al.*, 1998).

These studies include estimations of land use change rates and their effect on the release of carbon into the atmosphere, as well as its sequestration by terrestrial and aquatic ecosystems.

To estimate carbon sinks or sequestration potential it is necessary to have estimations of the carbon content in the vegetation and soils depending on each natural or disturbed ecosystem and its coverage proportion in the territory (Carbon density [C/ha] x ecosystem area [ha]). This can be achieved by taking representative field measures in order to have average estimates of carbon content in the different ecosystems or land cover classes.

2.6 Threats

Land-use change and management practices impact the flow of environmental services. Land use change refers to activities such as deforestation, forest plantations or natural regeneration. Management practices include the use of agrochemicals, low tillage practices and other soil conservation activities.

Certain types of land-use change and management practices represent threats to the provision of environmental services; therefore the threat or risk level should be assessed. In the current study the threat to the forest conservation activity is assumed as the spatial distribution of the risk of deforestation. In the case of agroforestry or forest plantation activities the threat level is assessed by the land use capacity as a proxy for the risk of implementing other land use activity instead of the eligible one; or the risk of implementing the activity and then having to change the land use because of unsuitable site conditions for its fulfillment.

2.6.1 Deforestation: from global to local perspectives

Forest destruction is the beginning of a series of processes that lead to environmental degradation. This includes erosion, climate change, biodiversity loss, air contamination, loss of watershed functions, decrease in the scenic quality and loss of wood and firewood (Bixbi and Palloni, 1996).

Despite the amount of existing literature, the causes of deforestation are still unanswered in the research fields of global environmental change. Rich arguments explain the underlying causes, although the empirical evidence still has problems with the statistical analysis between countries, which is, in some cases, linked to the uncertainty about deforestation rates (Geist and Lambin, 2001). There are two broad theories that explain this process. One considers shifting agriculture and population growth as the main deforestation drivers with other few variables, while the other uses many variables without a distinctive pattern (Geist and Lambin, 2001).

Among the specific causes of deforestation a highlight has been given by researchers to the combination of demographic pressure over the land with policies encouraging settlements in public lands, in such a way that an agrarian reform is avoided while relieving population pressure. Other indirect causes are growing benefits from commercial agriculture, increase in banana exports, cattle raising, land tenure institutions, policies, income distribution and inefficient technologies. Despite of research, studies show contradictions or inconclusive results concerning the causes of deforestation (Bixbi y Palloni, 1996). In an effort to solve this, Geist and Lambin (2001) made a global analysis, with a sub-national focus with the intent to find patterns. The results are disaggregated in three proximal causes: agricultural expansion, wood extraction and infrastructure expansion; and five broad causes: demography, economical, technological, political or institutional, and cultural.

In the Central American context, accessible low lands are under high risk of deforestation, demonstrated by the remaining forest patches and their inaccessibility. Pressures are originated by population growth, proximity to the North American market, government incentives that translate into intensive agriculture and cattle raising, along with subsistence agriculture, while the roads network increases the access to forest reserves (Achard *et al*., 1998). Harvey *et al* (2005) consider that these and other factors putted pressure on forests and more specifically to biodiversity, but today the pressure comes from the intensification of agricultural activities (*i.e.* agrochemicals, natural habitat loss within agricultural lands) and not mainly from changes in the configuration of landscapes (*i.e.* agricultural frontier and deforestation).

While evaluating the process in Costa Rica, Bixbi and Palloni (1996) found a univariate relationship between the potential population density and the deforestation probability, as well as more complex relationships with other factors such as accessibility, land tenure and ecological conditions.

Baxbi and Palloni (1997) synthesize the connections between deforestation and population growth. Scarcity of lands in areas that are traditionally agricultural, inequity in the access to lands and extensive production technologies, as well as the growing demand for firewood, wood and food, are directly related with destruction of forests. Their study is based on the assumption that the probability of deforestation increases with neighboring of settlements with poor farmers that grow at relatively higher rates. Some indirect connections are highlighted such as national and international markets, policies for local agrarian credits, new roads, terrain and weather conditions, increase in food consumption, import of wood extraction machinery, property rights, etc. These factors can also synergize, making the analysis of population effects more complex.

On a more detailed scale, Leclerc y Rodríguez (1996) identify the criteria to estimate the degree of threat of deforestation in the Central Volcanic Mountain Range (ACCVC) as the following: road density, farmer settlements of the Agrarian Development Institute (IDA), forest management plans, slope and distance to roads. Based on this methodology Pedroni *et al*., (2003) found a correlation between these parameters and deforestation areas during the 1986 to 1996 period.

2.7 Multi-criteria Decision Analysis (MCDA)

The study requires the integration of environmental management concepts in the form of criteria maps integrated into a hierarchical structure to evaluate the performance of certain activities. In this context the Multi-criteria Analysis methods and techniques can be used to solve the problem and therefore its basic concepts are reviewed in the following paragraphs.

Multi-criteria decision analysis (MCDA) is a process of taking complex decisions with mixed criteria in order to evaluate different alternatives. MCDA involves three general steps (Belton and Stewart, 2002):

- Problem identification and structuring: stakeholders, facilitators and technical analysts need to develop a common understanding of the problem, the decisions to be made and the criteria needed to evaluate the decision.
- Model building and use: includes modeling the decision maker preferences, value tradeoffs, goals, etc. in order to compare the feasible alternatives in a systematic and transparent way.
- Development of action plans: it means taking actions based on the analysis.

Malczewski (1999) further subdivides the model building step into defining the following items:

- a set of evaluation criteria (objectives and/or attributes) for the alternative actions,
- a set of alternatives or action variables,
- the decision environment which are the uncontrollable variables,
- the set of outcomes from each alternative and associated attribute.

The idea is to evaluate a number of alternatives (eligible areas for PES in this case) by a set of evaluation criteria (ES provision and activities risk maps) by using clearly stated preferences in an environment with fixed variables (*i.e.* land cover, topography, legal regulations, etc.).

The study in general aims at solving the problem identification and model building steps leaving the action plan to the national institutions involved.

2.7.1 Framework for Spatial MCDA

Spatial MCDA involves the combination of geographical data (input) into a decision (output). The decision making process defines a relation or decision rule between the input and output and involves the use of geographical data, the decision maker's preferences and manipulation of data and preferences according to certain decision rules. At the end we find multidimensional geographical data aggregated into unidimensional values for different decisions. “The critical aspect of spatial multicriteria analysis is that it involves evaluation of geographical events based on the criterion values and the decision maker’s preferences with respect to a set of evaluation criteria” (Malczewski, 1999).

Sometimes the problem complexity in terms of the amount of information and data and its interrelations can exceed the cognitive capacity of the decision maker. Therefore, the role of GIS and MCDA techniques is to improve the efficiency of the decision maker by solving spatial decision problems (Malczewski, 1999).

Spatial multi-criteria decision problems can be subdivided in two categories: spatial multi-attribute and spatial multi-objective decisions. They are also referred as multi-attribute decision making (MADM) and multi-objective decision making (MODM).

A MADM problem can be defined by the following decision rule (adapted from Malczewski, 1999):

$$[A_i\ (x_{i1}, x_{i2},\ldots,x_{in}) \rangle A_j\ (x_{j1}, x_{j2},\ldots,x_{jn})\ \vert\, V\ x_i, x_j \in X^m; i,j = 1,2\ldots m]$$

which can be interpreted as follows: “*Apply the decision rule to choose the best alternative (to order the alternatives* $\boldsymbol{x}_{i*}$*) in the set of feasible alternatives* $\boldsymbol{X}$*, according to the values of the n attributes*”.

A MODM problem can be defined by the following decision rule (adapted from Malczewski, 1999):

$$[A_i\ (f_{i1}, f_{i2},\ldots,f_{in}) \rangle A_j\ (f_{j1}, f_{j2},\ldots,f_{jn})\ \vert\, V\ f_i, f_j \in X^m, i,j = 1,2\ldots m]$$

which can be interpreted as follows: “*Apply the decision rule to choose the best alternative (to order the alternatives* $\boldsymbol{x}_{i*}$*) in the set of feasible alternatives* $\boldsymbol{X}$*, according to the values of the objective functions*”.

Belton and Stewart (2002) distinguish MADM as problems with a discrete set of alternatives to be evaluated (*i.e.* in which city, among a set of 6 possibilities, locate a new office of a company). MODM on the contrary have a huge (or infinite) number of possible alternatives from which the selection will be made based on the evaluated criteria and a set of feasibility constrains (*i.e.* the selection of the place for a new protected area might have a large number of possibilities, but the final selection will be made based on evaluation criteria and constrains such as areas without cities or annual crops, etc.)

There are a huge number of MCDA methods. The discrete MCDA methods (those with a discrete set of alternatives) can fall in three categories according to Guitoni and Martel, (1998):

- multi-attribute utility theory methods (MAUT),
- outranking methods,
- interactive methods.

The MAUT assume that there exists a utility or value function to represent the decision maker's preferences. Therefore after defining the function the ranking is straightforward. The function can be obtained in an additive, multiplicative, distributional, etc. way, assuming that there are partial utility functions according to each evaluation attribute (Guitoni and Martel, 1998).

Outranking methods or concordance methods, as in Malczewski (1999), use pairwise comparison of alternatives and provide an ordinal ranking of alternatives by telling, for example, if alternative A is preferred over alternative B. The method does not provide an idea of how much one alternative is preferred over another Malczewski (1999), but in some cases can select between strict or weak preferences (Belton and Stewart, 2002).

Interactive methods determine the best choice among the set of alternatives by a repetitive process in which the decision maker is presented with an evolving set of solutions until his preferences are met. The set of solutions evolves or changes according to the choice of the decision maker each time the set is presented and the decision rules updated in order to meet his preferences (Belton and Stewart (2002) and Malczewski (1999). As this is a not well structure method it is not recommended for group decision making (Belton and Stewart, 2002).

2.7.2 Steps in Spatial MCDA

(based on Malczewski, 1999)

The **problem definition stage** involves recognizing the "gap" between the reality and a different desired state. At this point the decision environment is defined and data is obtained and processed in order to find clues to identify opportunities or problems. This stage involves identifying the need of using available resources for PES efficiently and the opportunities to do it.

The **second step** involves defining the set of objectives concerning the decision problem and the measures for achieving those objectives. These measures are called *attributes*. A measurement scale must be defined for each attribute. The scale of measure defines how the attribute performs in order to achieve the objective and it is, therefore, the basis to compare alternatives. This step involved deciding how to find priority areas (based on ES provision and threat to activities that generates them) and the criteria and indicators that would be used to measure the ES and threats according to the general objective.

The evaluation criteria can be represented by *evaluation* or *attribute maps* (also known as *thematic maps* or *data layers*) or *constraint maps*. The first is a geographical attribute that allows the evaluation of the alternatives performances by the attribute, while the second displays limitations on the attributes or alternative decisions (i.e. a certain attribute value that defines a boundary in the alternative).

The definition of alternatives is linked to a value structure for the set of evaluation criteria (also called attributes). Attributes may be deterministic (values with a predictable effect on the output), probabilistic (limited information about the attribute values) or linguistic (imprecision or fuzziness concerning the description of semantic meaning of values).

The **third step** consists of defining weights for the evaluation criteria. Weights define the decision maker's preferences, by expressing the relative importance of the attributes to measure an alternative. Here the weights were assumed and/or calculated by expert assessment depending on the criteria and its characteristics.

A **fourth step** is accomplished by the design of an appropriate decision rule or aggregation function. The decision rule dictates how to rank alternatives or decides which alternative is preferred to another. A weighted addition method was used to aggregate criteria at the different hierarchical levels.

After defining the ranking of alternatives, a **sensitivity analysis** should be performed to evaluate the robustness of the analysis. An analysis is considered robust if changes in the inputs (attributes and decision maker's preferences) do not affect the output (ranking of alternatives).

The general process ends by making **recommendations** to support further actions. The last two steps were left for further study in order to test the methodology and then be able to use it for recommendations.

2.7.3 Attribute maps and scales of measurement

(based on Malczewski, 1999)

Attributes (criterion maps) can be measured by qualitative (i.e. vegetation or soil types) and quantitative (distance or elevation maps) scales.

Another distinction is made between natural and constructed scales. The first are those who have common usage and interpretation such as distance in meters to evaluate accessibility. The second involves subjective judgment, for example the aesthetic impact of a shopping mall in certain areas.

Both natural and constructed scales can be further subdivided in direct or proxy scales. Direct scales measure the degree of achievement of a certain objective directly (i.e. minimizing the cost of establishing a forest plantation by evaluating a map showing areas by the costs of establishing forest plantations), while proxy scales do it indirectly (i.e. measuring the use of scenic beauty by the number of tourists arriving at each location).

All scales can be applied to deterministic (when values are known with certainty), probabilistic (when values have a particular statistical distribution) or fuzzy attributes (elements without a well defined boundary).

2.7.4 Commensurate criterion maps

(based on Malczewski, 1999)

Attributes measured by different scales need to be transformed to comparable units before being aggregated in order to avoid an effect of the units used to measure the attribute on the results (further details in section 3.1).

Deterministic attributes are usually standardized (converted to commensurate scales) by linear scaling, value or utility functions approach. Linear scaling involves transforming all attribute values to certain scale by a linear function. The utility or value function converts different levels of an attribute into utility or value scores.

Two other approaches are the probabilistic and the fuzzy membership function. The probabilistic approach assumes that over repeated observations an event (outcome) will show a statistical regularity represented by frequencies between 0 and 1. Standardizing attributes can be also seen as a process of recasting values into a statement of set membership, where a fuzzy number provides the basis of defining a linguistic or fuzzy variable. The fuzzy numbers are states of a linguistic variable and the states are represented by linguistic concepts (i.e. “very short”, “short”, “medium”, etc.).

3. Materials y Methods

3.1 General approach

The methodology has two main components whose integration leads to the priorities for PES; this means that a map of ES provision is combined with a map of the threat or risk to the activities that generate ES.

Because the methodology is not producing priorities between the different activities but each one is evaluated separately, three priorities maps are generated, one for each eligible activity under the current PES scheme. To eventually compare priorities between activities a weight for each one should be defined based on knowledge of how priorities were calculated for each activity.

The quantification made for each ES as well as for the threat to the activities involves the combination of different criteria, measured with different units that have not only a different range of values but a different meaning in terms of the service evaluated. Adding data with different units of measurement and range on its values leads to units having an effect on the results. For example, adding a distance to forests layer (ranging from 0 to 50,000 meters) to a carbon content layer (ranging from 0 to 45 tons of carbon) might result in a layer with little or no effect from the carbon content layer (ranging hypothetically from 0 to 50,045). This issue is solved trough standardization of the criteria (as explained in section 2.7.4), in which all criteria are transformed into a common scale of measure and also the meaning of the values is assessed in terms of the objective (standardizations techniques are reviewed in Malczewski, 1999). In this study the "score range procedure" was used (as in Malczewski, 1999). For benefit criteria Equation 1a was used and for cost criteria Equation 1b. When *benefit criteria* is higher the value is more attractive and the criteria is to be maximized; and when *cost criteria* is higher, the value is less attractive and the criteria is to be minimized.

$$X'_{ij} = (X_{ij} - X_{jmin} / X_{jmax} - X_{jmin})*100$$ **Equation 1a**

$$X'_{ij} = (X_{jmax} - X_{ij} / X_{jmax} - X_{jmin})*100$$ **Equation 1b**

where:

X'_{ij} = standardized pixel value

X_{ij} = pixel value

X_{jmax} = maximum pixel value

X_{jmin} = minimum pixel value

Before integrating the criteria to generate the ES or threat maps, the relative importance of the criteria is assessed through the use of weights. Therefore the resulting map accounts for the relevance of each of the criteria to evaluate the output map (ES or threat map). Standardization and weights used to generate ES and risk maps to obtain priorities is based on weighted additions of standardized criteria (Figure 1 and Equations 2, 3, 4 and 5).

Activity priorities = ES + Risk **Equation 2**

ES = $\sum$[(Biodiversity * Wbd), (Carbon * Wc), (Water * Ww), (Scenic beauty * Wsb)] **Equation 3**

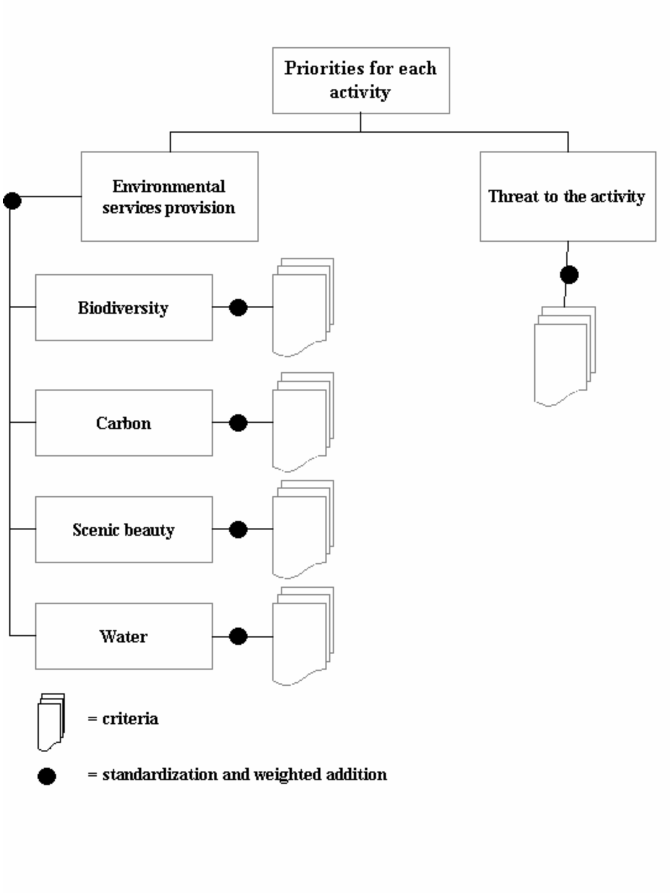
Activity risk = $\sum$ [(criteria 1 * W1), (criteria 2 * W2)…(criteria n * Wn)] **Equation 4**

ES (Biodiversity, Carbon, Scenic beauty or Water) = $\sum$[(criteria 1 ES * W1ES), (criteria 2 ES * W2ES)…(criteria n ES * WnES)] **Equation 5**

where:

ES = environmental service map
Risk = risk of implementation of an activity that generates ES
Wbd = weight of biodiversity environmental service map
Wc = weight of carbon environmental service map
Ww = weight of water environmental service map
Wsb = weight of scenic beauty environmental service map
Wn = weight of criteria map used to define each risk map
Criteria n ES = criteria used to define an environmental service map
WnES = weight of “Criteria n ES” map

Figure 1: General hierarchy for PES priorities



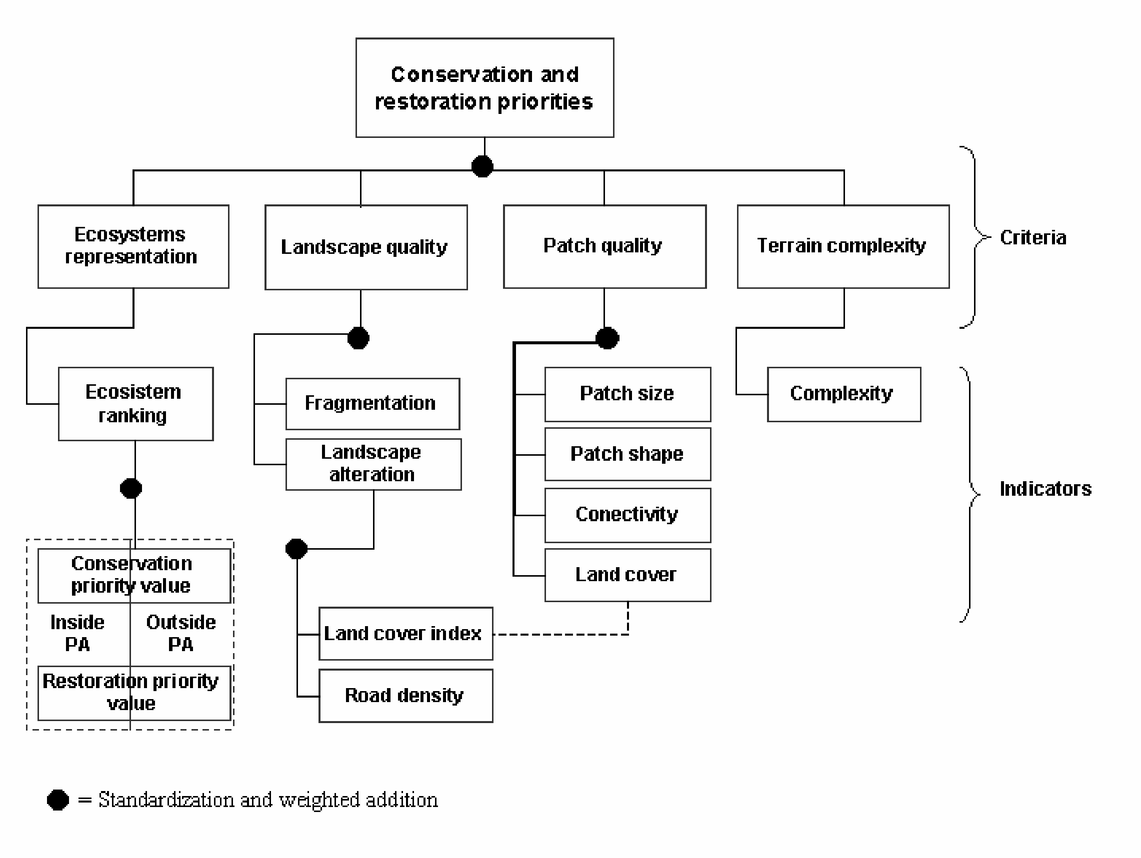
3.2 Biodiversity

The methodology used was developed specifically for this study and reviewed by a group of experts and it is based on the assumption that biodiversity environmental services have to be assessed using:

- representation criteria of ecosystems in protected areas (such as proposed by Scott and Jenings, 1998),
- landscape quality,
- forest patch quality,
- terrain complexity (as proposed by Roy and Tomar, 2000).

In this way the assessment considers ecological quality criteria as well as specific conservation and restoration needs for ecosystems poorly represented in the national protected areas network. Each one of these criteria is evaluated using different indicators as described in the following steps (Figure 2).

Figure 2: Biodiversity conservation and restoration priorities for PES



Weights were given by experts for different steps in the analysis (as shown with black dots in Figure 2), by answering different questions at each stage (Annex 6 shows the questionnaire given to the experts).

3.2.1 Terrain complexity

Terrain complexity is evaluated using a Digital Elevation Model (DEM) (Figure 1, Annex 1). A 10 meter pixel size DEM was used to calculate standard deviation of each pixel based on elevation values in a 250x250 meters window, resulting in a terrain complexity layer (Figure 2, Annex 1), that was standardized into a 0 to 100 scale with Equation 1a.

Elevation, slope, aspect and parent materials affect air and ground temperature and the quantities of nutrients, moisture, etc. and are, therefore, strongly related to the distribution of vegetation (Turner, *et al.*, 2001). The assumption is that as the terrain is more complex it has different orientations to the sun and therefore areas with different sun exposure, humidity, vegetation, etc., indicating a more diverse species environment. The map was standardized using equation 1a, assuming more species diversity when the complexity of the terrain is higher.

3.2.2 Patch Quality

The patch quality criterion is composed by the following indicators:

- patch size,
- patch shape,
- connectivity,
- biodiversity value of the land cover class.

To calculate patch size, shape and connectivity an undisturbed land cover class was generated based on Costa Rica 1996 land cover map provided by the National Meteorological Institute (1996). The resulting land cover class represents land covers without human intervention.

Cloud and shaded areas in the land cover map where replaced by classes from a forest cover map generated by FONAFIFO with satellite imagery from the year 2000. The remaining cloud and shaded areas were updated with a 1992 land use cover map from MAG (Livestock and Agriculture Ministry), resulting in a Costa Rica land cover map without clouds or shades (Figure 3, Annex 1).

The map of undisturbed land cover was obtained by grouping the following land cover classes: primary forest, secondary forest, mangrove, paramo and wetlands. The resulting undisturbed lands map was used for the following steps (Figure 4, Annex 1).

Patch size was evaluated by scaling patches from its lowest to highest area, resulting in a layer with highest value for biodiversity (100) on forest patches with 10,000 ha or bigger (according to Powel, 2000) and the lowest values for biodiversity (0) on the smallest patches. The assumption is that bigger patches provide better conditions for biodiversity. The following equation was used to standardize the patch size layer (PZ) (Figure 5, Annex 1 and Equation 6):

$$\mathbf{PZ} = 5.5*\mathrm{EXP}(0.00029*X_{ij}) \qquad \textbf{Equation 6}$$

where:

X_{ij} = standardized pixel value for patch size criteria

Patch shape was evaluated by the fractal dimension of each patch with Equation 7 as used in Fragstats (2005) (Spatial Pattern Analysis Program for Categorical Maps). The result is a layer whose pixel value is the fractal dimension of the forest patch that it belongs to (Figure 6, Annex 1). The fractal dimension layer (FD) was rescaled from 0 to 100 by linear transforming as showed in Equation 1a.

$$\mathbf{FD} = 2 \ln (0.25\, p_{ij}) / \ln a_{ij} \qquad \textbf{Equation 7}$$

where:

p_{ij} = patch perimeter

a_{ij} = patch area

The connectivity layer was calculated as the distance to the nearest undisturbed cover patch (Figure 7, Annex 1) and standardized as showed in Equation 1a.

The land cover biodiversity indicator was assessed through expert assessment by asking an evaluation of the biodiversity value of each land cover class on a scale from 0 to 100. The results of the given value were then averaged resulting in the land cover biodiversity value (Figure 8, Annex 1). The layer was standardized using Equation 1a.

Finally, all indicators where combined through simple weighted addition with Equation 8, to generate the **Patch Quality** indicator (Figure 9, Annex 1):

$$\textbf{Patch Quality} = [(PZ * 0.307) + (FD * 0.175) + (CON * 0.242) + (LCB * 0.275)] \qquad \textbf{Equation 8}$$

Weights used in Equation 8 were given by experts when asked to measure the relative importance of the indicators to define the patch quality criteria. The importance was assessed by scoring criteria between 0 and 100 and then rescaling the scores so they add 1.

3.2.3 Landscape quality

Landscape quality criterion (Figure 10, Annex 1) was evaluated as a combination of the following indicators: fragmentation and landscape alteration.

Fragmentation (Figure 11, Annex1) was assessed by calculating for each center pixel of a 3x3 km window, the natural cover area, by counting the number of pixels with natural cover. Therefore high numbers equal low fragmentation and vice versa.

Landscape alteration (Figure 12, Annex 1) was evaluated by combining a road density layer (Figure 13, Annex 1) and a landscape analysis of the biodiversity value of each land cover class (Figure 14, Annex 1). To calculate the second, land cover classes where given the value from the experts assessment of the biodiversity value of land cover classes, as explained in section 3.2.2 (Figure 8, Annex 1). Finally the center pixel of a 3x3 km window size was given the value of the sum of all pixels inside.

Fragmentation was standardized with Equation 1b and landscape alteration with Equation 1a, because in terms of biodiversity quality it is desirable to have low values for fragmentation and high values for landscape alteration given the way each indicator was measured.

Equations 9 and 10 explain the weights used for each indicator aggregation (obtained by expert assessment):

$$\mathbf{LA} = (LLCB * 0.601) + (RD * 0.399) \qquad \textbf{Equation 9}$$

$$\mathbf{LQ} = (FRAG * 0.471) + (LA * 0.529) \qquad \textbf{Equation 10}$$

where:

LA = landscape alteration map

LLCB = landscape analysis of the land cover biodiversity value

RD = road density map

LQ = landscape quality map

FRAG = fragmentation map

3.2.4 Ecosystems representation

Ecosystems were represented by Holdridge life zones (Figure 16, Annex 1). Life zones are defined by their precipitation, temperature, evapo-transpiration, humidity, altitude and latitude and can, therefore, be used as biotic units (Tosi, 1997).

Ecosystems were divided in four categories and each one given different priorities: conservation areas inside or outside protected areas; and restoration areas inside or outside protected areas. Conservation priorities were calculated for undisturbed land cover classes (explained in section 3.2.2) and restoration for disturbed land cover classes; from now on, conservation and restoration areas respectively.

Priorities for conservation of ecosystems with a conservation area under 10,000 ha were considered not viable. Powell (2000) uses this area threshold to define viable ecosystems based on the size of its area not disturbed by human activities, as they can hold viable populations of most large vertebrates according to Dinerstein *et al.* (1995) and were therefore given the highest priority (100). Ecosystems with conservation area over 10,000 ha where ranked using Equation 11. Equation 11 gives lower priority to ecosystems with larger areas remaining for conservation and higher priority to those with smaller areas remaining as their biodiversity is more threatened by destruction of its natural habitat.

Ranking = 100-((Undisturbed cover/Life zone area)*100) **Equation 11**

Priorities for restoration of ecosystems with conservation area under 10,000 ha where given the highest priority (100). It is assumed that they have less probability of recovering under static conditions as compared to ecosystems with larger areas remaining for conservation.

Ecosystems with area over 10,000 ha were calculated by an average between its existing conservation area (Equation 11) and a ranking by restoration area (Equation 12 and Figure 17, Annex 1). The ranking by restoration area gives priority to ecosystems having areas close to 10,000 ha, as they can become viable if restored. Lower ranking is given to ecosystems having smaller areas as they will not become viable; and to those with areas bigger than 10,000 ha as they can become viable and still keep areas not restored. Figure 3 shows Equation 12 and the way the ranking by restoration area was given.

Figure 3. Ranking by restoration area calculated with Equation 12.

The ranking by restoration area (Equation 12) is averaged with the ranking by conservation area (Equation 11) since ecosystems already viable should not be given priority on its restoration areas over ecosystems that are still not viable.

Ranking =

If $X<2500$ then, $(1*10^{-8}*X^3) - (6*10^{-5}*X^2) + (0.1217*X) + (0.9383)$

If $2500 \leq X \geq 12500$ then, $(5.241379*10^{-7}*X^2) + (7.9620689655*X) + (69.767217)$

If $X \leq 12500$ then, $87.396532*(12500/X)$

Equation 12

Final conservation and restoration priorities where evaluated by the importance of each activity whether it is implemented inside or outside protected areas. The relative importance was assessed by experts and resulted in weights that provide an idea of how successful can restoration or conservation activities are if they are implemented inside or outside protected areas. The weights were applied to conservation and restoration priorities as calculated in this section, depending on where the activity was implemented (inside or outside protected areas) resulting in the ecosystems priorities map (Table 1, Annex 1).

Resulting ecosystems priorities where standardized by Equation 1a to provide different rankings for areas within and outside protected areas as well as for conservation and restoration areas (Table 2, Annex 2).

3.2.5 Biodiversity

Integration of the previous described layers by a simple additive weighting, as described in Equation 13, resulted in the map representing biodiversity (BD) (Figure 15, Annex 1):

$$\mathbf{BD} = (ER * 0.4143) + (LQ * 0.3861) + (PQ * 0.1455) * (TC * 0.054)$$

Equation 13

where:

ER = Ecosystem representation
LQ = Landscape quality
PQ = Patch quality
TC = Terrain complexity

Weights for each criteria were evaluated by experts assessment, using the “pair wise” comparison method developed by Saati (1977) and whose calculation is automated in the GIS software IDRISI (available at www.clarklabs.org). The method asks the decision maker (the biodiversity expert in this case) to make pair wise comparisons between all criteria (to produce a ratio matrix) in order to calculate the relative importance among criteria. It takes as an input the pair wise comparisons and produces the relative weights. “Specifically, the weights are determined by normalizing the eigenvector associated with the maximum eigenvalue of the (reciprocal) ratio matrix” (further details and examples in Malczewski, (1999)).

3.3 Carbon

The biomass content of Holdridge life zones was used as an indicator of the carbon stock of undisturbed cover classes (primary forests, mangroves, paramo and wetlands) and secondary forests (Table 1) using values given by Tosi (1997) (Figure 4). For other land cover classes the potential for carbon sequestration was calculated as the difference between the carbon content of the existing land cover to average carbon content in forest plantations or agro-forestry systems (Table 2 and Figure 4). The resulting maps show carbon stock for forest and secondary forests (Figure 1, Annex 2), and the carbon sequestration potential from changing actual land use to forest plantations (Figure 2, Annex 2) or agro-forestry (Figure 3, Annex 2)..

Figure 4. Carbon environmental service.

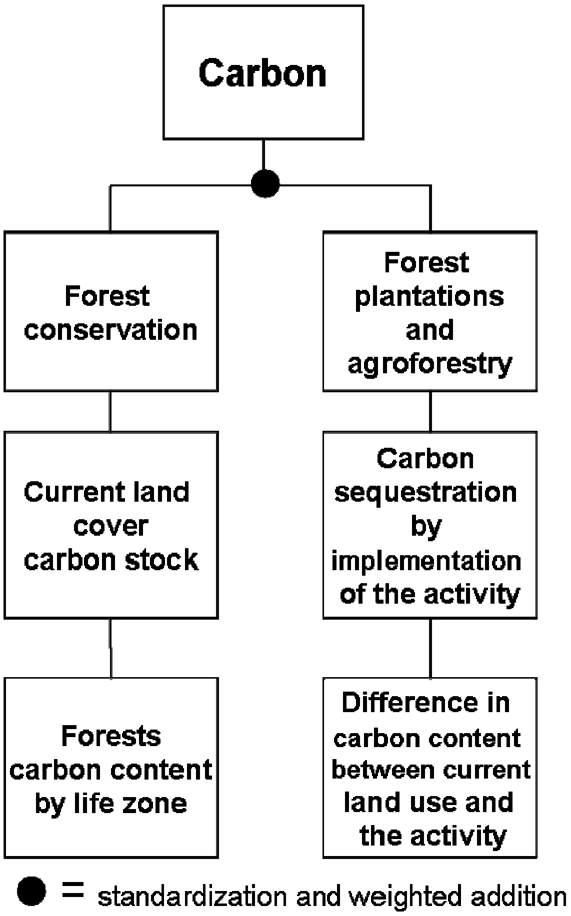


Table 1. Life zone biomass and forest and secondary forest carbon content (ton/ha).

Life zone	Biomass	Carbon content	
		Undisturbed cover [1]	Secondary forest[2]
Lower montane moist forest	171	86	43
Premontane moist forest	219	110	55
Tropical moist forest	282	141	71
Montane wet forest	272	136	68

Lower montane wet forest	326	163	82
Premontane wet forest	276	138	69
Tropical wet forest	324	162	81
Montane rainforest	254	127	64
Lower montane rainforest	295	148	74
Montane rainforest	254	127	64
Premontane rain forest	254	127	64
Tropical dry forest	198	99	50
Subalpine rain paramo	20	10	5

1. Carbon content of undisturbed land cover (primary forests, mangroves, paramo and wetlands) was assumed as 50% of its biomass.
2. Carbon content of secondary forests was assumed 50% of primary forests (PROARCA/CAPAS, 1998)

Table 2. Disturbed land cover biomass and carbon contents and sequestration potential by land use change to forest plantations and agroforestry (ton/ha).

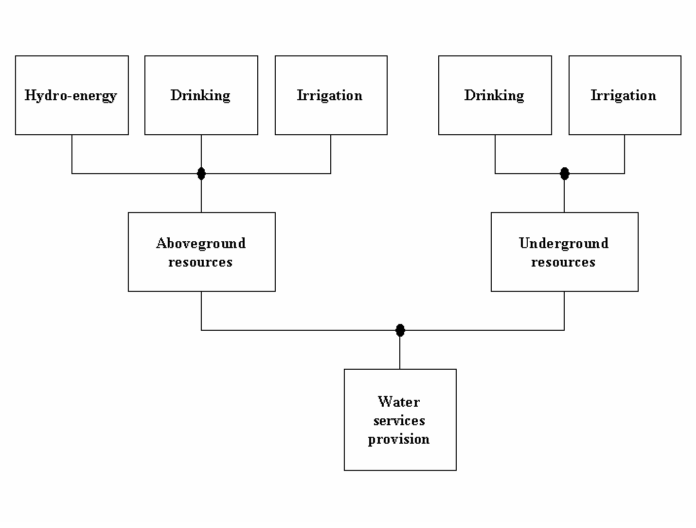
	Biomass	**Carbon[2]**	**Forest plantations sequestration potential[3]**	**Agroforestry sequestration potential[4]**
Burnt areas[1]	20	10	44	11
Urban areas[5]	0	0	54	21
Annual crops[5]	20	10	44	11
Perennial crops[5]	40	21	33	0
Pastures[5]	3	2	52	19
Mixed uses[1]	20	10	44	11
Initial forest sucessions[6]	10	5	49	16
Agricultural soils[1]	20	10	44	11

1. Biomass and carbon content assumed equal to annual crops
2. Carbon content assumed as 50% of its biomass content
3. Forest plantations average carbon content assumed as 54 ton/ha (Imbach *et al.*, 2005)
4. Agroforestry average carbon content assumed as 21 ton/ha (as in Locatelli and Pedroni, 2004)
5. Biomass content from Imbach *et al.*, 2005
6. Biomass content from PROARCA/CAPAS, 1998

3.4 Water

Water provision was evaluated by its current consumption for human use, irrigation and hydro-energy generation. Aboveground and underground water resources where considered and given priority according to the flow of water used. Figure 5 shows how the analysis was structured using the abovementioned criteria.

Figure 5. Water services provision map components.



• = Aggregation of standardized map layers. Standardization is made by linear scaling using Equation 1a.

Water in Costa Rica is a state owned good administered through concessions. Information on water concessions was provided by MINAE[4] , AyA[5] and ICE[6] in the form of point maps of wells and water takes or lists indicating the location (by name) along with the flow being used.

Areas that provide water from aboveground sources were given priority according to each concession basin and depending on the flow used as in Equation 17. Areas for underground water resources where given priorities by the area of the aquifer from which water is pumped and according to the flow used (Equation 17).

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[4] Ministry of Environment and Energy: is the state institution that administers concessions, except those of AyA and ICE who have rights over water use also.

[5] Aqueducts and Sewers Institute

[6] Costa Rica Electricity Institute

Pixel values over each basin or aquifer where given priority according to the flow used and then normalized by the area of each basin or aquifer. This is because the flow used has no relation with the basin or aquifer area, therefore high flow values can be on large or small basins or aquifers but the area to manage to ensure the same flow provision (i.e. by an eligible activities for PES) in a large basin is bigger than on a small basin. When each pixel value (which is equal to the flow used) is divided by the basin or aquifer area the problem is solved because priority are then given not only by the amount of water used but also considering the area that has to be managed in order to ensure its flow.

The water use map (Figure 1, Annex 3) is made by adding above (Figure 2, Annex 3) and underground (Figure 3, Annex 3) water resources (both resources maps are standardized with Equation 1a before adding them).

Aboveground water resources are generated by aggregating drinking (Figure 4, Annex 3), irrigation (Figure 5, Annex 3) and hydro-energy (Figure 6, Annex 3) water uses (resources maps are standardized with Equation 1a before adding them).

Underground resources integrate drinking (Figure 7, Annex 3) and irrigation uses (Figure 8, Annex 3) (resources maps are standardized with Equation 1a before adding them).

Figure 5, explains the hierarchical structure used to generate the water services provision map. Equations 14, 15, 16 and 17 show how each standardized map was aggregated using equal weights for all layers at each hierarchical level. For water ES weights where not assessed since it involves the consideration of many economic and social sectors and this was out of the scope of the study.

Water services provision = [(AR) + (UR)] / 2 **Equation 14**

AR = [(AHE) + (AD) + (AI)] / 3 **Equation 15**

UR = [(UD) + (UI)] / 2 **Equation 16**

AHE, AD, AI, UD, UI = flow / basin or aquifer area **Equation 17**

where:

AR = aboveground water resources

UR = underground water resources

AHE = aboveground water for hydro energy

AD = aboveground water for drinking

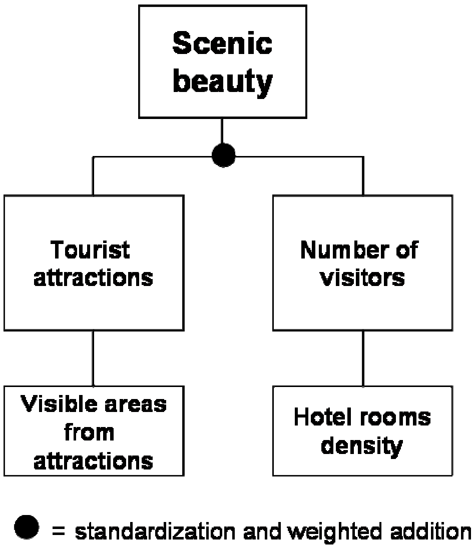
AI = aboveground water for irrigation
UD = underground water for drinking
UI = underground water for irrigation

3.5 Scenic beauty

Scenic beauty was prioritized according to the use of the service. Areas visited by tourists were used as a proxy for scenic beauty consumption. These areas where located according to potential tourist attraction areas identified by ICT[7] (Figure 6) and by calculating visible areas from each place with the use of the digital elevation model (DEM) (Figure 1, Annex 1). Locations were assessed as points and lines, the later for rivers and touristic roads and the former for any other tourist locations (beaches, waterfalls, etc.). The pixel value of the map of visible areas (Figure 1, Annex 4) accounts for the number of tourist attractions closer than 10 km that can see the pixel.

The map of visible areas was added to the map of hotel room's density (Figure 2, Annex 4) in order to give priority not only according to the number of attractions from which a specific point in the landscape can be seen but also according to the number of people using the scenic beauty of the place. Figure 6 shows how criteria were structured in the analysis.

Figure 6. Scenic beauty provision.



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[7] Costa Rica Tourist Board

Hotel room density was used as a proxy for the number of tourists visiting the area, assuming that the hotel infrastructure was built according to the number of visitors. The scenic beauty provision map is shown in Figure 3, Annex 4 and was generated by aggregating standardized layers (by Equation 1a) as shown in equation 18.

SB = (HR + VA) / 2 **Equation 18**

where:

HR = hotel rooms density

VA = number of tourist attractions closer than 10 km that can see the pixel

Hotel room's density was calculated by distributing the number of hotel rooms at each location radially to produce a continuous surface. The distribution takes in consideration the value at each point and distributes them proportionally in the pixels between all points by giving higher proportion to pixels closer to the hotel location.

3.6 Activities risk - Forest conservation

The methodology is adapted from Leclerc and Rodriguez (1996). It is based on developing a deforestation risk map (Figure 1, Annex 5) by combining population density (Figure 2, Annex 5), slope (Figure 3, Annex 5) and distance to roads (Figure 4, Annex 5). The combination was made with Equation 19 and the weights adapted from Leclerc and Rodriguez (1996).

Population density was standardized by Equation 1a while slope and distance to roads with Equation 1b since they are cost criteria (higher values mean lower deforestation risk).

Deforestation risk = [(Population density * 0.31) + (Slope * 0.16) + (Distance to roads * 0.53)] **Equation 19**

3.6.1 Population density

The population density map (Figure 2, Annex 5) was generated from population estimations by INEC[8] based on data from the 2000 national population census. An

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[8] National Statistics Institute

estimation of district wise population for June 2004 was used and distributed on the map based on:

- land cover classes: assessed according to their potential population density and standardized by Equation 1a (Table 1, Annex 5)
- slope: classes were generated according to the national standard for land use capacity (Cubero, 2005) (Table 2 and Figure 6, Annex 5) and ranked according to potential population density. The map was standardized according to Equation 1a.
- distance to roads: calculated from national roads coverage (Figure 4, Annex 5). It was assumed that areas at higher distances have less population density and therefore standardized using Equation 1b.

The criteria were combined with weights assigned as in Equation 20 to generate a surface for further steps (Figure 7, Annex 5).

Surface for Population Density = [(Land cover classes * 0.5) + (Distance to roads * 0.25) + (Slope classes * 0.25)] **Equation 20**

The next step was to distribute the census count data by district according to the *Surface for Population Density* to obtain the population density map, where the pixel value (X'_{ij}) accounts for the population density of the pixel (population living in a 900 m^2 pixel) (Equation 21).

$$\mathbf{X'_{ij}} = [(D_{pop} / \sum X_{dij}) * X_{ij}]$$ **Equation 21**

where:

X'_{ij} = Population (Nr) living in a 900 m2 pixel
D_{pop} = District total population
X_{dij} = Addition of the values of all the pixels within a district
X_{ij} = Pixel value in the Surfce for Population Density

3.6.2 Distance to roads

A distance to roads layer was generated by giving pixels the value of the distance to the nearest road in meters (Figure 4, Annex 5) and rescaled (0 to 100) with Equation 1b..

3.6.3 Slope

Slope classes (Table 2, Annex 5) were generated according to the national standard for land use capacity (Cubero, 2005) and standardized with Equation 1a (Figure 5, Annex 5).

3.7 Activities risk – Forest plantations and Agroforestry

Risk to forest plantation and agroforestry activities (Figure 5, Annex 5) was evaluated based on the land use capacity map developed by CCT[9], by assuming that lands suitable for annual crops represent the highest threat to forest plantation or agroforestry activities as opposed to reforestation or protection suitable lands (Table 3). The map was standardized with Equation 1a.

Table 3. Land use capacity classes and threat to forest plantations

Land use class	Threat level
Class I	7
Class II	6
Class III	5
Class IV	4
Class V	3
Class VI	2
Class VII	1
Class VIII	1

Land use capacity classes provide an idea of the land use activity that is suitable according to the following criteria: climate, soil type, erosion and drainage. Land use capacity classes are described by Cubero (2005) and recommend certain activities for each class:

- Class I: any agricultural or forest activity.
- Class II: weak limitations requiring management and soil conservation activities.
- Class III: annual crops require intensive soil conservation practices.
- Class IV: permanent or semi-permanent vegetation cover.
- Class V: pastures or natural forest management.
- Class VI: forest activities or permanent crops.
- Class VII: forest management or restoration.
- Class VIII: protection.

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[9] __Tropical Scientific Center

3.9 Priorities - Forest conservation, reforestation and agroforestry

Priorities were calculated by adding the ES layer with the risk to the activities layer standardized by Equation 1a (Equation 22). ES layer was generated by Equation 23 assuming equal weights for all services (0.25) and each map standardized by Equation 1a. The resulting maps give priorities for forest conservation (Figure 1, Annex 5), forest plantations (Figure 2, Annex 5) and agroforestry (Figure 3, Annex 5).

Priorities (each eligible activity) = ES + Risk (for each eligible activity)

Equation 22

ES = (ES Water * 0.25) + (ES Carbon * 0.25) + (ES Scenic beauty * 0.25) + (ES Biodiversity * 0.25) **Equation 23**

where:

Risk = risk to each eligible activity

ES Water, ES Carbon, ES Scenic beauty, ES Biodiversity = ES maps for each of the services as explained in sections 2.2, 2.3, 2.4 and 2.5.

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5. Article

5.1 Title

Determining spatial priorities Payment of Environmental Services in Costa Rica

Authors: Imbach, P.; Pedroni, L.; Koellner, T.; Alpizar, F.

Addresses of affiliations:

CATIE, Turrialba, Costa Rica

Tel, Fax, e-mail:

5582322, pimbach@catie.ac.cr

Present addresses:

Cambio Global, CATIE, Turrialba, Costa Rica

Address of correspondence:

Cambio Global, 7170 - CATIE, Turrialba, Costa Rica

5.2 Abstract

A methodology was developed to give priorities to areas in Costa Rica to receive Payment for Environmental Services (PES). Priorities are given according to the provision of environmental services of the areas and the risk of the society of loosing the benefits of such services. The methodology approach is based on providing priorities spatially and therefore it was developed using Geographical Information Systems. A Multicriteria Decision Analysis (MCDA) framework was used to combine the different criteria in the form of maps. The study is framed on the 1996 Forest Law of Costa Rica that dictates the services that are to be compensated, the land use activities that ensure them and a financial mechanism to make the payment sustainable. The eligible activities under the scheme are forest conservation, forest plantations and agroforestry systems. Environmental services (ES) provision was evaluated in for biodiversity, carbon, scenic beauty and water for human consumption, irrigation and hydro-electric generation. The risk of loosing the ES provision was evaluated as the risk of deforestation for forest covered areas and as land use change to intensive management crops for non forested areas (or as the risk of the above mentioned activities of being implemented). The resulting methodology is flexible as it can be adapted for different objectives since the ES provision and its risk can be evaluated separately for each service. It also allows being adapted to different societal or institutional preferences or changing scientific evidence since it integrates expert knowledge and variable weights to differentiate the importance of the criteria evaluated. Further work has to be developed in order to test the methodology robustness as well as autocorrelation among the biophysical variables used.

Keywords: environmental services, GIS, spatial priorities, biodiversity, carbon, water, scenic beauty.

5.3 Introduction

Ecosystems functions are defined as "ecosystems goods and services" when human values are considered (de Groot *et al.*, 2002 and Limburg *et al*, 2002) and are the direct or indirect benefits the population receives as a product from them (Costanza *et al.*, 1997).

Development of societies is dependent on the sustained provision of these environmental services (ES). Quantifications of ES at large (Costanza *et al*, 1997; estimates an annual average of 33 trillion US$) and small scales estimate the magnitude of this dependence. Human actions that threaten the environment, resources or ecosystems could increase the costs of keeping a long term flow of ES and reduce the human well-being potential. Therefore there is a value associated to ES, which is defined as its contribution to maintain a systems condition or as its contribution to a purpose (Costanza and Farber, 2002). Environmental policies are guided by mixed value systems, considering an intrinsic value in nature (as it is preserved in a sustainable way) and also an instrumental value (as it is used to satisfy human preferences); and deal with the fragility associated with the sustained provision of ES (Costanza and Farber, 2002; Farber *et al*, 2002).

The objective of the study is to develop a methodology to find priority areas for ESP. The method is based on finding the areas that provide most of ES and where this provision is at most risk. The methodology is applied to a case study in Costa Rica, following its current Forest Law and institutional guidelines. The risk of the ES provision is dependent on the implementation potential of land use activities that generates them under the current ESP scheme. Because both, ES and activities risks have a spatial distribution nature, the methodology is based on Geographic Information System (GIS). Therefore, the product could be used as a tool to assign ESP from a geographical perspective, based on bio-physical and socio-economic criteria.

The methodology is based on secondary data available at national level, and adapted to current efforts of Costa Rican institutions who are potential decision takers.

ESP priorities are political decisions, that suffer changes according to current institutional or governmental policies (i.e., one ES can be more relevant for the country or institutional efforts focus in only one ES). The methodology has the flexibility to adapt to changes in policy. It is useful to guide policies at a broad scale, based on biophysical aspects.

The case on study presented on this paper is based on the current Forest Law in Costa Rica (Asamblea Legislativa de la República de Costa Rica, 1996). The Forest Law defines biodiversity, water, carbon and scenic beauty as ES, and it dictates that users of the services should compensate its providers. It defines a juridical and institutional framework for an Environmental Services Payment (ESP) system.

The Law created the Fondo Nacional de Financiamiento Forestal (FONAFIFO)[10], as the institution entitled to administration and fund raising for PES (Chavez and Lobo, 2002) as well as to promote activities of forest management, reforestation, agro-forestry systems,

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[10] National Forestry Finance Fund

etc. It also receives applications for the PES, makes the respective payments and defines the areas where it will be applied. Currently forest conservation, forest plantations and agro-forestry (from now on the "activities") are the activities compensated for ES generation. The system funding is based on taxes to fuels, national and international agreements, projects and donations, which allowed introducing 315933 ha into the payments system in the year 2004 (FONAFIFO, 2005).

The system has proved to be successful, not only because the area integrated has had a sustained increase each year, but also for the period 1997-2000 only 34% of the demand to enter the payment system has been met (Barrantes, 2000). This situation highlights a need to be cost effective with the available funds, in order to have the best outcome on ES.

5.4 Methods and techniques

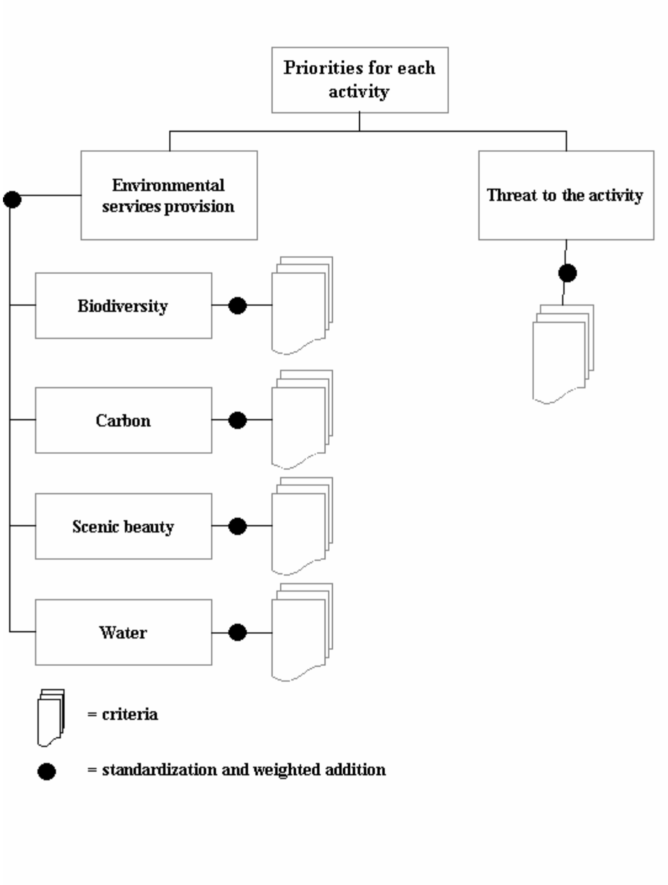
The method is based on mapping ES (carbon, biodiversity, scenic beauty and water for human uses) and risk to the activities that generate them (forest conservation, forest plantations and agro-forestry) to find priority areas for PES (Figure 1) under the Costa Rica Forest Law scheme. The method is a multi-criteria analysis integrated in a GIS that relies on secondary information collected from institutions in 2004 and, therefore, adapted to data generated by them. Key institutions that deal with ES were visited, the methodology presented and discussed, and geographical datasets collected for further use in the analysis.

Each ES and activities risk map is the product of a combination of criteria (in the form of maps). To aggregate criteria in order to produce ES and risk maps, they where standardized to a common scale to have commensurable map units (Malczewski, 1999). In the case study presented, linear transformation is used to produce criteria where its units of measure have the same range and significance in terms of the ES or risk map evaluated (0 to 100). Criteria are then aggregated using a simple additive weighting method (Malczewski, 1999) where a standardized criterion is multiplied by its weight which was given by experts.

For the case study presented all ES maps were aggregated in order to have a general ES provision map which was then combined with the risks map to obtain priorities according to FONAFIFO`s actual scheme, where all services are compensated indistinctively.

The methodology combines many different criteria. The standardization procedure used to make criteria commensurable before it is combined needs to be validated. Other transformation methods for standardization, besides the linear used here, must be also evaluated and parameterized based on specific measurements, in order to give a true meaning to the criteria in terms of its effect on ES provision (further information on standardization in Malczewski, 1999).

Figure 7. General hierarchical structure to define priorities for an activity.



5.4.1 Environmental Service: Biodiversity

Biodiversity conservation has evolved from conservation of particular species to a broader focus on preserving ecosystems functions and services, attempting to maintain all species, genes and ecosystems (Lathrop and Bognar, 1998; Ferrier, 2002; Sierra *et al.*, 2002). Costa Rica's Forest Law contemplates this broader approach since it considers biodiversity conservation for its uses, as well as ecosystems and life forms protection under the current PES system.

Different scales of analysis where combined in order to find the conservation and restoration priorities for biodiversity in Costa Rica. Conservation priorities where evaluated for forest conservation activities since they are applied on forested areas where its assumed biodiversity is at its highest potential; restoration priorities are assumed for non forested areas where biodiversity could be improved by forest plantations and agro-forestry systems. The assumption is that areas with higher conservation or restoration value are the ones where biodiversity provides higher ES.

Terrain complexity, patch quality, landscape quality and ecosystems representation criteria were aggregated to produce the biodiversity ES provision map (Table 4). Weights for the criteria were obtained from a biodiversity experts workshop held at CATIE[11] in 2004, by

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[11] Tropical Agricultural and Higher Education Research Center

using two methods: “pair wise” comparisons for weighting the criteria based on the methodology developed by Saati (1977) and a “ratio estimation procedure” for indicators by direct rating by using a 0 to 100 scale (both methods are fully explained in Malczewski (1999). The “pair wise” method was used on the top hierarchical level because it is more accurate as it is needed to compare each criterion with the remaining; and involves the calculation of a consistency ratio of the results to evaluate the comparisons coherence. The direct rating procedure is easier (simpler and faster) to use and was then applied to lower hierarchy indicators.

Ecosystems representation was evaluated using Holdridge life zones as a proxy for ecosystems in Costa Rica. Each life zone was ranked according to its undisturbed land cover area suitable for conservation and disturbed land cover area for restoration. Ecosystem conservation areas where ranked with the highest priority (100) if they had less than 10000 ha, assumed as a viability threshold according to Dinerstein (1995) and Powell (2000). Life zones with conservation areas higher than the viability threshold where ranked by the ratio between the total life zone area and the undisturbed cover area.

Ecosystem restoration areas where ranked with the highest priority if their conservation priority was the highest (100) and by and average between its conservation ranking and a restoration area ranking. Restoration area ranking was estimated by giving higher priorities to ecosystems with the lowest restoration area and lower priorities with those with higher restoration areas as it was assumed that they have a higher probability of restoration on a scenario without PES.

Landscape quality was assessed by combining a landscape alteration and fragmentation criteria. Both criteria were evaluated by using a window of 3x3 km that moves across the map and assigns a value to the center pixel depending on all the values within the window. Fragmentation analysis assigns a value to the center pixel depending on the percentage of undisturbed cover within the window. Landscape alteration was calculated by combining a road density map with a landscape analysis of the biodiversity value of the land cover classes found. The biodiversity value was evaluated for all land cover classes trough expert consultation by assessing its species richness. The resulting biodiversity value map was analyzed at landscape level by a moving window giving the center pixel the average value of all values within the window.

Patch quality criteria is composed of patch size, patch shape, connectivity and land cover biodiversity value (as assessed by the experts). Terrain complexity was calculated by assigning the center pixel of a 250m window the standard deviation of all pixels within the window.

Table 4. Criteria and indicators used to find biodiversity provision by assessing its conservation and restoration priorities

Conservation and restoration priorities				Hierarchical level	Weighting method
Ecosystems representation	**Landscape quality**	**Patch quality**	**Terrain complexity**	Criteria	"Pair wise" comparisons
- Remaining undisturbed and disturbed life zone area - Subject to protection in the Protected Areas system	- Fragmentation - Landscape alteration (road density and land cover biodiversity value analysed at landscape level by a 3 km window)	- Size - Shape - Connectivity - Land cover biodiversity value	- Standard deviation of the DEM in a 250 m window	Indicators	Direct rating

The methodology assesses biodiversity aspects at different scales, from pixels (terrain complexity) up to national level (ecosystems representation), although there is overlapping scales between criteria. Patch quality, for example, is a criteria whose scale of measure varies according to the size of the patch analyzed (from 1 to more than 800000 ha on the case study presented) sometimes similar to landscape quality criteria.

Expert assessment used to define weights allowed to identify the importance of the criteria considered based on knowledge that would not be otherwise available for this study.

Species endemism, bio-geography, and a broader context for ecosystem representation criteria, can improve the analysis, as well as field measures used to parameterize the standardization of criteria.

5.4.2 Environmental Service: Water

Water in Costa Rica is a public good and it is administered through State given water concessions. Water concessions used in the study were provided by MINAE[12], ICE[13] and AyA[14].Water for drinking, irrigation and hydro-energy are considered under the law scheme for this ES, therefore a map for each one was created. The three maps where then combined to produce a final water ES map using equal weights.

Since water comes from above and below ground resources, both sources were assessed and prioritized according to the flow used, which was assumed as a proxy for consumers of potable water, area irrigated or amount of electrical energy produced, depending on the water use.

Priorities for underground resources were given to each aquifer depending on the flow extracted and the aquifers area. For aboveground resources the sub-watersheds were delineated for each outlet and priorities given according to the flow used and the sub-

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[12] Energy and Environment Ministry

[13] Costa Rica Electricity Institute

[14] Institute of Aqueducts and Sewer Systems

watershed area. Areas of aquifers or sub-watersheds were used to prioritize since it was assumed that the level of effort to sustain a certain flow depends directly on the area that has to be putted under water conservation management strategies.

Surface and underground water resources where assessed for all three uses considered, except for hydro-energy where underground resources are not used.

Priorities for water for drinking, irrigation and hydro-energy were aggregated (using equal weights for each use) providing a general aboveground water resources map which was combined with a general underground resources map, to obtain the final water services provision layer. Above and underground water priorities where aggregated using equal weights since they both provide the same service.

For this ES equal weights were assumed since evaluating the importance of each water use involves bringing many sectors of the society into the discussion and it was out of the scope of the study.

The methodology is based on the assumption that eligible PES activities improve water quality as compared to an intensive agriculture baseline that is not eligible for PES. Water for human consumption is improved by activities that are less intensive in agro-chemical use as well as a reduction in sediment transport (Meybeck and Helmer, 1996). Hydro-energy receive benefits in terms of sediment reduction, the main problem addressed by changing land use activities (Rodney, 2000) to the ones eligible for PES.

Underground resources where assessed on a smaller scale because of the quality of the available aquifers and soils map, being an area of improvement for future efforts. Accounting for slope is also an indicator that be combined with infiltration rates to assess the effect that land use activities can have on water quality. As the relation between different soil types infiltration rates and slope was not available it was excluded from the case study.

5.4.3 Environmental Service: Carbon

This ES was prioritized by the current carbon stock in existing forests (eligible for forest conservation activities) and the carbon sequestration potential in deforested areas by implementing the eligible activities (agro-forestry or forest plantations). The carbon stock in forests was given by Holdrigde life zones (Holdridge, 1978). Life zones are defined by its precipitation, temperature, evapo-transpiration, humidity, altitude and latitude and can, therefore, be used as units with similar carbon content (Tosi, 1997).

Areas with sequestration potential where given priority by the difference in carbon content from its actual land use and an average estimated for the activity (forest plantations or agroforestry).

After subtracting the average value for carbon content of the activity from the land use carbon content, the resulting layer was standardized giving to similar maps for agroforestry or forest plantation activities. This is because the land use carbon content was the same for both cases as it comes from the same land use map. Therefore a single map for carbon provision can be used for the whole country, combining forested and non forested areas. Although, it is important to notice that the effect for climate change mitigation could be different if the activity preserves carbon sinks or removes carbon from the atmosphere. This issue should be addressed in future studies in order to make both forested and non forested areas comparable in order to have a single carbon service map.

Life zones can be used for carbon content estimates in climax ecosystems as they are based on climatic variables (Tosi, 1997). This might not always be consistent with reality because (other than climatic) biophysical variables and management causes can affect carbon contents (Montagnini and Nair, 2004).

Assuming that agro-forestry and forest plantations would fix carbon depending on its life-zone should be tested on field, although it could provide an initial framework to identify relative carbon productivity differences at national scale.

Although not considered in this study, under the current PES scheme, ES are state owned when under payment. Therefore, it is important to consider the possibility of using this right over carbon stocks, in the Clean Development Mechanism framework, as it could provide additional funding to FONAFIFO to strengthen the system.

5.4.4. Environmental Service: Scenic beauty

Costa Rica with its 4.1 m inhabitants (INEC, 2005) receives around 1.2 m tourist a year (CANATUR, 2005). Tourist industry in 2003 generated an amount equal to 20% of the country exports (Estado de la Nación, 2005). Natural diversity as the main attraction has made tourism one of the main economic activities (Barrantes, 2000), making this ES of particular importance to the country development. Tourists are, therefore, assumed in the study as the users of scenic beauty.

The methodology is based on finding the tourist attractions and prioritizes them by the number of visitors to each location. Tourist attractions where identified by ICT[15] as sites with existing or potential interest for tourists.

Since the number of tourist visitors for each tourist attraction was not available, a map of hotel room's density was used as a proxy. The assumption is that tourist infrastructure (hotel rooms) is built around the attraction places in direct relation to the number of visitors. The room density map was generated from a national census of hotels performed by ICT that included information of number of rooms.

For the purpose of identifying areas of scenic beauty use, the area of influence of each attraction was defined in the map as the visible areas from the attraction up to a distance of 10 km. Visible areas where calculated using a digital elevation model (DEM) and then pixels given priority by the number of attractions visible and room density. Both layers were standardized and then aggregated to produce scenic beauty priorities.

Scenic beauty quality is generally approached based on user perceptions and then translating these perceptions to the map (Preston, 2001). The approach suggested here assumes, as the Forest law does, that the activities under PES improve visual quality of the landscape. This could not always be true, as it depends on the landscape character as defined by Galliano and Loeffler 2000, and it should therefore be assessed.

The method described could be biased, as the hotel rooms considered are the ones registered at the ICT only, and there might be a greater offer whose location is unknown. The average stay at each location could be also considered, since the method shows high priorities in the central metropolitan area, and this could be, for example, because the main international airport is nearby and not because a special tourist interest.

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[15] Costa Rica Tourism Board

5.5.5.Risk in forested lands

The risk to this activity was assessed as the risk of deforestation in forested areas. The methodology is adapted from Lecrerc and Rodríguez (1996), and it combines criteria of distance to forests, population density and slope to define the probability of deforestation. Criteria are standardized and combined using weights from an expert assessment done by FUNDECOR[16] in 1996, using the "pair wise" method previously explained.

Distance to forest was calculated as the distance to undisturbed land cover classes. Slope was categorized in classes used to define the official national map of land use capacity by MAG[17]. The population density map was generated using projections of district wise population in June 2004, which were calculated by INEC[18] based on the 2000 census data. District population was then distributed within each district area based on a layer resulting from a combination of layers (land cover classes, distance to roads and slope) that were arbitrarily assessed in terms of its population density.

5.5.6 Risk in non forested lands

All non forested areas where considered suitable for agroforestry or forest plantations activities. Priorities where given depending on the land use capacity of the soil as it was assumed that this can measure the bio-physical aptitude of the land to implement these economic activities. MAG developed the methodology for the land use capacity classes considering factors of soil physics, climate, drainage and erosion (Cubero, 2005). The national land use capacity map consists of eight classes that define a gradient of suitable uses for the land from intensive agriculture to permanent crops, forestry activities and conservation.

It was assumed that intensive agriculture suitable lands represent areas with higher risk to forest plantations or agroforestry since this activity could be more profitable. Areas suitable for forestry activities or conservation represent the lower risk because implementing other activities (such as intensive agriculture) is less probable.

5.5.7 Priorities for PES

Priorities are evaluated for the assessed activities separately, because the methodology does not give priorities between activities (such as in indicating that an area is better for agro-forestry than for forest plantations) but prioritizes areas for each specific activity (as in indicating that an area is better for agro-forestry than other areas).

Priorities are also evaluated for each ES separately since each service is an objective in itself. The priorities were calculated by aggregating standardized ES maps with the risk map, providing four priorities maps, one for each ES considered within the areas eligible for each one of the three activities.

For the specific case study presented the four services where grouped using equal weights. This is because FONAFIFO is currently paying for all services together and therefore they should assess the weight for each ES depending on current circumstances. In this case forested areas could be considered as priorities for forest conservation activities and

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[16] Central Volcanic Mountain Range Foundation

[17] Agriculture and livestock Ministry

[18] National Institute of Statistics and Census

deforested areas as priorities for agroforestry or forest plantations. This could prove useful for FONAFIFO since it assigns separate funding for each one of the activities, and could therefore give priorities separately.

Because assigning priorities for a specific activity implies assigning weights to each ES (in order to give priorities to them before aggregation of ES), a variable decision in time left to the user (FONAFIFO in this study), we calculated priorities using equal weights for each ES.

5.6 Results: Costa Rica case study

Combination of ES provision maps (Figure 8) with risk to the activities that generate them (Figure 9), provide PES priorities for each activity (Figure 10).

Figure 8. ES provision maps: (A) Biodiversity, (B) Carbon, (C) Water and (D) Scenic beauty.

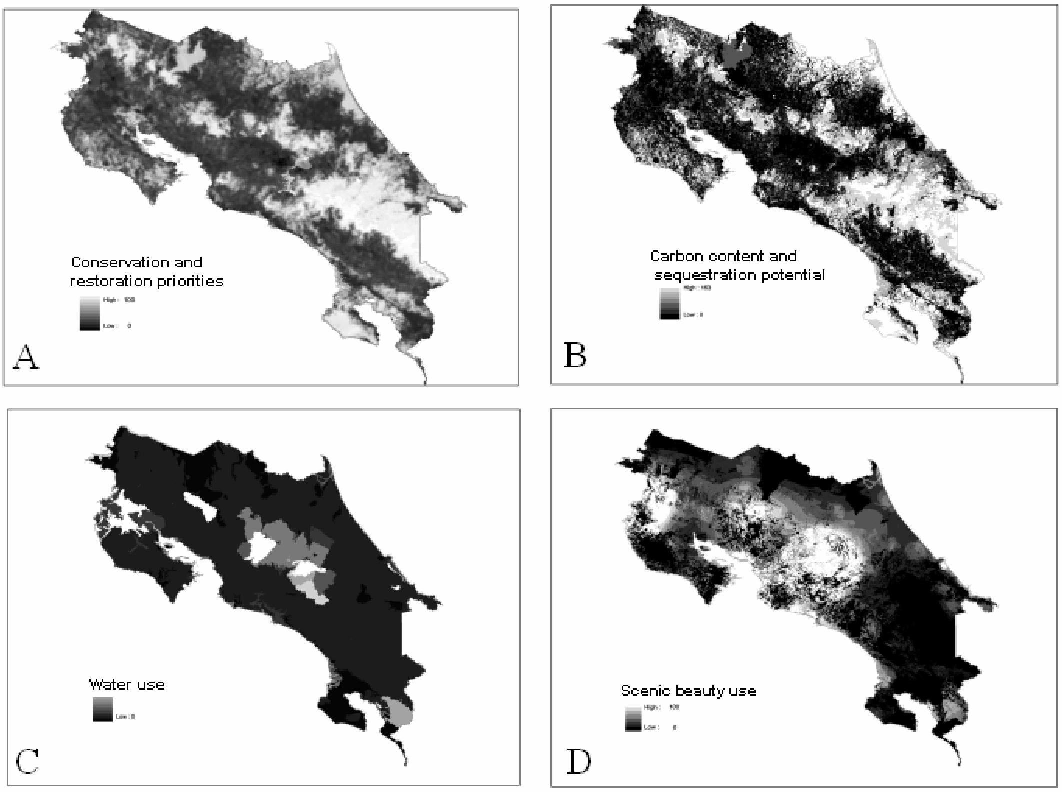


Figure 9. Risk to forest conservation (deforestation risk), forest plantations and agroforestry. (Agroforestry and forest plantations risk produced the same result)

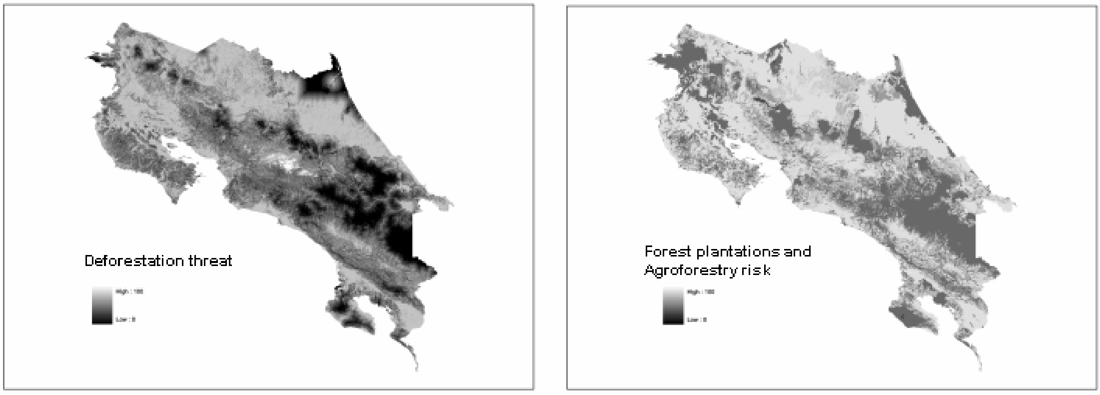
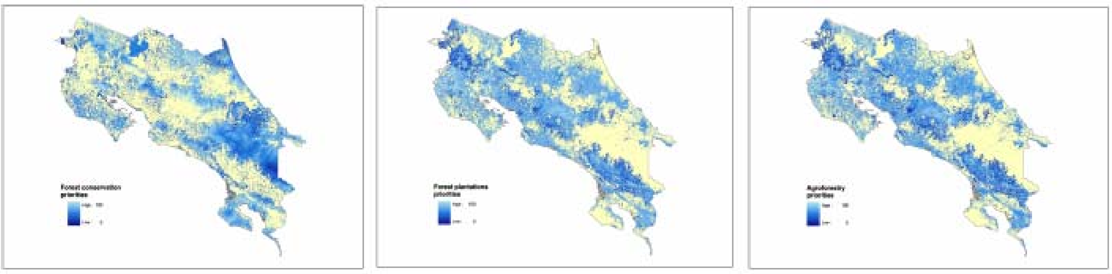


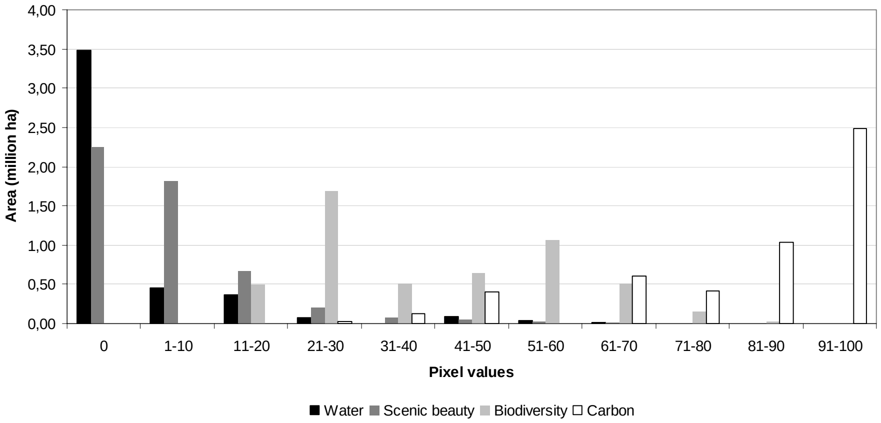
Figure 10. PES priorities for forest conservation, forest plantations and agroforestry



5.7 Discussion

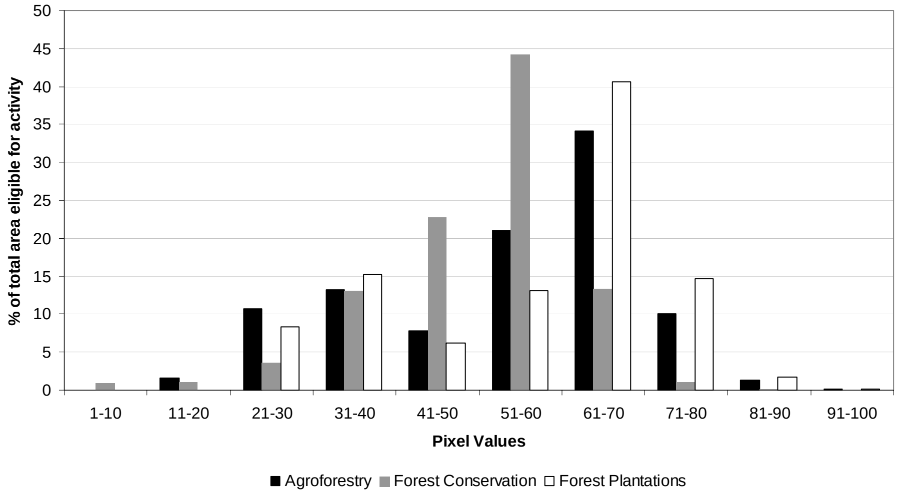
ES services provision is not equal throughout the landscape. Services such as water or scenic beauty are of local use, meanwhile biodiversity or carbon provide global benefits and the relative provision within each service is unique. The spatial distribution of each service relative provision provide an idea of the area suitable for PES, and therefore on which service priorities should be in order to have a sustained provision. Figure 11 shows carbon having most of the area with a high relative provision (area weighted provision average = 41,2), followed by biodiversity (39,8), scenic beauty (6,2) and water (3,4). This indicates that carbon is the service with greater area with high provision, and that on the opposite side; water has a smaller area that provides most of the service.

Figure 11. Spatial distribution of ES provision (relative provision of each service on a 0 to 100 scale)



Each activity priorities have a unique distribution depending on the ES relative provision (Figure 11) and how it is spatially combined with its risk classes. Figure 12 describes the spatial distribution of each activity priorities, where forest plantations has the higher area weighted average (57,3), followed by agroforestry (54,0) and forest conservation (50,1). The total area assumed eligible for forest conservation is smaller (2.42 million hectares) than for agroforestry or forest plantations (2.60 million hectares); therefore Figure 2 is normalized by the total eligible area for each activity. This indicates that under the forest conservation eligible area there is a relative bigger area with higher priorities, as compared to forest plantations or agroforestry, therefore, it could be a criteria to give priority to this activity over the others.

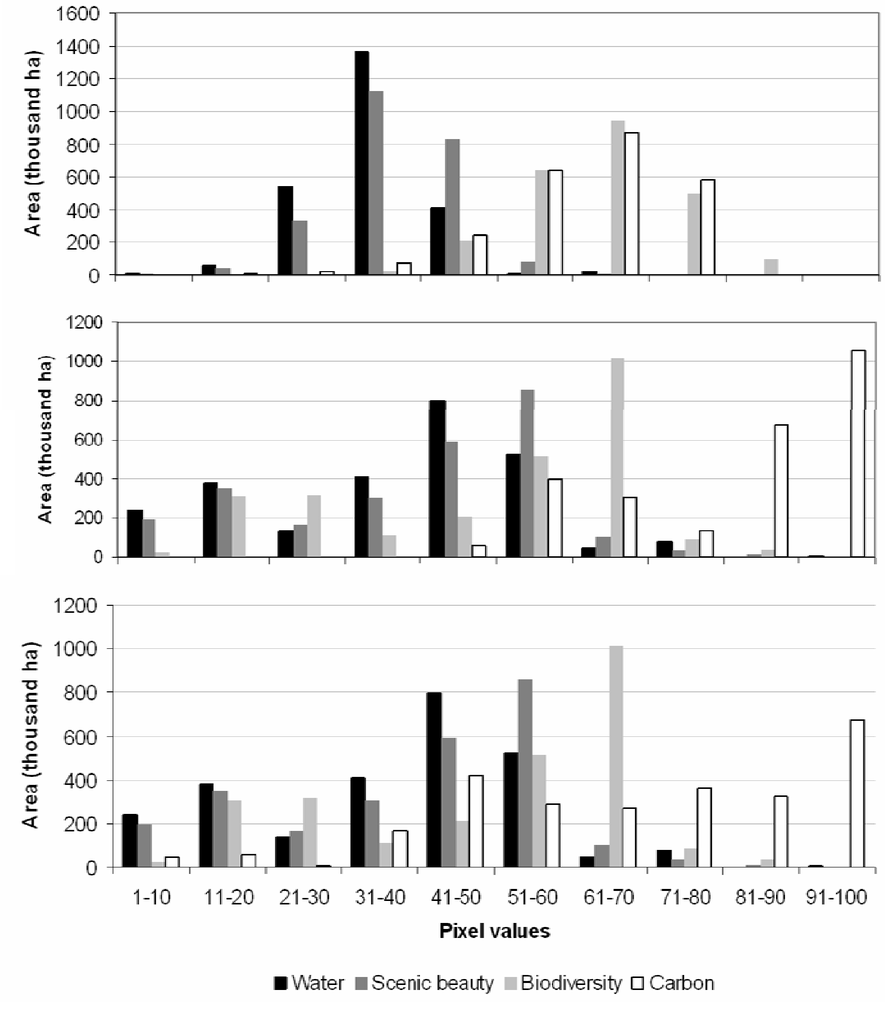
Figure 12. Spatial distribution of priorities for each activity (relative priorities given on a 0 to 100 scale and normalized by the total eligible area for each activity)



Each activity priority in Figure 12 can be further disaggregated by evaluating each ES with its risk under the current activity separately, as shown in Figure 13. In the case study all services where considered equally important to define the activities priorities and this might not be FONAFIFO decision. Finding the relative priority of each service (each service provision aggregated to the activity risk separately) within an activity shows which service could be attended first. Carbon has higher priority followed by biodiversity and then by water and scenic beauty who have rather similar priorities in all activities. Forest conservation has a bigger distance from biodiversity to water and scenic beauty as compared with forest plantations or agroforestry.

Although this analysis indicates priorities for each service under an activity in terms of the area and its priorities, this might not be the only criteria to define services importance. Services consumed locally, for example, such as water or scenic beauty could be considered more important and therefore given higher weights.

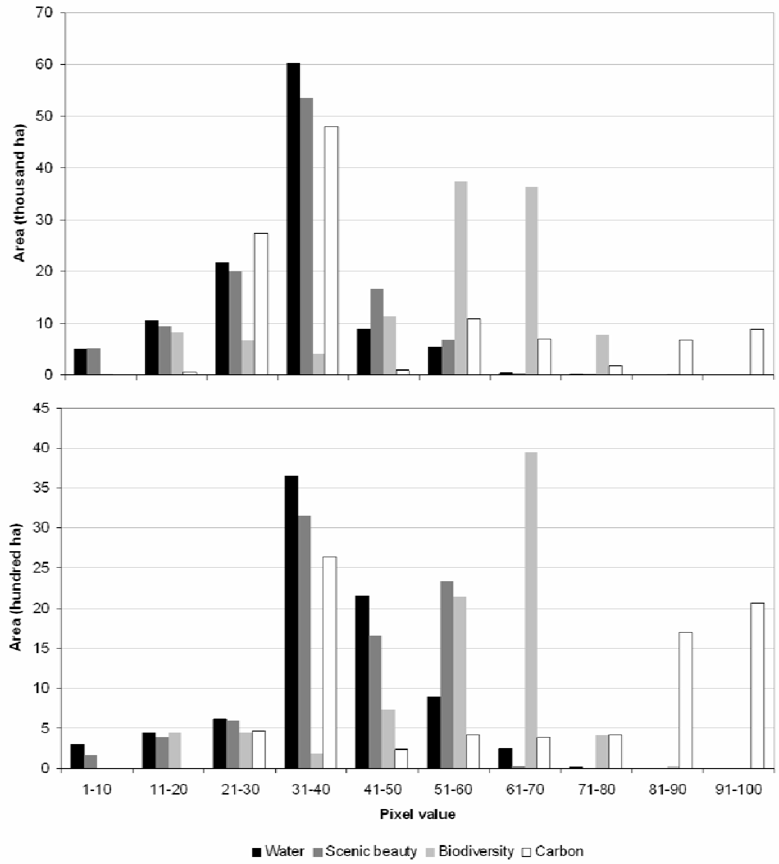
Figure 13. Biodiversity, carbon, scenic beauty and water priorities under each activity.



	Pixel value average		
	Forest conservation	**Forest plantations**	**Agroforestry**
Water	34.5	39.9	39.9
Scenic beauty	37.8	41.7	41.7
Biodiversity	63.6	49.7	49.7
Carbon	61.9	80.6	69.7

PES given in the 1994-2002 period is evaluated based on which services where given priority under the scheme presented, for forest conservation and forest plantations (Figure 14). The priorities given to PES (evaluated by the average pixel value of areas paid in the period) do not follow the same order presented by priorities obtained in the case study and present differences depending on the activity evaluated (average pixel values in Figure 14). Some similarities are found between the priorities of already paid PES and priorities obtained in the study: - water is the less important service, - biodiversity is the second most important paid service and - carbon is the most important service (in forest plantations).
Although PES in this period (1994 – 2002) shows, in some cases, the same average priority as when the whole eligible area for the activity is evaluated, it might not indicate that the priorities used equal those on the current study. This could be interpreted as if payments where assigned randomly over the territory and therefore when compared with the PES priorities show the same average as the whole country priorities.

Figure 14. Biodiversity, carbon, scenic beauty and water priorities under forest conservation and forest plantations in areas under PES (1994 – 2002 period).



	Forest conservation	**Forest plantations**
Water	32.4	39.5
Scenic beauty	67.8	41.3
Biodiversity	53.7	56.0
Carbon	44.9	63.7

5.8 Further issues

Priorities as defined in the study provide a bio-physical framework to take decisions. Socio-economic data, such as opportunity costs of land use activities, can modify these priorities. Lands uses with opportunity costs higher than what is currently paid under the PES scheme can exclude areas that are priority under this method.

Another issue is the mechanism by which the methodology presented can be used at FONAFIFO. Currently, PES is assigned on a “first come, first serve” basis, which would not allow deciding which request is priority.

Requests for PES that fall inside its priority areas, given by low Social Development Index counties, biological corridors, water resources protection areas, and soil or biodiversity degraded lands (FONAFIFO, 2005b), are accepted. Using the current priorities implies a modification of the current administrative procedures.

5.9 Conclusions

A methodology that integrates technical information to help decision makers find priorities for PES is presented. It allows the integration of information which is, usually not centralized for decision making at governmental level. Therefore, it can be used to have an integrated background to promote coordinated policies and efforts among national institutions.

The methodology provides the necessary flexibility to adapt to changes in institutional and governmental policies, giving the opportunity to support changing needs for development. Although the method is solely based on technical data it allows considering stakeholders opinions in order to have a desired effect in the resulting priorities.

Decisions are taken based on field information, such as the bio-physical data that is used to generate the different criteria; as well as expert knowledge, used to aggregate these criteria into ES and risk maps. Expert knowledge, in the form of criteria weights, allows integrating information that would be otherwise unavailable or costly, such as the relative importance to biodiversity of the criteria used to define this ES map (i.e. patch or landscape quality).

On top of this, is the possibility of integrating all or just one ES and risk maps, to help institutional policies such as FONAFIFO or others (as could be the case of the Instituto Costarricence de Turismo[19], which would only deal with scenic beauty). Weights for ES to define priorities were not addressed here as it is a step left to the stakeholders sphere as it is based on changing socio-economic trends and priorities.

The method could provide the PES scheme a transparent method to prioritize areas, where each payment can be fully explained in terms of the benefits it provides to the society, which is the essence behind the Forest Law. It would also allow using the scarce funds efficiently reducing the risk of paying for areas with low services provision or where the service is not under risk.

Further work is needed to validate standardization procedures and weights. Both issues could be based on field measurements in order to make the system robust and adapted to time and space conditions. Spatial correlation among the maps could lead to over estimating criteria; accounting for this could improve the integrity and simplify the method by removing redundant criteria.

This study does not take into account development trends and future needs of ES, neither change in factors that induce risk to the activities, but gives a snapshot of the current situation of ES and its risks.

Acknowledgements:
The authors would like to thank Jose Miguel Zeledon from Sectorial de Aguas of MINAE, Xinia Soto from InBio, Alberto Sanchez from ICT and Jorge Mario Rodriguez from FONAFIFO, without whose support this study would not have been possible.

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6. Annexes

6.1 Annex 1 ES – Biodiversity

Figure 1. Digital elevation model (DEM)

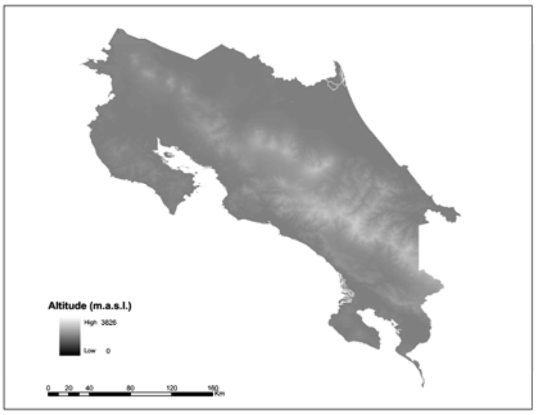


Figure 2. Terrain complexity

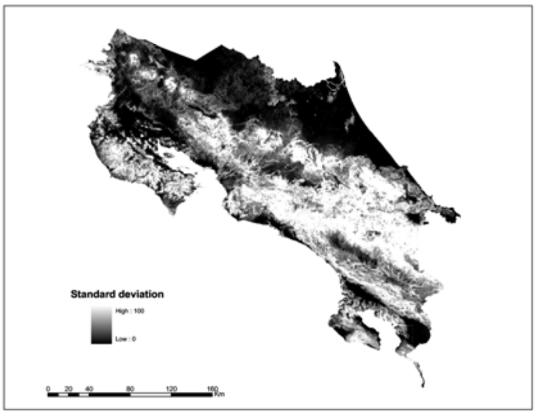


Figure 3. Costa Rica land cover map

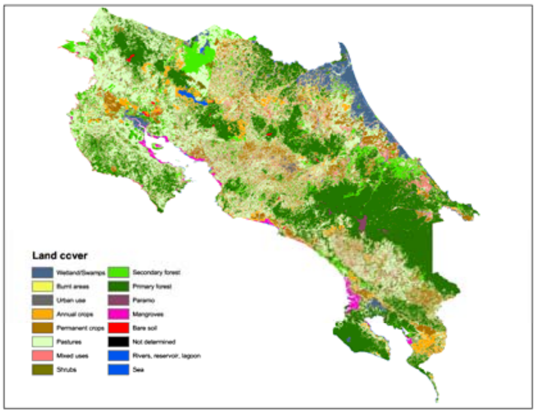


Figure 4. Undisturbed ecosystems

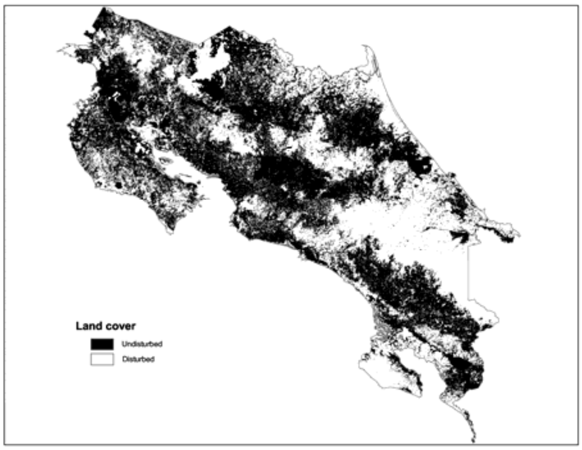


Figure 5. Patch size

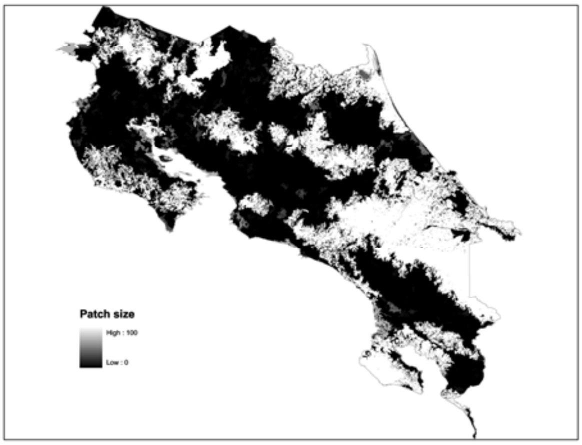


Figure 6. Patch shape

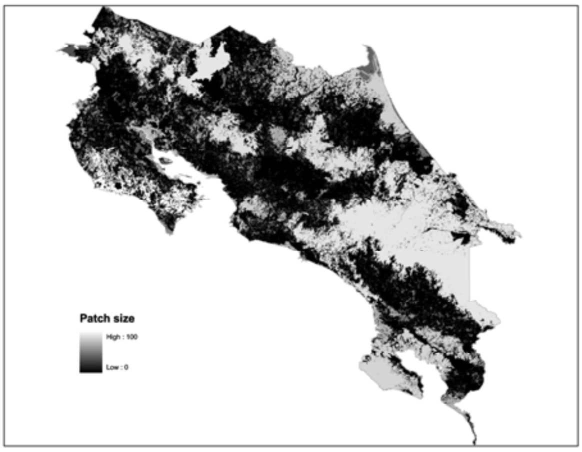


Figure 7. Connectivity

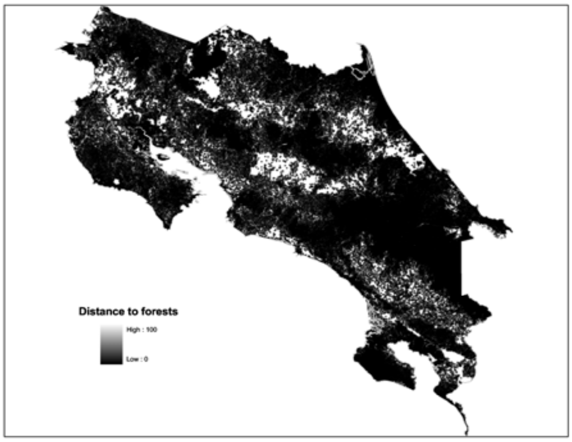


Figure 8. Land covers biodiversity value

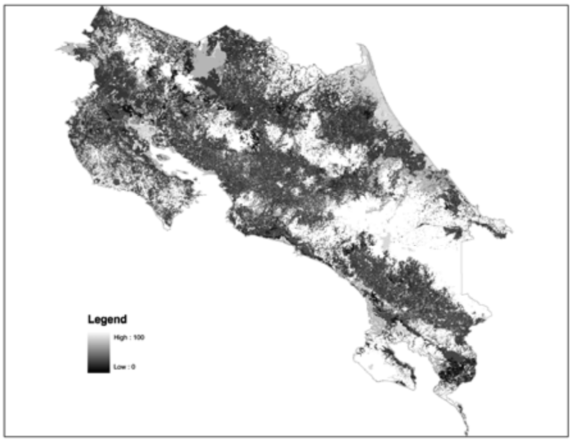


Figure 9. Patch quality

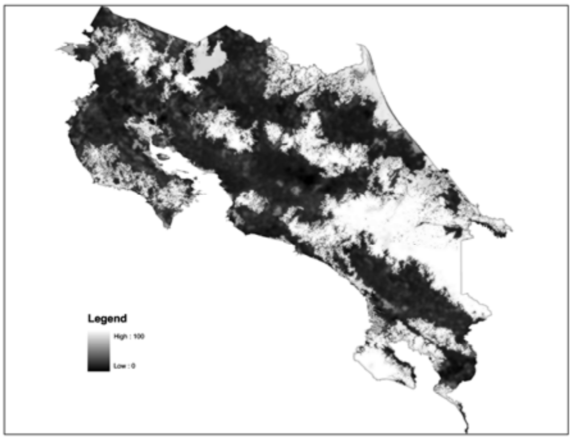


Figure 10. Landscape quality

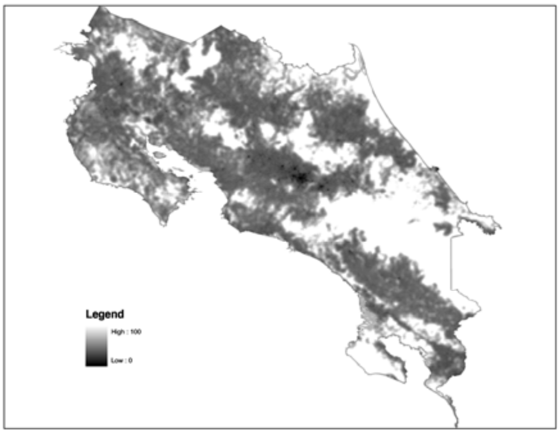


Figure 11. Fragmentation

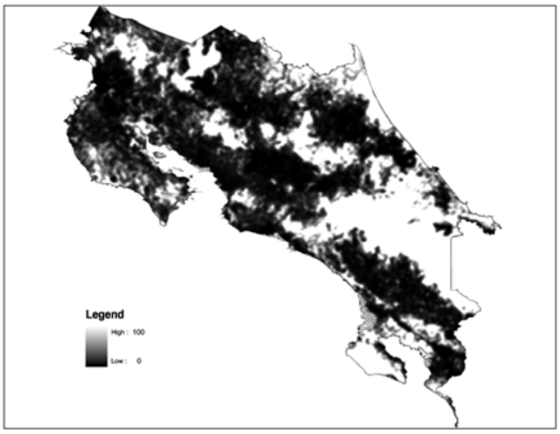


Figure 12. Landscape alteration

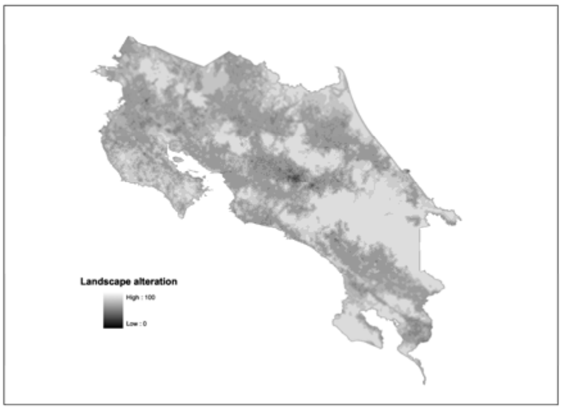


Figure 13. Road density

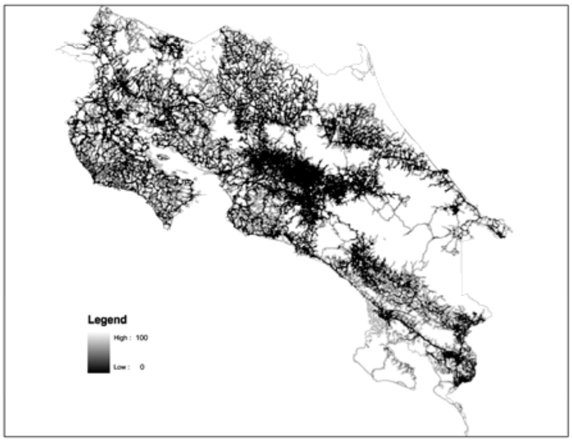


Figura 14. Landscape evaluation of the land covers biodiversity value

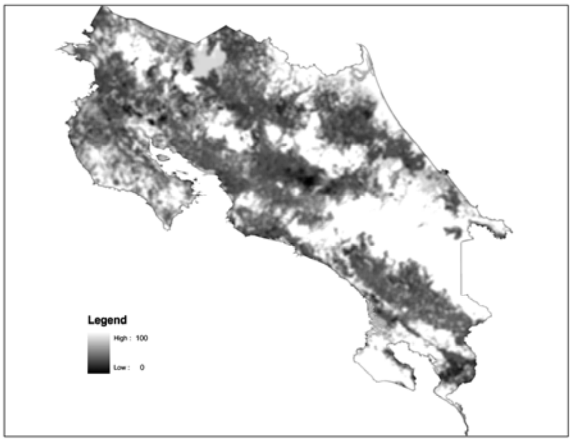


Figure 15. Biodiversity provision

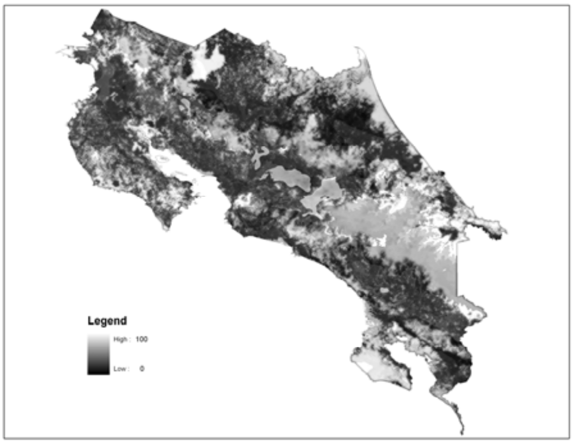


Figure 16. Holdridge life zones

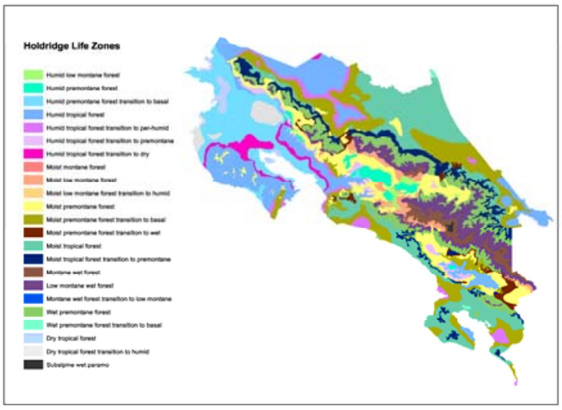


Table 1. Importance of restoration and conservation activities inside or outside protected areas (PA).

	Weight
Conservation inside PA	0,353
Conservation outside PA	0,304
Restoration inside PA	0,160
Restoration inside PA	0,183

Table 2. Ecosystem representation priorities by life zone ranking

Life Zone	**Conservation inside PA**	**Restoration inside PA**	**Conservation outside PA**	**Restoration outside PA**
Dry tropical forest	73	41	73	41
Dry tropical forest transition to humid	70	33	70	33
Humid tropical forest	58	17	58	17
Humid tropical forest transition to dry	67	29	67	29
Humid tropical forest transition to per-humid	69	28	69	28
Humid tropical forest transition to premontane	78	37	78	37
Moist tropical forest	36	5	36	5
Moist tropical forest transition to premontane	30	7	30	7
Humid premontane forest	100	100	100	100
Humid premontane forest transition to basal	69	24	69	24
Moist premontane forest	67	23	67	23
Moist premontane forest transition to basal	63	20	63	20

Moist premontane forest transition to wet	62	32	62	32
Wet premontane forest	20	0	20	0
Wet premontane forest transition to basal	100	100	100	100
Humid low montane forest	100	100	100	100
Moist low montane forest	49	22	49	22
Moist low montane forest transition to humid	100	100	100	100
Low montane wet forest	4	5	4	5
Moist montane forest	100	100	100	100
Montane wet forest	0	42	0	42
Montane wet forest transition to low montane	100	100	100	100
Subalpine wet paramo	100	100	100	100

6.2 Annex 2 ES – Carbon

Figure 1. Undisturbed cover and secondary forest carbon stock (ton/ha)

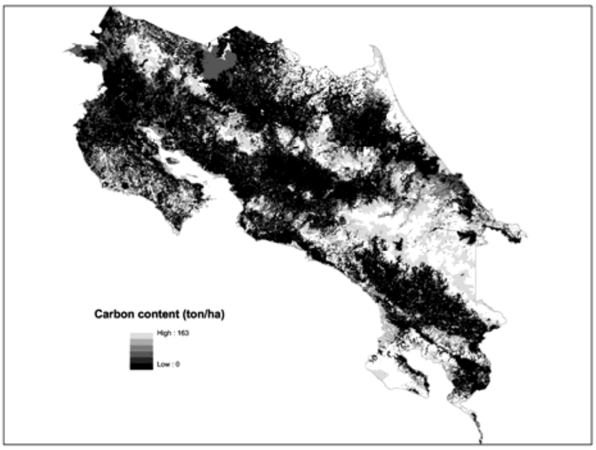


Figure 2. Forest plantations carbon sequestration potential

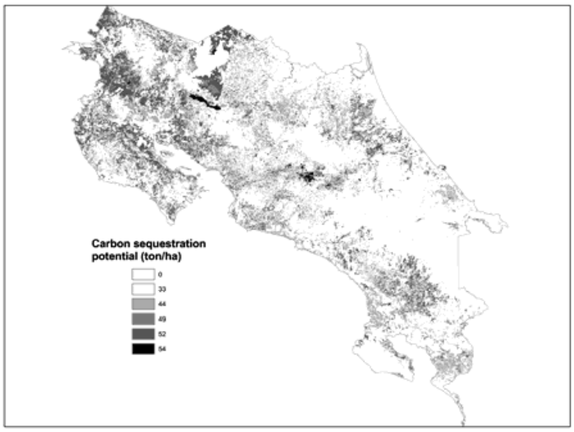
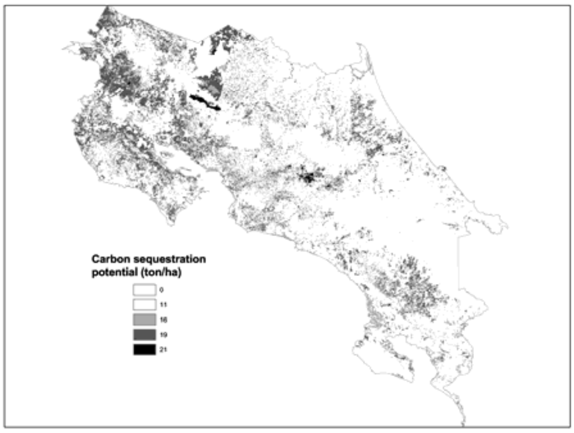


Figure 3. Agroforestry carbon sequestration potential



6.3 Annex 3 ES – Water

Figure 1. Water services provision

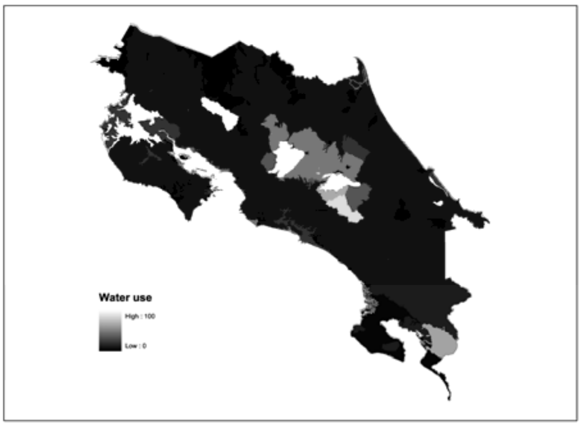


Figure 2. Aboveground water services provision

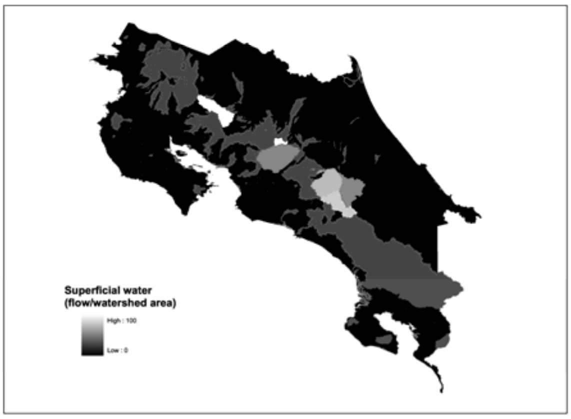


Figure 3. Underground water services provision

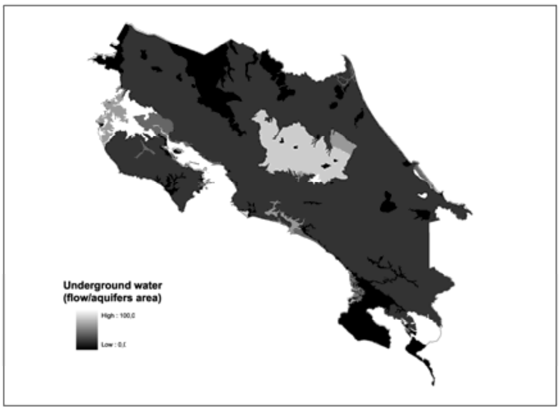


Figure 4. Aboveground drinking water service provision

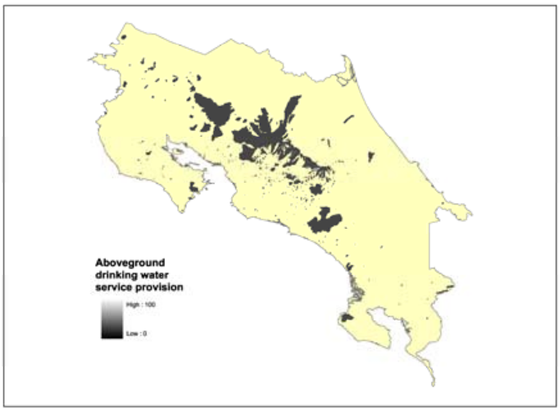


Figure 5. Aboveground irrigation water service provision

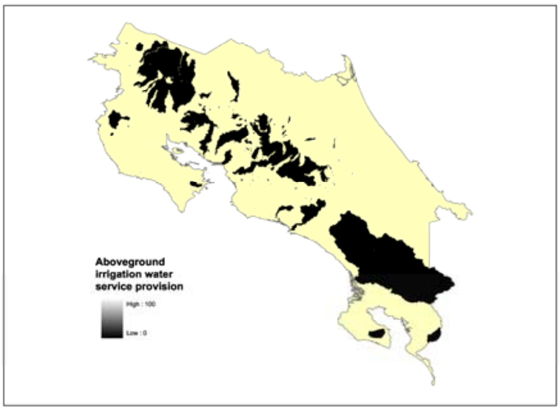


Figure 6. Aboveground hydro-energy service provision

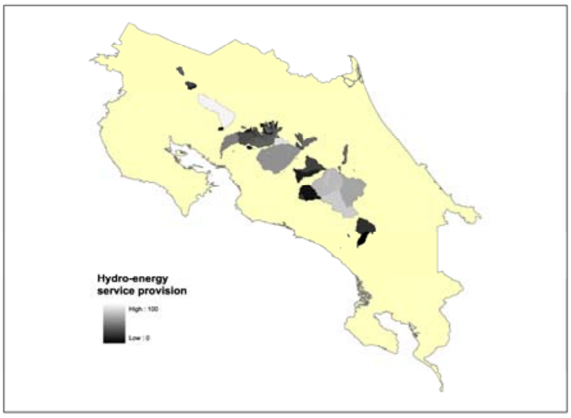


Figure 7. Drinking underground water service provision

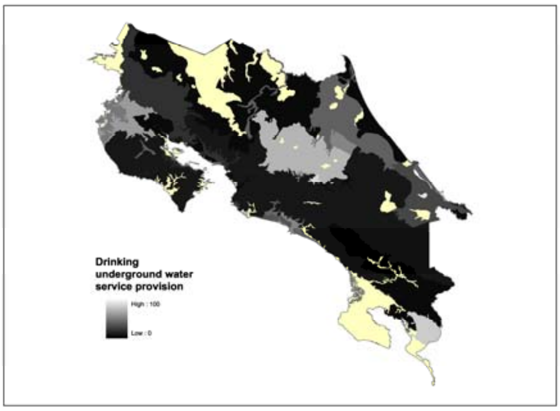
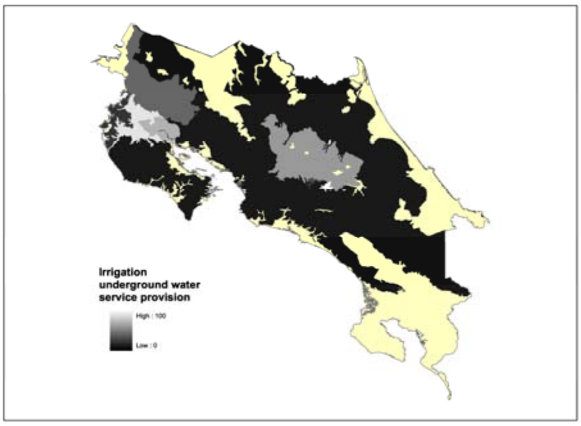


Figure 8. Irrigation underground water service provision



6.4 Annex 4 ES – Scenic beauty

Figure 1. Number of visible tourist attractions

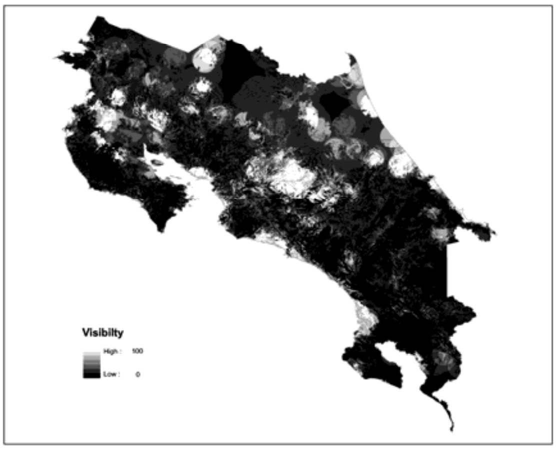


Figure 2 Hotel rooms density

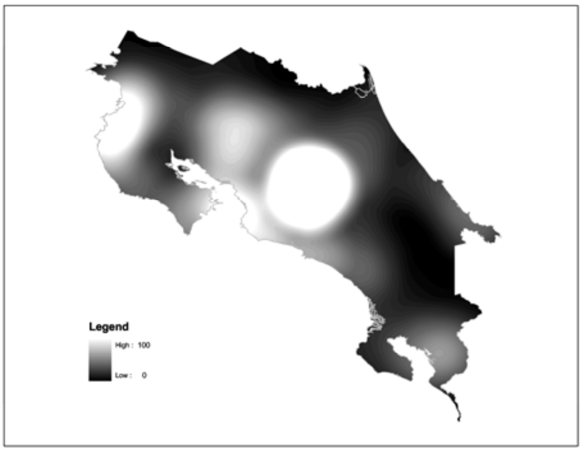
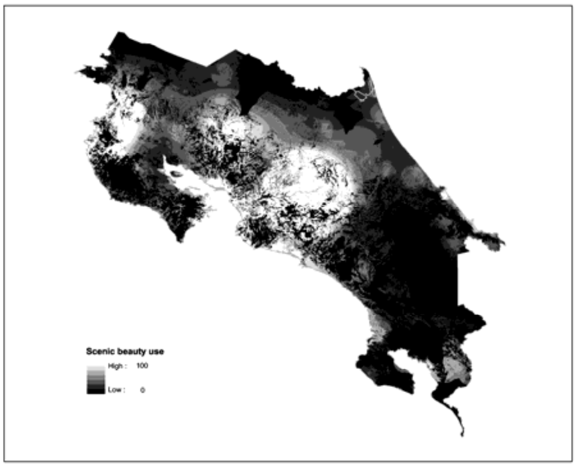


Figure 3. Scenic beauty use



6.5 Annex 5. Risk to activites and priorities for PES

Figure 1. Deforestation risk

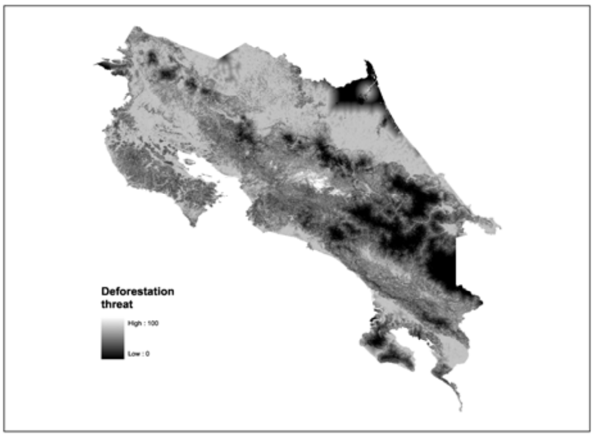


Figure 2. Population density threat

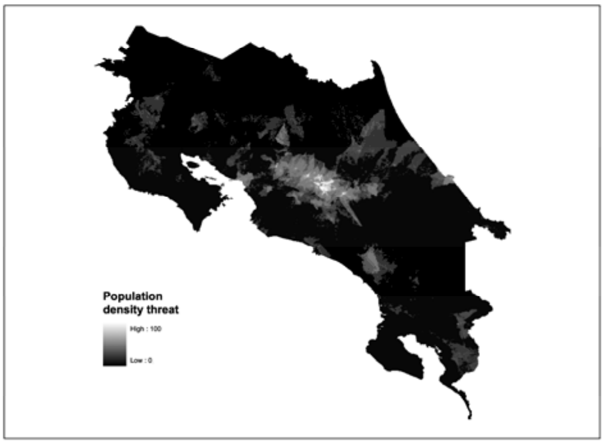


Figure 3. Slope threat

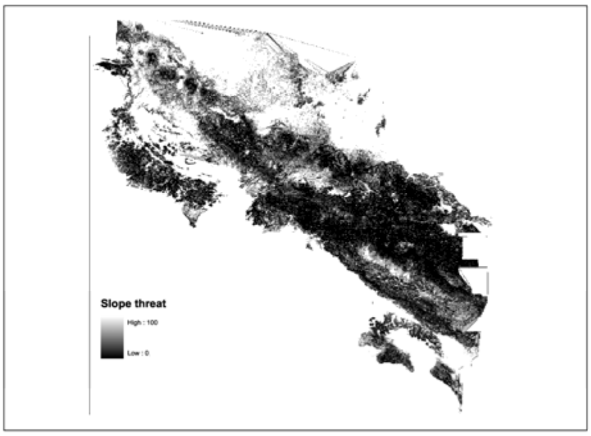


Figure 4. Distance to roads threat

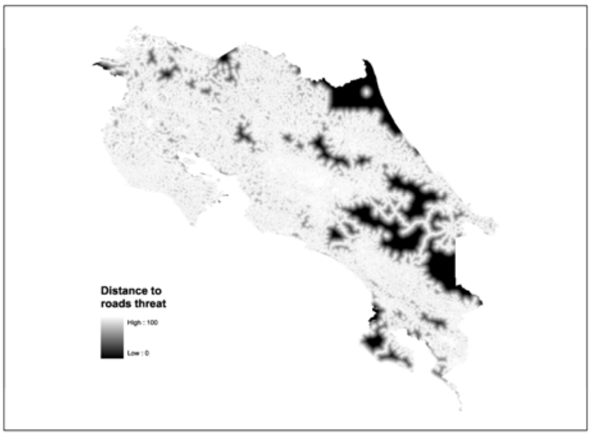


Figure 5. Slope classes

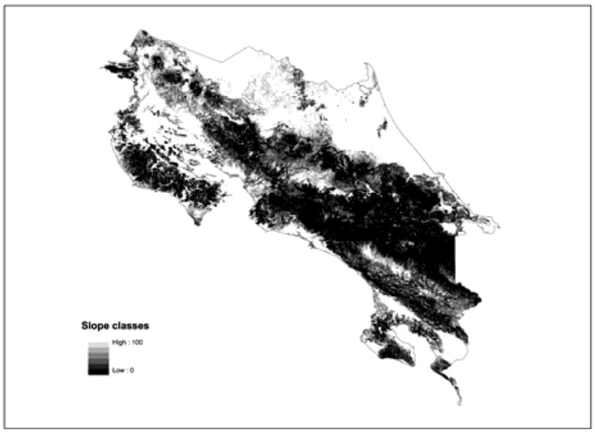


Figure 7. Cost surface used for population density calculation

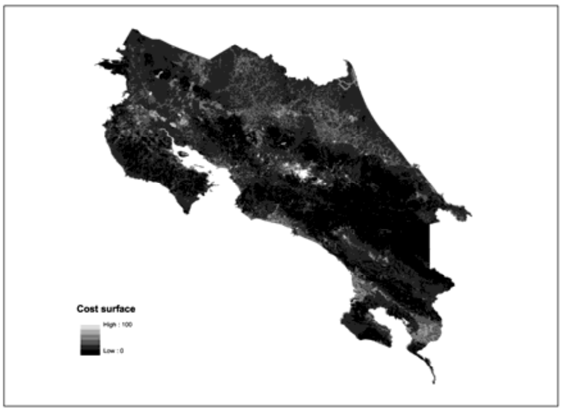


Table 1. Land cover classes and its suitability for population

	Population suitability
Burnt areas	**80**
Urban areas	**100**
Annual crops	**80**
Permanent crops	**70**
Pastures	**60**
Mixed uses	**90**
Shrubs	**40**
Secondary forest	**20**
Primary forest	**10**
Paramo	**10**
Mangroves	**10**
Bare soil	**90**
Water	**0**
Wetlands	**10**

Table 2. Slope classes and its population suitability

Slope (%)	Population suitability
0 - 3	**1**
3 - 8	**2**
8 - 15	**3**
15 - 30	**4**
30 - 50	**5**
50 - 75	**6**
75 ‹	**7**

Figure 5. Forest plantations risk

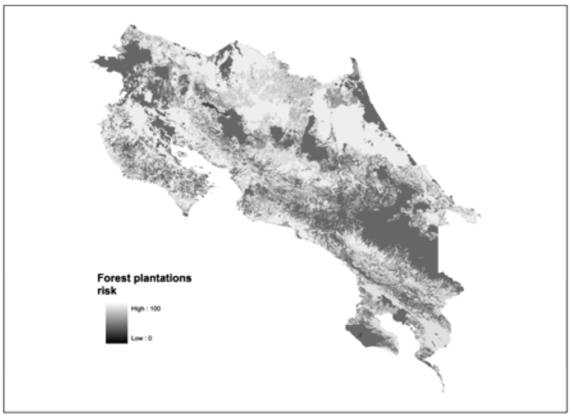


Figure 6. Agroforestry risk

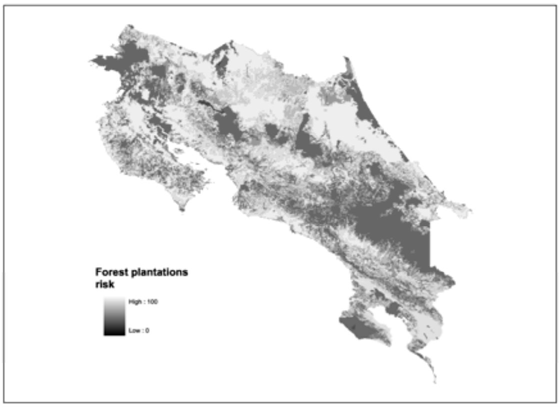


Figure 7. Forest conservation priorities

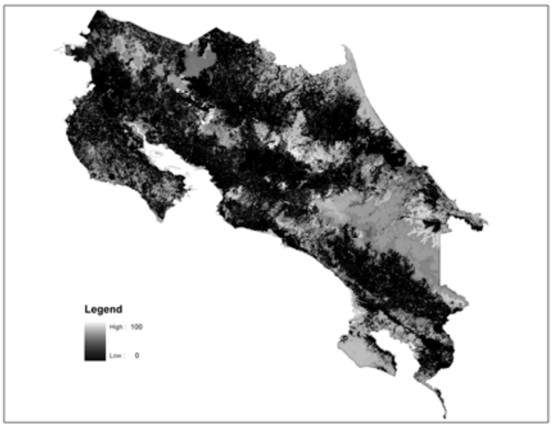


Figure 8. Forest plantations priorities

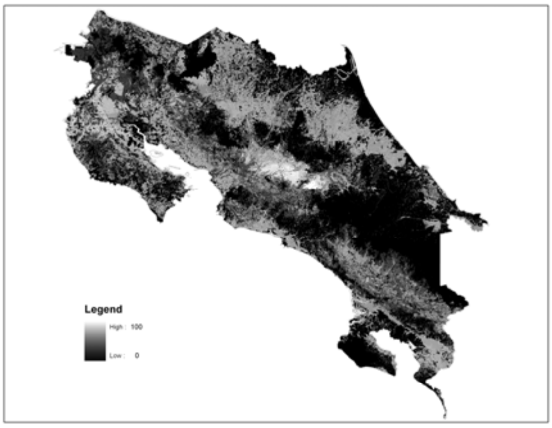


Figure 9. Agroforestry priorities