Opportunity cost of natural forest management in the Arenal-Huetar Norte Conservation Area, Costa Rica

Christian Zúñiga-Méndez (czunigamendez@gmail.com)
Universidad Nacional de Costa Rica
https://orcid.org/0000-0002-2531-0641

Victor Meza-Picado
Instituto de Investigación y Servicios Forestales (INISEFOR) Universidad Nacional

Sebastian Ugalde-Alfaro
Oficina Nacional Forestal (ONF)

Jhonny Méndez-Gamboa
Comisión de Desarrollo Forestal de San Carlos (CODEFOSA)

Research

Keywords: Opportunity cost, forest management, landscape mapping, conservation planning, Costa Rica

DOI: https://doi.org/10.21203/rs.3.rs-35216/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License
Abstract

Background: Part of the success of forest conservation programs is due to the economic sustainability they can provide to owners of forest resources, and how these management mechanisms can be used within an increasingly aggressive productive landscape matrix. However, there are currently no precise or up-to-date data on the economic relationships between land uses and their respective productive activities. This study designed a model to evaluate the opportunity cost of natural forest management, taking as a reference the primary productive activities that take place within the Arenal-Huetar Norte Conservation Area, in Costa Rica.

Methods: Profitability data from 24 sites in natural forests with a forest management plan approved by the State Forest Administration was used, as well as geographic and productive information on alternative land uses.

Results: Based on these data, an opportunity cost map was generated which shows a marked segregation of the forests into two main areas: a) a high-opportunity cost area, located south of the study area; and b) a medium-low opportunity cost area, to the center-north of the study area.

Conclusions: It is concluded that ideal areas for timber harvesting are currently restricted to places far from the market, and with low opportunity costs (ranging between $0 ha\(^{-1}\) year\(^{-1}\) and $500 ha\(^{-1}\) year\(^{-1}\)).

1. Background

Forest conservation as a development strategy should not be seen as a secondary option for land use, but as a growing need in contemporary societies. Despite improvements in forest ecosystems in terms of both area and management mechanisms (FAO 2016), deforestation and degradation, even today, continue to cause the loss of biodiversity and natural habitat. This dynamic has also increased the production of greenhouse gases and the climate crisis, resulting in a decrease in the quality of life of communities that depend directly or indirectly on products and resources of forests (Andrew and Bariweni 2018).

From the point of view of land use competitiveness, tropical forest ecosystems have been vulnerable in recent decades, and have been characterized by low profitability compared to other alternative land uses, which makes them less likely to remain standing. Discussions of biodiversity conservation must therefore begin with an understanding of the ecological, social and economic pillars upon which sustainable forest management (SFM) are based. To improve decision-making, it is necessary to have indicators that effectively measure these pillars, making it possible to locate forests with SFM within a productive matrix (Adamowicz 2003).

In this case, the most important information related to the economic pillar has to do with profitability. This may be evaluated using the conceptual-economic framework of Opportunity Cost (OC), which
provides tools to analyze patterns of behavior, allocation and effective use of scarce resources (Case and Fair 1997; González 2000; Sullivan et al. 2004). In simple terms, OC is what is lost by having chosen another option. In the specific case of SFM, OC can be evaluated as the net income per hectare per year or the net present value that is no longer received for not harvesting the forest sustainably, but rather doing nothing with the forest or investing in other land uses such as agriculture or livestock (although Costa Rican environmental legislation prevents land use change, it continues to occur in practice) (Louman et al. 2001; Kniivilä and Saastamoinen 2002; Navarro and Bermúdez 2006; Vega-Araya 2014; Andrew and Bariweni 2018).

The country has the potential for forest management in an area of approximately 867,590.4 ha, which is equivalent to 32.8% of the national forest cover (Camacho 2014). Despite this, the yield of wood from the management of mature forest has decreased, contributing only 6.1% of the total volume consumed locally (Barrantes and Ugalde 2019). Given this situation, some authors have acknowledged that there is little interest on the part of forest owners in adopting SFM, due to its low profitability, problems in maintaining a cash flow with constant income, and better returns from other economic activities. These factors contribute to the displacement of forests by other alternative uses, through illegal mechanisms (Navarro and Bermúdez 2006; Navarro et al. 2006; Meza 2008; Camacho 2015; de Camino et al. 2016; MINAE 2018).

The low profitability of SFM compared to alternative land uses is an alarming sign. It is therefore vitally important to identify and compare the incomes generated by different uses of the land, and how differences in the income they produce affect producers’ decisions to invest in SFM (or not). This economic and decision-making approach has not been frequently used in the region, and no data or body of literature has been produced in the last 10 years that allows the creation of economic clusters according to different land uses which compete with forests. This study is intended to fill this gap, and presents a model for calculating the opportunity cost of SFM in the Arenal-Huetar Norte Conservation Area of Costa Rica, based on a set of geographic and economic data of SFM and principal alternative activities. This empirical data is used to provide a graphic and geospatial perspective on OC trends, and shows that to ensure biodiversity conservation it is necessary to design and adjust schemes differentiated according tithe OCs for each region.

2. Materials And Methods

• Study area

The research was carried out in the Arenal-Huetar Norte Conservation Area (AHNCA), located between the Las Haciendas River in Upala and the Sarapiquí River in La Virgen de Sarapiquí. It is bordered to the north by Nicaragua, to the west by the Cordillera de Guanacaste, to the east by the Sarapiquí and Toro Amarillo rivers, and to the south by the canton of Naranjo. It covers 13% of the national territory (6,724.67 km²), and is the region with the highest levels of use of natural forest in the country (SINAC and SIREFOR 2011,
The farms used for the analysis are privately owned and located in the cantons of San Carlos and Sarapiquí.

The study was oriented towards the creation of an opportunity cost model for the districts of Florencia, Cutris, and Pital de San Carlos, as well as Cureña de Sarapiquí (Figure 1). The model focuses on SFM activities, and also evaluates other primary productive activities that take place in land adjacent to forests.

**Base information sources**

The opportunity cost model was based on four sources of base information:

- Current plant cover distribution according to the Costa Rica National Forest Inventory (IFN) 2013-2014 (Ortíz-Malavassi *et al.* 2013; Programa REDD/CCAD-GIZ and SINAC 2015).
- Definition of primary productive activities and their geographical extension, according to the 4th National Agricultural Census of Costa Rica (INEC 2014).
- Profitability of primary agricultural production activities that compete with SFM for land use.
- Agricultural Values Platform prepared by the Technical Standardization Body (ONT) of the Ministry of Finance of Costa Rica.

**Data processing, cleaning, and management**

Spreadsheet applications and Geographic Information Systems (GIS) were used when working with the data, which followed the sequence below:

- **Distribution of vegetation coverage within the study area**

  In this step, polygons derived from the vector layers of the National Forest Inventory were used as the unit of geographic analysis (Ortíz-Malavassi *et al.* 2013). This data set contains attributes for different types of vegetation cover, of which the following were used in this analysis: mature forest, forest plantations, pastures and agricultural crops.

- **Determination of alternatives for primary agricultural production**

  Using information generated by the 4th National Census of Agriculture 2014 (INEC 2014), data were obtained on the area (ha) planted for annual, permanent, forest, ornamental and pasture crops; as well as the area dedicated to livestock activities (meat, milk and dual-purpose) within the zones of pasture.

- **Determination of profitability of primary agricultural production activities**

  Profitability data for primary production activities was obtained from several secondary sources (ONF[1]; Calvo and Somarriba 1998; Navarro and Bermúdez 2006; Pitacuar 2010; Sánchez 2010; Sánchez *et al.* 2013; Vega-Araya 2014; Presidency of the Republic of Costa Rica and MINAE 2014; Azofeifa-Alvarado *et
In the case of timber harvesting, the financial indicator called Forest Value (FV) (Zúñiga-Méndez 2018) was used for those forest units under forest management with an area of between 50 ha - 100 ha. All data were indexed to 2014 and the microeconomic indicator called Equivalent Annual Value (EAV) was used to standardize them. It expresses the net profit ($ha^{-1} year^{-1}$) that a producer would receive from dedicating his entire life to a given activity, assuming that the conditions for carrying it out it remain constant. EAV is expressed as follows:

\[
(1)
\]

Where:

\[
\begin{align*}
EAV &= \text{Equivalent Annual Value, in $ha^{-1} year^{-1}}. \\
NPV &= \text{Net Present Value, in $ha^{-1}}. \\
LEV_{\infty} &= \text{Land Expectation Value, in $ha^{-1}}. \\
i &= \text{discount rate (for this procedure an interest rate of 5.2\% is used for all productive activities)} \\
t &= \text{shift, production cycle}
\end{align*}
\]

- **Categorization of primary agricultural production activities according to vegetation coverage and weighted average profitability for each class**

This procedure consisted of crossing information about vegetation cover categories with different primary production activities. Annual and permanent crops were classified as agricultural crops; forest crops were placed in the category of forest plantations; cattle ranching was placed in the category of pastures; and timber harvesting was placed in the category of mature forest vegetation cover. Once this procedure was defined, the average profitability of each of the vegetation cover categories was calculated, weighting the EAV of the productive activities by the geographical extent of the areas in which they took place.

- **Calculation of the adjustment factor for agricultural values**

Values for this factor were obtained using data from the ONT’s Agricultural Values platform, which is defined in terms of agricultural areas. The purpose of this factor was to adjust profitability values according to the specific production conditions and characteristics of each geographic unit, including market access, urbanization, public services, infrastructure, land use, capacity for use, area, regularity, slope, access roads and hydrology. To determine this factor, equation (2) was used.

\[
(2)
\]

[Please see the supplementary files section to view the equations.]
Where:

\( \text{AF}_{AV} = \) Adjustment factor for agricultural values.

\( \text{EAV}_{AZ} = \) Equivalent annual value by type of agricultural zone, in \$/ha\(^{-1}\) year\(^{-1}\).

\( X = \) Average of the equivalent annual values of all the agricultural areas.

\( \text{SD} = \) Standard deviation of the equivalent annual values of all agricultural areas.

- **Adjustment of profitability of vegetation cover according to agricultural values**

Equation (3) was obtained using the method for calculating opportunity cost proposed in (Vega-Araya 2014). However, the components used in the original source were modified to obtain an estimate of profitability closer to the socioeconomic conditions that exist at a given location, and then use it as the basis for calculating the OC of the geographical unit with respect to its neighbors.

\[
\text{Protability}_{aj} = \text{adjusted profitability, in \$/ha\(^{-1}\) year\(^{-1}\).}
\]

\[
\text{Protability}_{vc} = \text{weighted profitability by type of vegetation cover, in \$/ha\(^{-1}\) year\(^{-1}\).}
\]

\( \text{AF}_{AV} = \) adjustment factor for Agricultural Values.

- **Determination of the opportunity cost of timber harvesting in natural forest with respect to the alternative productive activities in the vicinity**

Opportunity cost was evaluated as the difference between the profitability of the vegetation cover minus the profitability of the timber harvest. The result should be interpreted as what forests owners forfeit if they choose to dedicate their land to forest management rather than to agriculture, livestock or forest plantations. This procedure was performed for all categories, as follows:

\[
\text{OC}_{VC} = \text{opportunity cost by type of vegetation cover, in \$/ha\(^{-1}\) year\(^{-1}\).}
\]

\( \text{Profitability}_{vc} = \text{weighted profitability by type of vegetation cover, in \$/ha\(^{-1}\) year\(^{-1}\).
Profitability$_{FV}$ = profitability of timber harvesting in forest = annualized Forest Value (FV); in $\text{ha}^{-1} \text{year}^{-1}$.

After calculating $OC_{VC}$, a Neighborhood Analysis was carried out; this is a GIS process that permits the evaluation of the behavior of a variable (in this case opportunity cost) around a specific location. To do so, a raster layer (cells of 270 x 270 m) with opportunity cost information for different types of vegetation cover was used. In addition, the Focused Statistics tool was used, which allows obtaining a raster data matrix in which each output cell value is a function of the values of the input cells that are around it. A neighborhood or donut shape was used as the neighborhood limit, whose area lies between two circles of different sizes, and which determines the final value of each cell (Figure 2). The resulting value represents the average opportunity cost of the activities carried out in the vicinity of the unit being analyzed.

[1] Oficina Nacional Forestal de Costa Rica (ONF) Escenarios de productividad para Melina y Teca [Productivity scenarios for Melina and Teak]. Unpublished observations.

3. Results

3.1. Current area and distribution of vegetation cover by canton

The distribution of vegetation cover by district is not dominated by a specific type of vegetation. Mature forest was the only type of coverage that dominated two of the four districts analyzed. Thus, mature forests cover more than 43% (36,636.41 ha) of the total area of Cutris, 39% (14,192.45 ha) of Cureña, 23% (8,775.73 ha) of Pital, and 10% (1,922.55 ha) of Florencia (Table 1, Fig. 3a). Pasture covers the second-largest area in the study 43% of Florencia (8,469.16 ha), 24% of Pital (9,270.19 ha), 22% of Cutris (18,789.89 ha) and 8% of Cureña (2,998.18 ha) (Table 1, Fig. 3a). At the same time, an inverse relationship can be observed between the areas covered by pasture and by mature forests; the greater the extent of pastures, the smaller the area of mature forest, and vice versa. This condition is most clearly seen in Florencia, where the percentage of pastures is 43% (8,469.16 ha) and that of mature forest is 10% (1,922.55 ha). In the case of Agricultural Crops, the dynamics are different. In Cureña, only 2% (846.65 ha) of the district is dedicated to agriculture; in Cutris 10% (8,772.80 ha), in Pital 19% (7,211.15 ha), and in Florencia 28% (5,556.90 ha) (Table 1, Fig. 3b).
Table 1
Area (ha) and distribution of vegetation cover by study area districts. AHNCA, Costa Rica.

| District | Mature forest | Forest plantation | Pasture | Agricultural crops | Total |
|----------|---------------|-------------------|---------|-------------------|-------|
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
|          |               |                   |         |                   |       |
Table 2
Area (ha) and Equivalent Annual Value (EAV) (\$ha^{-1} \text{ year}^{-1}) of the main activities of primary agricultural production in the study area, by category of vegetation cover and by district. AHNCA, Costa Rica.

| Vegetation cover | Productive activity/crop | Florenci a | Pital | Cutris | Cureña | Total area (ha) | (%) | EAV (\$ha^{-1} \text{ year}^{-1}) |
|------------------|--------------------------|------------|-------|--------|--------|----------------|-----|-------------------------------|
| Permanent agricul tural crops | Pineapple | 30.0 | 5,431.1 | 3,723.2 | 489.0 | 9,673.4 | 54.0 | 2,668.3 |
|                     | Sugar cane | 1,690.0 | 4.0 | 2,367.9 | 1.3 | 4,063.2 | 23.0 | 1,496.7 |
|                     | Palm heart | 1.0 | 281.1 | 0.0 | 0.0 | 282.1 | 2.0 | 2,365.4 |
|                     | Oil palm | 0.0 | 0.0 | 220.0 | 55.0 | 275.0 | 2.0 | 1,181.6 |
|                     | Plantain | 143.5 | 11.8 | 29.8 | 45.0 | 230.1 | 1.0 | 3,770.7 |
|                     | Cacao | 0.5 | 0.0 | 95.5 | 70.0 | 166.0 | 1.0 | 72.2 |
| Annual agricul tural crops | Cassava | 319.1 | 1,447.5 | 290.5 | 114.3 | 2,171.4 | 12.0 | 2,211.7 |
|                     | Rice | 190.0 | 0.0 | 41.4 | 0.0 | 231.4 | 1.0 | 603.4 |
|                     | Corn | 97.1 | 10.1 | 35.2 | 33.0 | 175.4 | 1.0 | 0.0 |
|                     | Yam | 3.0 | 29.4 | 46.8 | 47.1 | 126.2 | 1.0 | 1,165.9 |
|                     | Other 39 agricultural crops | 262.6 | 74.5 | 208.8 | 65.7 | 611.5 | 3.0 | NA |
| Subtotal | 2,736.8 | 7,289.4 | 7,059.1 | 920.3 | 18,005.7 | 100.0 |
| Forest plantation | *Gmelina arborea* | 27.0 | 469.5 | 1,445.0 | 421.0 | 2,362.4 | 39.0 | 293.0 |
|                     | *Tectona grandis* | 25.3 | 148.4 | 1,019.6 | 0.0 | 1,193.3 | 20.0 | 1,014.3 |
|                     | Other 29 species | 248.2 | 435.6 | 1,534.7 | 289.9 | 2,508.3 | 41.0 | 653.7 |
| Subtotal | 300.4 | 1,053.4 | 3,999.3 | 710.9 | 6,064.0 | 100.0 |
### 3.3. Profitability by vegetation cover category

Despite having smaller planted areas compared to forest plantations and pastures, agricultural crops have the highest profitability of any type of vegetation cover, which ranges from $1,507.4 \text{ ha}^{-1} \text{ year}^{-1}$ to $2,545.5 \text{ ha}^{-1} \text{ year}^{-1}$ (Table 3) due to the presence of highly profitable agro-export crops (Table 2). Forest plantations are the second most profitable type of coverage, with profitabilities ranging from $440.1 \text{ ha}^{-1} \text{ year}^{-1}$ to $651.6 \text{ ha}^{-1} \text{ year}^{-1}$. The district with the highest income from forest plantations is Florencia, followed by Cutris (Table 3). In the case of pastures, profitability ranges from $316.2 \text{ ha}^{-1} \text{ year}^{-1}$ to $630.2 \text{ ha}^{-1} \text{ year}^{-1}$, which is lower than what is obtained from agricultural crops and forest plantations, but higher than what is obtained from mature forest (Table 3). The average profitability of forest management in mature forest was estimated using Forest Value (FV), which corresponds to a forest management unit with an area between 50–100 ha; this figure was $33.4 \text{ ha}^{-1} \text{ year}^{-1}$ [26], the lowest profitability of any type of land use.

| Vegetation cover | Florencia | Pital | Cutris | Cureña | Total area (ha) | (%)  | EAV ($\text{ha}^{-1} \text{ year}^{-1}$) |
|------------------|-----------|-------|--------|--------|-----------------|------|----------------------------------|
| Pastures         |           |       |        |        |                 |      |                                  |
| Beef cattle      | 2,733.2   | 5,949.3 | 13,021.9 | 4,247.4  | 25,951.9         | 38.0 | 107.6                           |
| Dairy cattle     | 6,224.1   | 4,733.2 | 6,086.1 | 1,799.2 | 18,842.5         | 28.0 | 1,040.9                         |
| Dual-purpose cattle | 2,664.6 | 6,730.8 | 10,308.0 | 3,818.9  | 23,522.2         | 34.0 | 206.7                          |
| Subtotal         | 11,621.9  | 17,413.3 | 29,416.0 | 9,865.5  | 68,316.7         | 100.0|                                  |

Table 3

Average profitability ($\text{ha}^{-1} \text{ year}^{-1}$) for vegetation cover categories, by district. AHNCA, Costa Rica.

| Vegetation cover | Florencia | Pital | Cutris | Cureña | Average |
|------------------|-----------|-------|--------|--------|---------|
| Agricultural crops | 1,507.4   | 2,545.5 | 2,072.0 | 2,059.6 | 2,046.1 |
| Pastures         | 630.2     | 399.6  | 335.4  | 316.2  | 420.3   |
| Forest plantations | 651.6    | 543.7  | 615.3  | 440.1  | 562.7   |
| Mature forest    | 33.4      | 33.4   | 33.4   | 33.4   | 33.4    |

### 3.4. Opportunity cost of timber harvesting in natural forest with respect to alternative productive activities
The opportunity costs of SFM are greatest when it is compared to agricultural crops, in which case OCs range from $1,474.0 ha\(^{-1}\) year\(^{-1}\) to $2,512.1 ha\(^{-1}\) year\(^{-1}\) (Table 4). Comparisons with forest plantations showed intermediate opportunity costs, with the economic pressure caused by timber harvesting ranging between $406.7 ha\(^{-1}\) year\(^{-1}\) and $618.2 ha\(^{-1}\) year\(^{-1}\). Finally, comparisons with pastures produced OC estimates that range from $282.8 ha\(^{-1}\) year\(^{-1}\) to $596.8 ha\(^{-1}\) year\(^{-1}\), much lower than those of agricultural crops. In practical terms, OCs of SFM are higher in places where productive activities are carried out close to markets, service providers and infrastructure; these factors favor the production and marketing of products, increasing the profitability of the activities. This suggests that in those cases where conditions are not favorable for carrying out a productive activity, the OC of SFM is lower, and SFM is therefore a more competitive use of land.

It is necessary to clarify that only values of primary productive activities were considered when estimating OCs, leaving aside industrial activities, agro-industrial processing, trade and services, real estate developments, etc. Had these activities been taken into account, OC ranges would have been higher, mainly in those places where there is a significant presence of such activities, such as the district of Florencia. Additionally, an inverse relationship is observed between the area occupied by a given type of plant coverage and the opportunity cost of productive activities. This is clear in the case of pastures, which cover the largest total area, but at the same time exert the least economic pressure on the forest, since they have the lowest OC. The opposite happens in the case of agricultural crops that, despite having the smallest planted areas, involve products that generate high incomes. This implies a higher OC and consequently, a greater pressure on timber harvesting (which is made evident by the observed increase in area dedicated to pineapple in the region).

| Vegetation cover | Florencia | Pital | Cutris | Cureña | Average |
|------------------|-----------|-------|--------|--------|---------|
| Agricultural crops | 1,474.0 | 2,512.1 | 2,038.7 | 2,026.2 | 2,012.7 |
| Pastures | 596.8 | 366.2 | 302.0 | 282.8 | 387.0 |
| Forest plantations | 618.2 | 510.4 | 581.9 | 406.7 | 529.3 |
| Mature forest | - | - | - | - | - |

### 3.5. Opportunity cost according to neighborhood analysis

Using cartographic units (graphic elements associated with a territorial unit existing in reality), a set of values was generated between $\leq 0$ ha\(^{-1}\) year\(^{-1}\) and $\geq 4,000.0$ ha\(^{-1}\) year\(^{-1}\); representing the OC of adjacent productive activities for a specific cartographic unit (Fig. 4). These, in turn, were classified into three zones: high OC, medium OC and low OC.
Sites with high OCs (ranging from $1,000.0 \text{ ha}^{-1} \text{ year}^{-1}$ to $ \geq 4,000.0 \text{ ha}^{-1} \text{ year}^{-1}$) are located in the southern parts of Cutris and Pital, and almost all of the district of Florencia. It is assumed that these values are influenced by a high presence of agricultural crops and pastures, which have production chains that generate high returns, as is the case for products such as pineapple, cassava, plantain and sugar cane. Agriculture and livestock predominate in this region due to conditions of infrastructure, services, and access to markets that provide more productive scenarios for these activities. These areas are indicated by red colors in the Opportunity Cost Map (Fig. 4).

The medium OC sites (with values of $100.0 \text{ ha}^{-1} \text{ year}^{-1}$ to $1,000.0 \text{ ha}^{-1} \text{ year}^{-1}$) are colored light green, yellow, and light orange on the Opportunity Cost Map. Low OC sites (which range from $\leq 0$ to $100.0 \text{ ha}^{-1} \text{ year}^{-1}$) are located in the central and northern part of the study area and are colored dark green in the Opportunity Cost Map (Fig. 4). The low OC activities that are carried out in these regions are defined by three conditions: 1) they are crops with low profitability; 2) they are crops that are established in places which are difficult to access, and are biophysically and geographically limited; 3) the land is suitable for forestry, which restricts the activities to be carried out within the forest to timber harvesting.

Using the estimates and cartographic mapping of OCs, it was determined that economic expectation is lower where large areas of forest are located. Seventy-three percent (73%) of mature forest is in the low OC zone, while 82% of the area dedicated to agricultural crops is located in the high OC zone.

### 4. Discussion

Timber harvesting takes place in two clearly defined areas, in terms of opportunity cost: 1) high-opportunity cost areas, and 2) low-opportunity cost areas. The values of OC vary according to the productive dynamics of the region, which are mainly related to the predominantly agricultural landscape (agriculture and livestock). In recent years, agricultural practices have optimized the production of some crops, with pineapple, sugar cane, and oil palm experiencing the greatest productive advances (OECD and FUNDEVI 2017), and many of these crops displacing traditional products and other land uses, such as mature forest (Morales and Rodríguez 2010; Sierra et al. 2016; OECD and FUNDEVI 2017).

In the Huetar Norte Region, net deforestation is decreasing, and it is possible that the region is beginning to enter a period of transition from exploiting forests towards a more highly dynamic use of the soil, even though more than 50% of net deforestation in Costa Rica took place between 1987 and 1997 (Sierra et al. 2016). This evidence reflects divergent behavior in land use: although mature forests cover the largest areas in the region, agricultural crops and pastures for livestock dominate the region in economic terms. Meanwhile, the use and consumption of natural forest wood has fluctuated, and has provided a very low percentage of the total of local wood consumed in the last five years – only 6.1% of the volume used at the national level (Barrantes and Ugalde 2019).

Under current conditions, forest management would automatically have a high opportunity cost for producers in the southern regions of the study area, making it difficult to compete with other land uses
with higher economic yields. SFM is possible in areas far from the market and where site conditions limit agricultural production. Our analysis shows that forests under active forest management are currently located in areas of low opportunity cost. Priority should be placed on focusing efforts in these areas, where there are greater opportunities for adoption of sustainable forest management. Not only are they located in the regions with the highest concentration of mature forest, but this type of activity could be more competitive with respect to alternative uses. In other words, with the introduction of forest management in marginal zones, forest owners would be receiving economic benefits which are more competitive with those of other land uses (Navarro and Bermúdez 2006).

5. Conclusions

From an investor’s point of view, the approach used in this study makes it possible to show graphically where sustainable forest management is feasible and where it is not. The OC model shows the losses that producers face when they decide to invest in SFM instead of other types of land use such as cattle, agriculture or forest plantations. These OCs could be used as a reference to calculate compensation for owners who practice SFM in their forests, or who receive Payment for Environmental Services, with opportunity cost payments differentiated according to region. The methodology used here assists in determining the economic performance of land use (the economic and environmental components of SFM) (Naidoo and Adamowicz 2006; Adams et al. 2010; Bryan et al. 2011; Nakajima et al. 2017). However, the adjustment required for implementing a differentiated compensation associated with OC would force a paradigm shift in the current institutional framework in Costa Rica – changes for which the country may not be ready for or interested in carrying out.

Abbreviations

SFM: Sustainable Forest Management; OP: Opportunity Cost; AHNCA: Arenal Huetar Norte Conservation Area of Costa Rica; IFN: Costa Rica National Forest Inventory; ONT: Technical Standardization Body; GIS: Geographic Information Systems; FV: Forest Value; EAV: Equivalent Annual Value; NPV: Net Present Value; LEV: Land Expectation Value.

Declarations

Acknowledgments

To the Comisión de Desarrollo Forestal de San Carlos (CODEFORSA) and to the subregional offices of the Sistema Nacional de Áreas de Conservación (SINAC) in San Carlos and Pital, for giving us access to the management plans which were consulted. Likewise, we would like to thank the Technical Standardization Body (ONT) of the Ministry of Finance of Costa Rica, for providing us with maps of the agricultural zones in the study area.
Authors’ contributions

Each author contributed different sections of the paper according to their expertise and they shared the effort to produce this paper equally. All authors read and approved the final manuscript.

Funding

This study was supported by the Oficina Nacional Forestal (ONF) and the Instituto de Investigación y Servicios Forestales (INISEFOR) of the Universidad Nacional. Any opinions, findings and conclusions expressed in this article are those of the authors alone, and do not necessary reflect the views of ONF and INISEFOR.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Author details

1 Instituto de Investigación y Servicios Forestales, Universidad Nacional, Heredia 40101, Costa Rica; victor.meza.picado@una.cr; http://orcid.org/0000-0002-8223-4761. 2 Oficina Nacional Forestal de Costa Rica (ONF), San Antonio 40701, Belén, Costa Rica, sugalde@oficinaforestalcr.org. 3 Comisión de Desarrollo Forestal de San Carlos (CODEFORSALSA), Quesada 21001, San Carlos, Costa Rica, jmenendez@codeforsa.org.

References

Adamowicz W (2003) Economic Indicators of Sustainable Forest Management: Theory versus Practice. J For Econ 9:27–40.

Adams VM, Pressey RL, Naidoo R (2010) Opportunity costs: Who really pays for conservation? Biol Conserv 143:439–448. doi.org/10.1016/j.biocon.2009.11.011.
Andrew CE, Bariweni PA (2018) Opportunity Costs of Forest Conservation in Wilberforce Island, Niger Delta, Nigeria. JASEM 22:1965–1968. doi.org/10.4314/jasem.v22i12.16.

Azofeifa-Alvarado D, Azofeifa-Alvarado D, Solís-Carballo E (2015) Modelo para el pronóstico financiero de siembra y comercialización de tubérculos: Caso Ñame [Model for financial forecast of planting and marketing tubers: Yams]. Disertation, Instituto Tecnológico de Costa Rica.

Barrantes Rodríguez A, Ugalde Alfaro S (2019) Usos y aportes de la madera en Costa Rica: Estadísticas 2018 & Precios 2019 [Uses and contributions of Wood in Costa Rica: 2019 Statistics & 2019 Prices]. Oficina Nacional Forestal (ONF), Costa Rica.

Bryan BA, King D, Ward JR (2011) Modeling and mapping agricultural opportunity costs to guide landscape planning for natural resource management. Ecol Indic 11:199–208. doi.org/10.1016/j.ecolind.2009.02.005.

Calvo G, Somarriba E (1998) Sombras leguminosas para cacaotales: Costos y beneficios financieros [Legume shading for cocoa plantations: financial costs and benefits]. CATIE, Costa Rica.

Camacho Calvo AM (2015) Diagnóstico corto sobre las barreras que desalientan el manejo de bosques naturales en Costa Rica y propuestas de solución [Short diagnosis on the barriers that discourage management of natural forests in Costa Rica and proposed solution]. FONAFIFO-REDD, Costa Rica.

Camacho Calvo AM (2014) Superfície de bosques susceptible de manejo forestal en Costa Rica y estimación de su potencial productivo [Forest area subject to forest management in Costa Rica and stimulation of its productive potential]. FONAFIFO-REDD, Costa Rica.

Case K, Fair R (1997) Principios de microeconomía [Principles of microeconomics]. Prentice-Hall Hispanoamericana S.A., Mexico.

Cómo funciona Estadísticas focalizadas [How Focused Statistics works].
https://desktop.arcgis.com/es/arcmap/10.3/tools/spatial-analyst-toolbox/how-focal-statistics-works.htm. Accessed 02 Dec 2019.

de Camino Velozo R, Villalobos R, Morales Aymerich JP (2016) Costa Rica Case Study: Prepared for FAO as part of the State of the World’s Forests 2016 (SOFO). In: FAO (ed) El estado de los bosques del mundo 2016 (SOFO). FAO, Roma, p 50.

Food and Agriculture Organization of the United Nations (FAO) (2016) Evaluación de los recursos forestales mundiales 2015: ¿Cómo están cambiando los bosques del mundo? [Global Forest Resources Assessment 2015: How are the world's forests changing?] FAO, Roma.

Geotecnologías S.A. (n.d.) Atlas Costa Rica 2014: Distritos2014 [Atlas Costa Rica 2014: Districts 2014] [Data layer]
González Díaz B (2000) El coste de oportunidad como herramienta empresarial [Opportunity cost as a business tool]. Universidad de Oviedo, Spain.

Instituto Nacional de Estadística y Censos (INEC) (2014) VI Censo Nacional Agropecuario 2014: Base de datos de cultivos anuales, permanentes, forestales, pastos y actividades pecuarias de los distritos Pital, Cutris y Florencia de San Carlos, y Cureña de Sarapiquí [4th National Agricultural Census 2014: Database on annual, permanent, forest, pasture and livestock activities in the Pital, Cutris and Florencia de San Carlos districts, and Cureña de Sarapiquí]. INEC, Costa Rica.

Kniivilä M, Saastamoinen O (2002) The opportunity costs of forest conservation in a local economy. Silva Fenn (Hels) 36:853-865. doi.org/10.14214/sf.526.

Louman B, Quirós D, Nilsson M (2001) Silvicultura de bosques latifoliados húmedos con énfasis en América Central [Silviculture of humid broadleaf forests with emphasis on Central America]. CATIE, Costa Rica.

Meza Picado VH (2008) Evaluación de la eficiencia económica y la integridad ecológica para dos tipos de bosques húmedos intervenidos bajo manejo forestal con diferentes intensidades de cosecha en la Región Norte y Atlántica de Costa Rica [Evaluation of economic efficiency and ecological integrity for two types of humid forests placed under forest management with different harvest intensities in the North and Atlantic Regions of Costa Rica]. Disertation, Centro Agronómico de Investigación y Enseñanza (CATIE).

Ching Sancho W (2018) Capítulo III: Actividades y eventos que generan presión e impacto en el ambiente costarricense. In: Ministry of Environment and Energy of Costa Rica (MINAE) (ed) Estado del ambiente: Costa Rica 2017. [Chapter III Activities and events that generate pressure and impact on the Costa Rican environment. In: Ministry of Environment and Energy of Costa Rica (MINAE) (ed) 2017 State of the Environment Costa Rica] MINAE, Costa Rica.

Morales Hidalgo D, Rodríguez Quirós R (2010) Alternativas rentables productivas por región [Profitable productive alternatives by region]. Ministry of Agriculture and Livestock (MAG), Costa Rica.

Naidoo R, Adamowicz WL (2006) Modeling Opportunity Costs of Conservation in Transitional Landscapes. Conserv Biol 20:490–500. doi.org/10.1111/j.1523-1739.2006.00304.

Nakajima T, Kanomata H, Shiraishi N, Matsumoto M (2017) Development and analysis of an opportunity cost simulation accounting for the spatial distributions of local forest management. Ann For Sci 60: 145–159. doi.org/10.15287/afr.2016.770.

Navarro GA, Vieto RJ, Bermúdez G (2006) Costos de acceso a la legalidad, cadenas y actores de mercado de la madera legal e ilegal en Costa Rica [Costs of access to legality, market chains and actors to legal and illegal timber in Costa Rica]. SINAC-FAO, Costa Rica.
Navarro G, Bermúdez G (2006) Rentabilidad del manejo de bosques naturales y su competitividad respecto a otros usos de la tierra en Costa Rica [Profitability of natural forest management and its competitiveness with respect to other land uses in Costa Rica]. CATIE, Costa Rica.

Organización para la Cooperación y el Desarrollo Económicos (OCDE), Fundación de la Universidad de Costa Rica para la Investigación (FUNDEVI) (2017) Interacciones entre Políticas Públicas, Migración y Desarrollo en Costa Rica [Interactions between Public Policies, Migration and Development in Costa Rica]. OECD, Paris. doi.org/10.1787/9789264279018-es

Ortíz-Malavassi E, Méndez A, Gómez A, Villavicencio D, Solano M, Ortega N (2013) Tipos de Bosque 2012_INFv5 [Forest Types 2012_INFv5] [Data layer].

Pitacuar Meneses ML (2010) Análisis económico para entender la forma en que se asignan los bosques y otros usos de la tierra en el Corredor Biológico San Juan La Selva, Costa Rica [Economic analysis to understand the way in which forests and other land uses are assigned in the San Juan La Selva Biological Corridor, Costa Rica]. Disertation, Centro Agronómico de Investigación y Enseñanza (CATIE).

Presidency of the Republic of Costa Rica, Ministry of Environment and Energy of Costa Rica (MINAE) (2014) Decreto N° 38323—MINAE. Pago por Servicios Ambientales para el año 2014 [Payment for Environmental Services for the year 2014]. Diario Oficial La Gaceta, Costa Rica.

Programa REDD/CCAD-GIZ, Sistema Nacional de Áreas de Conservación (SINAC). Inventario Nacional Forestal de Costa Rica 2014-2015: Resultados y caracterización de los recursos forestales [National Forest Inventory of Costa Rica 2014-2015: Results and Characterization of Forest Resources]. Programa Regional REDD/CCAD-GIZ, El Salvador.

Sánchez R, Reyes V, Mora R, Castro R, Madrigal P, Ovares C, Cascante S (2013) Valoración económica de usos alternativos de la tierra del área de amortiguamiento y del Humedal Nacional Térraba—Sierpe (HNTS) [Economic valuation of alternative land uses in the buffer zone and the Térraba-Sierpe National Wetland (HNTS)] Programa Regional CCAD/REDD-GIZ, El Salvador.

Sánchez Meza R (2010) Estudio de la rentabilidad social del bosque tropical, políticas y estrategias para la sostenibilidad: Caso Corredor Biológico San Juan la Selva [Study on the social profitability of tropical forests, policies and strategies for sustainability: Case of the San Juan La Selva Biological Corridor]. Disertation, Centro Internacional de Política Económica para el Desarrollo Sostenible (CINPE-UNA).

Sierra R, Cambroner A, Vega E (2016) Patrones y factores de cambio de la cobertura forestal natural de Costa Rica, 1987-2013 [Patterns and factors of change of the natural forest cover of Costa Rica, 1987-2013]. Forest Carbon Partnership Facility (FCPF), Washington D.C.

Sistema Nacional de Áreas de Conservación (SINAC) (1998) Atlas Costa Rica 2014: AConservacionSINAC2014 [Atlas Costa Rica 2014: AConservationSINAC2014] [Data layer].
Sistema Nacional de Áreas de Conservación (SINAC), Sistema de Información de Recursos Forestales (SIREFOR) (2011) Reporte estadístico forestal 2011 [Forest Statistics Report 2011]. SIREFOR, Costa Rica.

Sistema Nacional de Áreas de Conservación (SINAC), Sistema de Información de Recursos Forestales (SIREFOR) (2012) Reporte estadístico forestal 2012 [Forest Statistical Report 2012]. GIZ, Costa Rica.

Sistema Nacional de Áreas de Conservación (SINAC), Sistema de Información de Recursos Forestales (SIREFOR) (2013) Reporte estadístico forestal 2013 [Forest Statistical Report 2013]. GIZ, Costa Rica.

Sullivan WG, Wicks EM, Luxhoj JT (2004) Ingeniería económica de DeGarmo [DeGarmo Economic Engineering]. 12th ed. Pearson Education, Mexico.

Vega-Araya E (2014) Desarrollo de un modelo de montos diferenciados de PSA considerando el costo de oportunidad asociado al uso de la tierra [Development of a model of differentiated amounts of PES considering the opportunity cost associated with land use]. FONAFIFO, Costa Rica.

Zúñiga-Méndez C (2018) Rentabilidad del aprovechamiento maderable de los planes de manejo aprobados en el periodo 2010 – 2013 y su efecto en el costo de oportunidad de la tierra, para el Área de Conservación Arenal – Huetar Norte, Costa Rica [Profitability of timber harvesting from management plans approved in the 2010-2013 period and its effect on the opportunity cost of the land, for the Arenal Conservation Area - Huetar Norte, Costa Rica]. Disertation, Universidad Nacional.

**Figures**
Figure 1

Example of the Focused Statistics process with a ring neighborhood (internal radius of 1 cell, external radius of 3 cells). Source: Based on (Cómo funciona Estadísticas focalizadas 2019).
Figure 2

Geographic location of the study area. AHNCA, Costa Rica.
Figure 3

(a) Distribution of vegetation covertypes by district; (b) Proportion of agricultural crops by district.
AHNCA, Costa Rica.
Figure 4

Opportunity Cost Map based on productive activities carried out in areas with different types of vegetation cover in the study area. AHNCA, Costa Rica.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Equations.docx