Posters
Valuing Forest Fire Damage to the Environment¹

Esteban Castellano, José María Rábade, Carmen Aragoneses²

Abstract
Forest fire damage to the environment must be re-evaluated. On the one hand, negative impacts of small forest fires on the environment are negligible, requiring little attention. On the other hand, large fire damages and losses are much greater than those accounted for from losses of goods and services with market values alone. Tecnologías y Servicios Agrarios, S.A. (TRAGSATEC) has developed a model that accounts for all factors that increase the productive, recreational, and ecological value of ecosystems, from a societal point of view, for all locations on the territory. The forest fire protection plans for an area can evaluate its economic efficiency by using a forest fire simulator to compare the total value of the area burn under the plan’s recommended measures, and what it would burned without the plan.

Investments in the environment have always been harmed in conventional economic analysis by the fact that a large part of the goods the environment produces have no market price. This situation is particularly striking in Spain because of the enormous reduction in the public deficit pursued by the country in recent years in order to adapt the economy to the standards of the group of countries that have adopted the Euro currency as their common currency.

As an engineering company, Tecnologías y Servicios Agrarios, S.A. (TRAGSATEC) has designed general action plans against forest fires in various regions of Spain (competence for environmental matters has been assigned to the regional authorities). In this context, a methodology has been developed that allows financial justification of the budget for the actions envisaged in the proposed plan. The valuation data presented in this paper come from the model's application to the Madrid region.

The methodology is based on two computer models developed on a geographic information system (GIS): an integrated economic valuation (IEV) model for forest systems and a forest fire behavior simulator (FFS). Both models comply with technical specifications. They give individualized estimates for each forest hectare of the region. In addition to the specific plant cover of each 1-hectare cell, the models include the parameters defined by the cell's situation (slope, distance from population centers, etc.). Given that the main objective of the models is the valuation of forest fire areas, it will be assured that the areas with major fires (500 hectares or 1,200 acres) are significant at the model scale.

The IEV estimates the value of the forest systems, including all aspects of their value. Specifically, a valuation is given for priced goods (e.g., the wood), unpriced goods with a use value (e.g., recreation), and non-use goods (e.g., their existence per se).

The valuation is made by making an estimate of the annual income generated by the forest ecosystem and calculating the present value of the infinite stream of cash flows equal to the calculated income. It is assumed that the forest ecosystem will remain in its current state; intergenerational justice can thus be guaranteed, even with results obtained by applying different discount techniques with positive rates.

The capitalization of the annual income from all goods produced by the forest ecosystem is done by using a social time preference rate (STPR) discount rate. The rate used in the model's application to the Madrid region was 2 percent.

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Technical specifications of the FFS include its use of BEHAVE equations to parameterize the fires behavior. It can generate a tessellation tile for each fire perimeter corresponding to the time intervals defined. It also allows automatic loading of the conditions of the fires to be simulated (for example, weather conditions and coordinates of the origin of all fires that occurred during the last decade).

**Proposed Methodology**

**Integrated Economic Valuation (IEV) Model for Forest Systems**

For valuation purposes, the goods produced by forest ecosystems are classified in three aspects: productive, recreational, and environmental.

**Productive Aspect**

This category groups the income of all priced products generated by the forest ecosystem (private goods): wood, timber, fruit, grazing land, hunting, cork, seeds, etc.

The process begins by estimating the annual income generated by the cell for each element in the model. This is done by estimating the production of the element in the cell and valuing said output at its unharvested market price. If the forest ecosystem is immature, a financial adjustment is made between its age and the rotation (date on which exploitation begins). Lastly, if the element is of sufficient economic importance, the cells are reclassified (the income for the territory as a whole remains unchanged) according to the territorial parameters of each one of the cells capable of influencing the income of the element. In the case of wood, these parameters would be slope and accessibility, for example.

**Recreational Aspect**

This category reflects the value of forest ecosystems as leisure areas. Each one of the recreational areas is valued using the Travel Cost Method. The model requires valuation of all recreational areas of the region. Some are very small and have no visitors data. These are valued by estimating visits as a function of the variables that define the attractiveness of the recreational area: landscape of the surrounding zone, type of water-related activity pursued in the areas, and type of plant cover.

The landscape is valued with the hedonic prices method, as it already forms part of the pricing function of the homes in towns surrounding the city. The other two explanatory variables are the distance to the capital and the population density of the town in which the home is located.

**Environmental Aspect**

This aspect covers public goods with no use. It includes option, donation, legacy and existence values and is valued using the contingent valuation method. Some 1,122 valid questionnaires were completed by citizens age 16 or more residing in the region with a single dichotomous question on their willingness-to-pay (WTP) to assure the survival of the region’s forest systems. The resulting WTP was $38 per citizen per year.

In order to obtain the environmental value in a cartographic format, the overall results of the contingent valuation must be incorporated into each of the 1-hectare cells defined in the region. This was done by consulting a panel of experts on the parameters that determine the environmental quality of a point in the form of a quantitative index. The overall WTP was then distributed proportionally to the value of the index at each point of the area.

**Aggregate Economic Value**

The total economic value is determined in each cell by merely adding up the three aspects considered. Before adding up the three aspects, an adjustment
must be made for elements that could be counted twice. For example, citizens may internalize in their WTP the recreational use they make of the forest ecosystems, and there are obvious incompatibilities between some of the priced elements. The first duplication is avoided by adding a question in the questionnaire regarding the respondent's recreational use of the ecosystems and analyzing the response in the two subsamples. The second duplication is avoided by inclusion in the model of a matrix of incompatibility coefficients that discounts double use.

This coverage grid is the final result of the model and allows the integrated value of any tract of significant size to be automatically determined.

**Forest Fire Behavior Simulator (FFS)**

**The General Plan (GP) for Defense against Forest Fires**

The GP is the source of the data that determine fire behavior in the region's ecosystems. The fire's reaction is established by studying the risk (frequency and causality), weather, flammability, combustibility, and slope of the terrain.

The result of the planning process is a set of proposed actions for prevention, control, and extinguishment. These actions have a financial cost for society that needs to be justified.

**FFS Inputs**

The elements that define a fire's reaction to ecosystems are incorporated in the simulator in different forms:

- Basic coverages---The slope of the terrain is input into the FFS with a digital elevation model (DEM) and its combustibility by transforming the different types of vegetation into fuel models.
- Fire parameters to be simulated---The frequency is input by means of the coordinates of a historical series of fires that occurred during the previous decade, and meteorology is accounted for by inputting the wind speed and direction existing in each of the historical fires. This information is obtained from the fire reports.

**FFS Outputs**

The surveillance and extinguishment actions included in the GP involve shortening the time needed for bringing the fire under control, and the prevention actions involve the greater improbability of a fire's advance (barriers, etc.), which may be expressed as a smaller blaze area for a given duration of the fire.

The collection of historical fires may be simulated two times: once with the basic conditions and control times that actually took place and another with the proposals formulated in the GP and the target control times.

The result is a difference in the burned land area (smaller on average), which is taken as the land area saved by the GP and capable of valuation by using the IEV.

**Results of the FFS**

The land area saved each year was estimated (table 1). The base 10-year historical series of fires was applied to the two situations studied: the territory without the actions proposed in the GP and with the historical control times and the territory with implementation of the proposals and the target control times (table 1). The average land area in each year for these two situations is totalled for the number of fires that occurred, and the saved area is obtained as the difference between the totals for both situations.
Table 1—Forest fire behavior simulator (FFS) results: annual saved surface estimation.

<table>
<thead>
<tr>
<th>Year of GP</th>
<th>Number of fires</th>
<th>Without general plan</th>
<th>With general plan</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total average surface</td>
<td>Total surface</td>
</tr>
<tr>
<td>1</td>
<td>69</td>
<td>5 341</td>
<td>3 218</td>
</tr>
<tr>
<td>2</td>
<td>116</td>
<td>3 404</td>
<td>2 233</td>
</tr>
<tr>
<td>3</td>
<td>140</td>
<td>70 9,780</td>
<td>65 9,168</td>
</tr>
<tr>
<td>4</td>
<td>148</td>
<td>17 2,557</td>
<td>16 2,397</td>
</tr>
<tr>
<td>5</td>
<td>295</td>
<td>3 985</td>
<td>2 655</td>
</tr>
<tr>
<td>6</td>
<td>398</td>
<td>3 1,071</td>
<td>2 622</td>
</tr>
<tr>
<td>7</td>
<td>77</td>
<td>8 621</td>
<td>5 379</td>
</tr>
<tr>
<td>8</td>
<td>129</td>
<td>16 2,039</td>
<td>13 1,726</td>
</tr>
<tr>
<td>9</td>
<td>102</td>
<td>19 1,934</td>
<td>17 1,744</td>
</tr>
<tr>
<td>10</td>
<td>302</td>
<td>3 806</td>
<td>2 530</td>
</tr>
<tr>
<td>Total / Average</td>
<td>1,776</td>
<td>11.56 20,539</td>
<td>9.95 17,673</td>
</tr>
</tbody>
</table>

Table 2—General Plan (GP) results: cash flow and financial ratios.

<table>
<thead>
<tr>
<th>Year of GP</th>
<th>Total saved surface</th>
<th>Surface average value</th>
<th>Saved surface value</th>
<th>GP cost</th>
<th>Profit / -Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>122</td>
<td>12,081</td>
<td>1,473,882</td>
<td>4,674,306</td>
<td>-954,217</td>
</tr>
<tr>
<td>2</td>
<td>170</td>
<td>10,993</td>
<td>1,868,810</td>
<td>3,870,646</td>
<td>-150,557</td>
</tr>
<tr>
<td>3</td>
<td>612</td>
<td>12,799</td>
<td>7,832,988</td>
<td>920,109</td>
<td>2,799,980</td>
</tr>
<tr>
<td>4</td>
<td>161</td>
<td>18,790</td>
<td>3,025,190</td>
<td>833,735</td>
<td>2,886,354</td>
</tr>
<tr>
<td>5</td>
<td>330</td>
<td>10,845</td>
<td>3,578,850</td>
<td>768,954</td>
<td>2,951,135</td>
</tr>
<tr>
<td>6</td>
<td>449</td>
<td>10,749</td>
<td>4,826,301</td>
<td>617,800</td>
<td>3,102,289</td>
</tr>
<tr>
<td>7</td>
<td>242</td>
<td>14,707</td>
<td>3,559,094</td>
<td>1,481,540</td>
<td>2,238,549</td>
</tr>
<tr>
<td>8</td>
<td>313</td>
<td>11,655</td>
<td>3,648,015</td>
<td>401,865</td>
<td>3,318,224</td>
</tr>
<tr>
<td>9</td>
<td>190</td>
<td>18,886</td>
<td>3,588,340</td>
<td>509,832</td>
<td>3,210,257</td>
</tr>
<tr>
<td>10</td>
<td>276</td>
<td>13,766</td>
<td>3,799,416</td>
<td>809,070</td>
<td>2,911,019</td>
</tr>
<tr>
<td>Annual average</td>
<td>287</td>
<td>12,985</td>
<td>37,200,886</td>
<td>14,887,857</td>
<td>22,313,033</td>
</tr>
</tbody>
</table>

The first implicit assumption is that the number of fires depends on socio-economic conditions and not on the GP actions and, therefore, will remain constant for as long as the conditions remain constant (citizen awareness initiatives may improve the situation but not to a significant degree in the short term). The second assumption is that without the GP actions, fire control effectiveness would be the same as in the past, unlike the effectiveness that will be achieved with the GP, which is taken as the GP target levels.

Results of the GP Cash Flow and Financial Indicators

To value the area difference of the two situations simulated for all fires of the historical series, the total saved area and average value per hectare were determined by using the IEV method (table 2).

The average values per non-forested hectare saved are $10,501/ha and $23,919/ha per forested hectare. In the region of Madrid, the value of an ecosystem is distributed in the following proportions: productive value, 10 percent; recreational value, 15 percent; and ecological value, 75 percent.

The total value of the saved area is calculated by simply multiplying the average value per hectare by the number of hectares saved. The result gives the
profit generated by the GP but not necessarily with the time sequence expressed by the historical series. For this reason, each annual period is assigned the average gain for the period during which the GP is in force.

The GP costs are taken as the aggregate budget for the proposed incremental actions. They are concentrated in the initial years of the GP because they primarily consist of forestry and infrastructure work (broad-leaf re-population, barriers, improvements to access ways, increase in water points, etc.). In this case the projected sequence in which the actions are to be undertaken is of bearing for the GP cash flow.

The difference between the stream of value saved from fire and of the costs necessary for generating those savings gives the GP cash flow, which may be analyzed using financial ratios.

**Conclusions**

The proportions in which the different aspects contribute to the aggregate economic value of the forest systems of the region of Madrid may be considered atypical, reflecting the peri-urban location of the forest ecosystems in this large metropolitan capital of Spain.

The plans for protecting the forest ecosystems against fire may be financially justified (positive net present value [NPV], high profitability and internal rate return [IRR], and short pay-back) if we consider all goods produced by the systems, irrespective of whether or not they have a price. If only priced goods are considered, however, the high costs of protection do not appear justified.

<table>
<thead>
<tr>
<th>Financial ratios</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV 2 percent</td>
<td>$19,507,598</td>
</tr>
<tr>
<td>Profitability 2 percent</td>
<td>239.25 percent</td>
</tr>
<tr>
<td>IRR</td>
<td>124.18 percent</td>
</tr>
<tr>
<td>Payback 2 percent</td>
<td>2.41 years</td>
</tr>
</tbody>
</table>

The forest fire simulation models, used in combination with the geographical models for integrated valuation of forest systems, allow the effectiveness of the GPs to be determined, simulating a representative collection of the fires in the zone in pre-GP and post-GP conditions and valuing the different land areas affected by fire.
Defense System against Forest Fires in the Andalusian Region in Spain

Ernesto Fernández de la Fuente

Abstract
In response to the harsh climate conditions of the Mediterranean region in the Andalusian region of Spain, Andalusia developed a new model of defense against forest fires in 1993. The system, known as the Andalusia Community Forest Fire Plan (INFOCA), was organized through forest defense centers at the provincial, regional, and local levels. The new organization required a significant increase in financial and fire fighting resources.

Location and Characterization of the Area
Spain is located in southwestern Europe and forms the western coast of the Mediterranean Sea. Andalusia is located in southern Spain and the region contains both forest areas and plan protected areas (natural parks and similar).

The population of Andalusia is 7,216,649, with 53.4 percent urban inhabitants and 46.6 percent rural inhabitants. Within an area of 87,000 km², 47 percent is agricultural land, 3.5 percent has other uses, and 49.5 percent is classified as forest areas. Of the total forest area, 10.31 percent is densely wooded, 52.78 percent is pasture land and sparsely wooded scrubland, and 36.91 percent is treeless.

Precedents
The region of Andalusia is a clear example of the harsh climate of the countries in the Mediterranean region, which has given rise to a climactic model of high summer temperatures, a big drop in relative humidity, and drying winds. The orography of the area has slopes that reach 3,480 m in only 34 km, which is a serious problem that can cause forest fires to spread rapidly. Fires affect vegetation, fauna, and the loss of land by erosion.

The current model of defense against forest fires in Andalusia originated in 1993. The model changed in that year as a result of analysis by all the stakeholders, including forest administration, private landowners, agrarian organizations, trade unions, and the university. The events that gave rise to the debate that led to the abandonment of the previous system were the sharp increase in the area of land burned in 1991 and the fire in the Grazalema Nature Park that caused the death of five firefighters.

Number of Fires and Area Affected
In 1993 to 1998, the Andalusia Community Forest Fire Plan (INFOCA) increased the average financial investment by 60 percent compared to the previous period (1988 to 1992), reduced by one-half the area affected by fires each year, and reduced the number of large fires.

The Forest Defense Centers, the Provincial Operations Centers, and the Regional Operations Center are all located within Andalusia. They have the following resources:

- Ground resources:
  - 234 fire lookouts
  - 263 specialized firefighter teams

1An abbreviated version of this paper was presented at the Symposium on Fire Economics, Planning, and Policy: Bottom Lines, April 5-9, 1999, San Diego, California.

2Natural Media Defense Manager, Environment Management Enterprise (EGMASA), C / Johan G. Gutenberg, Egmasa Building, 41092 Isla de la Cartuja, Seville, Spain.
- 155 mobile firefighter team
- 4 special back-up brigades
- 92 fire engines
- 9 mobile meteorology and transmission units
- 1 advanced forest fire tracking unit
- 4,526 total number of people in ground resources.

- Aircraft resources:
  - 21 helicopters for transport/ fire suppression
  - 5 ground loading planes
  - 2 Canadair CL215 amphibian planes
  - 3 coordination planes.

**Fire Fighting Action Plan**

Andalusia has the following technical resources for management and coordination:

- **Centers:**
  - Regional Operating Center
  - Provincial Operating Center
  - Local Forest Defense Center.

- **Prevention and planning:**
  - Thematic mapping
  - Risk indexes
  - High priority action plans against forest fires
  - Preventive silviculture improvement in infrastructures
  - Routes into the forest
  - Water supply points
  - Helicopter pads
  - Fire lookout information and awareness-raising campaigns.

- **Detection:**
  - Network of fire lookouts
  - Automated detection infrared (IR) wood system
  - Mobile observation teams.

- **Suppression:**
  - Specialized teams transported in helicopters
  - Firefighters' jeeps
  - Mobile firefighters
  - Back-up brigades
  - Heavy machinery
  - Meteorological transmission mobile unit (UMMT) and advanced forest fire follow-up unit (UNASIF).

- **Aircraft resources:**
  - ACT (Air Tractor; PZL, Grumman)
- Helicopters for transport/fire suppression (Bell 205 and 206)
- Canadair CL215
- Planes for coordination and display of aerial photography.

- Follow-up activities:
  - Investigation into causes
  - Beginning legal action (autonomous police)
  - Damage assessment
  - Plans to aid the natural regeneration of vegetation
  - Reforestation.

This action plan is backed up by public collaboration in a two-pronged system of detection, via a free telephone line for emergency warnings, and of fire suppression, through the Local Rapid Assistance Groups (volunteers).

In the constant struggle against forest fires, new technology and materials are appearing. Although this is not the definitive solution, new technology has been a very useful tool in helping with some of the difficulties involved in fighting against forest fires. Some of the new technology includes:

- Bacares, the specialized system for geographic information.
- System for the display of real time images of forest fires.
- An automated infrared surveillance and detection system for forest fires (Bosque System).
- A digital model of land-simulation of fire behavior (ARC/INFO CARDIN).
- Network of automatic weather stations.
- Remote sensing of forest fires.
- FORMA-2, a program of in-service training for workers.
- Integrated crisis management systems for large fires.
- Introduction of quality and environmental management systems.

**International Cooperation**

The Andalusian regional government has developed cooperation programs with the Kingdom of Morocco and the Eastern Republic of Uruguay. The cooperation program includes:

- Drawing up the fire management plan in the Rif region of northern Morocco.
- Building and opening the Center for Training in the Defense against Forest Fires, The Forest Reserve of Cape Polonio, and the Aguas Dulces (region of Rocha).
The Impacts of Forest Fires on Wilderness Recreation in Eastern Manitoba, Canada

Peter C. Boxall, David Watson, Randal Hoscheit, Jeffrey Englin, Grant Hauer

Abstract
This study examines the role of historic fire in the choice of recreational canoe routes in forests located in the Canadian Shield. Forests burned 10 years previous to the year we observed route choices resulted in dis-utilities to the recreationists. Forests that burned over 64 years provided significant positive utility. This information was used to develop an intertemporal amenity function which was combined with timber growth and fire risks in a Faustmann optimal rotation framework. The resulting model suggests that harvesting should be delayed in areas with significant recreational canoeing benefits.

The Precambrian Shield of Canada provides some of the finest wilderness recreation opportunities in North America in the form of lakes and rivers surrounded by forests. Forests of this region are subject to periods of natural disturbance caused by fires. Nopiming Provincial Park, Manitoba is located within the Shield. The park is a 1,440 km² area located about 150 km east of Winnipeg, a city of about 550,000 people. Much of the park is forested with jack pine (Pinus banksiana). However, black spruce (Picea mariana), white spruce (Picea glauca) and trembling aspen (Populus tremuloides) stands are also found there. The park was subjected to severe fires during 1983 (fig. 1) and hosts a limited harvest of timber that is used in a pulp mill nearby.

This poster presents results of our study on the role of burned forests on recreation site choice of canoeists. During 1993 we developed a voluntary registration system for overnight canoeists, conducted field inventories of characteristics of routes, and linked routes with the provincial forest inventory by using a geographical information system (GIS). The final data set involved trip information from 388 visitors to 20 different canoe routes.

Significance of Fire on Canoe Route Choice
Random utility models were used to estimate impacts of the 1983 burned areas on canoe route choice in 1993. Canoeists were assumed to choose routes that provide them with the largest utility or benefit (Boxall and others 1996). The model estimates the probabilities of choosing each of the 20 routes as a function of the characteristics of the routes and travel costs. We found that the presence of 1983 burns along canoe routes had a negative effect on choice (table 1), and that canoeists preferred older jack pine stands to mature black spruce or aspen stands.

Valuing Old Burns
Simulations were conducted where the areas burned in two fires in 1983 were returned to mature forest. An issue to consider with this method is the type of forest present before the fires; two simulations were used: change burned areas to original forest age, and change burned areas to mature forest. Changes in the probabilities of visiting each canoe route were calculated using each method. Since canoeists prefer to visit routes closer to their homes (all other things equal) we calculated the costs saved as a result of the simulation. We found that the 1983 fires caused a loss in the value of trips in 1993 from $2.91 / ha to $21.76 / ha.

1An abbreviated version of this paper was presented at the Symposium on Fire Economics, Planning, and Policy: Bottom Lines, April 5-9, 1999, San Diego, California.
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3Associate Professor, Department of Applied Economics and Statistics, University of Nevada, Reno, NV.
4Assistant Professor, Department of Rural Economy, University of Alberta, Edmonton, Alberta, Canada.
Table 1: Effect of 1983 burns on canoe route choice and canoeist preferences.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Cost</td>
<td>-0.0573</td>
</tr>
<tr>
<td>Area of recent cut-blocks</td>
<td>0.5262</td>
</tr>
<tr>
<td>Burns 10 years or more recent</td>
<td>-0.1016</td>
</tr>
<tr>
<td>Area of mature Jack pine</td>
<td>0.6854</td>
</tr>
<tr>
<td>Area of mature black spruce</td>
<td>-0.9988</td>
</tr>
<tr>
<td>Area of white spruce (any age)</td>
<td>6.2029</td>
</tr>
<tr>
<td>Area of aspen (any age)</td>
<td>-3.1102</td>
</tr>
<tr>
<td>Cottages</td>
<td>-1.3374</td>
</tr>
<tr>
<td>Longest portage</td>
<td>-0.0018</td>
</tr>
<tr>
<td>Number of portages</td>
<td>-0.0774</td>
</tr>
<tr>
<td>Heritage river constant</td>
<td>3.6939</td>
</tr>
<tr>
<td>Fishing quality constant</td>
<td>0.7075</td>
</tr>
</tbody>
</table>

Figure 1
Study area: Nopiming Provincial Park, Eastern Manitoba, Canada.
**Fire and Harvest Rotation Age**

Severe fires occurred in Nopiming Provincial Park in 1983. The historical fire risk in this area is 1.5 percent. With this information we attempted to include the recreation values and fires risks in examining questions regarding the timing of timber harvests.

Since burned areas from the 1983 fire provided a disamenity to recreationists 10 years after the fire, and mature jack pine stands provided a positive amenity, a function can be constructed to describe the recreation benefits of jack pine stands over time. This function is based on two points: the first an estimate of the 1983 fire damages 10 years after the fire, and the second an estimate of the benefits provided by mature forest stands 64 years after fire. Marginal values of a hectare of these two ages of stands were estimated by dividing their parameter values (table 1) by the travel cost parameter. Converting these values from a km$^2$ to a hectare basis yielded values of $0.0169$ and $0.1133$/ha/ trip, respectively. The 10-year-old fire (10-year-old forest in 1993) provided negative values while the mature forest (64 years or more after fire) provided positive values. Following Englin (1990) these two points were used to estimate a two-piece linear function for an individual recreationist:

Value = $-0.039 + 0.0019(t)$, in which $t < 65$ years,

Value = 0.089, in which $t \geq 65$ years.

This function (fig. 2) suggests fire damages are worth $-0.039 / ha just after fire occurs and increase to $0.00 / ha at about 17 years after fire. Stands continue to increase in value until 65 years when they reach a constant positive value for ages greater than 65 years.

Economic aspects of timber harvesting are frequently examined through optimal rotation models. The Faustmann model is the original development of this problem but only considers timber values in a deterministic framework. Hartman (1976) extended the basic Faustmann model to include amenities affected by forest harvests. An additional extension to the Faustmann model was the inclusion of fire risks formulated by Reed (1984). Reed showed that fire risks serve to shorten timber-only rotation periods since delaying harvest increases the risk of losing value due to fire. In the Nopiming case, however, multiple use of forest stands is a concern. Thus, integrating fire risk into the Hartman model is appropriate. Englin and others (1999) derive the Hartman objective function with fire risk. This function is:

$$ PV(T) = \frac{(\lambda + r)}{r} \left[ V(T) + e^{(\lambda + r)T} \int_0^T \left( \int_0^T F(x) e^{-rx} dx \right) e^{-dx} dx + e^{rT} \int_0^T F(x) e^{-rT} dx \right] - c_b e^{(\lambda + r)T} - \frac{\lambda c_p}{r + \lambda} (e^{(\lambda + r)T} - 1) $$

in which $V(t)$ is the value of timber at time $t$, $c_b$ is the harvesting cost, $r$ is the discount rate, $F(x)$ is the flow of amenities (i.e., canoeing), $\int F(x) e^{-rx} dx$ is the discounted flow of amenities, $\lambda$ is the Poisson parameter describing the average rate of fires, and $c_p$ is the cost of replanting after fire or harvest. The derivation of this function involves considerable calculus which is not reported here for brevity.

The amenity function described above was used for $F(x)$ and the timber growth function was:

$$ \ln(m^3/ha) = 6.1192 - 66.6471 \text{ (age)}^{-1} $$

![Figure 2](image-url)

The recreation benefits of jack pine stands over time.
The simulation involved substituting these functions into the objective function, setting the harvesting and post-fire replanting costs to zero, and calculating the value of the objective function for a series of rotation ages ranging from 0 to 150 years under a set of fire risks. The rotation age that maximized the value of the objective function is the optimal rotation age.

Accounting for risk of fire in a Faustmann framework suggests that harvesting should be done at a younger age than the Faustmann rotation (table 2). As fire risks increase, the optimal harvesting age decreases. This finding validates the model developed by Reed (1984). Considering a fire risk of 0 percent and implementing the Hartman rotation model suggests that harvest timing should be delayed, by as much as 10 percent if 200 recreationists are involved. When the amenity function values are included along with fire risk, our results suggest that harvesting should still be done at an older age. Thus, the amenity values tend to outweigh the risks of fire on timing of rotation. This information provides guidance to managers on spatial patterns on integrating timber values with non-timber values. However, these results are sensitive to the number of recreationists involved.

**Synthesis**
Fires affect recreation use patterns and values. These models can be used to establish fire protection priorities that include recreation values. For example, the Tulabi route (fig. 1) is currently the most valuable route in the park because of the types of forests found along its waterways. The model can also be used to examine gains (or losses) of other management policies such as new cottage subdivision developments. Integrating this information with timber values suggests that forest managers should delay harvests on those canoe routes with sizeable areas of older forests along them. In places where fire, wilderness recreation, and timber harvesting occur together, the number of recreationists may play a larger role than fire in determining harvest timing decisions.

**References**


Hartman, R. 1976. The harvesting decision when a standing forest has value. Economic Inquiry 14:52-58.

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