Economic estimation of forest fire damage in N-E Italy[1]

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Abstract

In Italy, about 45,000 ha of forest areas are burned each year. The ignitions are mainly human-caused (over 90 percent) and about 50 percent are arsons. The recent Italian National Law n. 353/2000 therefore prescribes that costs of human-caused fires must be refunded by the person responsible (when discovered). Two main components of the costs are identified: those paid for the active fire-fighting operations and the costs due to forest ecosystem disturbance. This study proposes a methodological framework for estimating the total costs of forest fires and applies the method to a specific area (Veneto region) of the north-eastern Italy.

The costs of active fire-fighting were calculated taking into account all Regional forest fire-fighting organizations. Data on volunteers and regional operators, forest fire statistics, equipment and machinery types and use were studied and unit costs (€ h^{-1}) calculated at both provincial and regional level.

Environmental costs are estimated accounting for different forest benefits:

- wood production;
- climate change mitigation (CO_2 stocks);
- nature and biodiversity conservation;
- hydrogeological protection;
- tourism activity.

Environmental cost complies with the Veneto region forest situation. It is computed by local prices and considering the 2003 Forest Inventory. This method is designed to require very few input data to be measured in the burnt area namely the percentage of dead trees, stand age, distance from the main road and the length of it that could be damaged by falling rocks. A GIS-ACCESS application allows cost computation to be automated and to integrate all the results. These results will be used in legal proceedings when the person responsible for a fire is caught.

Introduction

In Italy, about 45,000 ha of forest areas are damaged by fire each year (1970-2005 National Forestry Service statistics[5]). More than 90 percent of forest fires are human-caused (Lovreglio and others, 2006). In N-E Italy 50.2 percent are arsons and this represents the main problem in fire management policy (*figure 1*). This is the reason why at national level, as in most of European countries, specific regulations have been approved by State (Law 353/2000) and regional authorities. To improve the effectiveness of public actions in fire prevention, a State law requires, on a compulsory basis, forest authorities to evaluate direct and indirect financial and economic damage and to demand that the fire raiser pays a full refund. More precisely, two main components of the damage are defined by the law and should be evaluated: the total costs for fire fighting operations and costs due to environment degradation. Several authors (Gonzalez-Caban and others, 1984; Gonzalez-Caban and McKetta, 1986; Wood, 1988; Marchetti and Pettenella, 1994; Baiguera and Pettenella, 1997; Giau, 1998; Hesseln, 2000; Marangon and

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[5] http://www2.corpoforestale.it/web/guest/serviziattivita/antincendioboschivo

Tempesta, 2001) have taken the economic impact of fire on forest environments into account and considered methods for financial assessment of both components. Extinguishing cost is the easiest component to compute because accounting documentation is usually available and provides an objective evaluation. Furthermore, it provides a rational basis to analyze the fighting system by a critical approach. On the contrary, environmental damage is difficult to assess. At international level Costanza's study (1997) represents a reliable reference for ecosystem benefits estimation, but it is difficult to transpose this approach to a small scale.

This study aims to identify which economic parameters are required to define the cost of fire-fighting operations in Veneto region and to define a handy methodology for estimating environmental damages in burnt forests. All the goods and services that a forest provides have been considered and an effort has been made to provide final users (Forest Service personnel) with an operative tool that quickly compute the whole damage value, without losing reliability in legal actions.

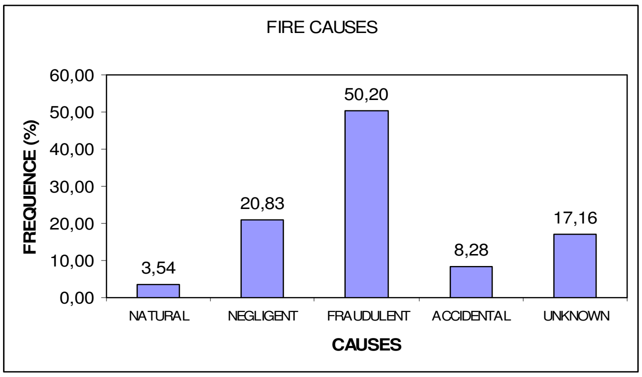

Figure 1— Fire causes during 1991-2005 in Veneto region (derived from Regione Veneto wildland forest fires database, 2007)

Estimation of forest fire-fighting unit costs

Forest fire fighting organization

Veneto is divided into five provinces where the Regional Forestry Service (R.F.S.) operates. In each area forest fire-fighting is organized by a Provincial Forestry Service (P.F.S.) responsible for the territory (these are: Verona (VR), Vicenza (VI), Padova and Rovigo (PD/RO), Belluno (BL), Treviso and Venezia (TV/VE)). The P.F.S. are coordinated by the Forestry and Economic Regional Head Office (sited in Mestre – Venezia) that organizes all the fire-fighting operations (it is also the Operative Regional Centre, COR for aerial-fight) and all the training activities for volunteers (Cavalli and others, 2002); it provides funds designated for the acquisition of new equipment. Each P.F.S. has two teams of operators that support the activities of the volunteers and do the reclamation of land damaged by fire. Volunteer organizations (Forest Fire Fighting volunteers – F.F. volunteers) also participate in fire-fighting and prevention operations. These organizations are coordinated in basic homogeneous areas by a chief organization that is alerted by the R.F.S. when fire occurs. The chief organization is responsible for the equipment, its distribution and any requests for funds to the Forestry and Economics Regional Head Office.

Collecting data

The research considered all the operations and costs incurred by volunteers and R.F.S. in the years 2002, 2003 and 2004. In the last years an information database based on GIS software has been introduced for the registration and management of operations, but a regional database of equipment and its deployment is still lacking: each chief area organization wrote the databases on their own. For this reason, to collect data on personnel and equipment a questionnaire was drawn up and given to each P.F.S. operators crew and to some volunteer F.F. organizations. 22 out of 113 organizations were analyzed (almost 20% of the total). The organizations were assisted directly by a person responsible for the research when help was asked for in getting input data.

Operators and volunteers

To characterize cost elements it is useful to separate P.F.S. operators from F.F. volunteers. F.F. volunteers are divided into two categories, depending on the required medical and physical check-up: those who can operate on the fire front and those who cannot. Some essential data must be considered to estimate the total hourly cost (Bacchini and others, 2005):

- personal protective clothing equipment;
- learning/training costs based on training courses already organized;
- medical check-up costs necessary to obtain physical suitability;
- insurance costs based on contracts signed with insurance agencies (only F.F. volunteers);
- management costs of the organizations like paperwork, computer, phone bills, water, etc. (only F.F. volunteers);
- refund of taxes paid by the employer (only F.F. volunteers);
- salary in relation to the hour and day of the service call (only P.F.S. operators).

To obtain an hourly unit cost, the amount of the different invoices is related to the effective operative fire-fighting time during each year and the relative P.F.S. *Table 1* shows F.F. volunteer and R.F.S. operator hourly costs.

Table 1— *Operators and volunteers costs.*

Volunteers at the fire front	**BL**	**PD/RO**	**TV/VE**	**VI**	**VR**	**unit**
	5.95	15.86	6.86	6.17	24.73	€ h^{-1}
Volunteers not at the fire front						
	5.16	12.08	5.65	5.31	19.69	€ h^{-1}
Regional fire-fighting operators						
	5.23	5.52	6.50	6.58	6.83	€ h^{-1}
+ Hourly costs for regional operators	In working time	Out working time	Extra-time night	Extra-time holidays	Extra-time holidays night	
Heading group (specialized super)	17.03	18.57	19.88	21.00	22.50	€ h^{-1}
Heading group (specialized)	15.97	17.42	18.65	19.70	21.10	€ h^{-1}
Operator (specialized super)	15.31	16.85	18.16	19.28	20.78	€ h^{-1}
Operator (specialized)	14.36	15.81	17.04	18.09	19.49	€ h^{-1}

Equipment costs elements

In Italy, machinery and equipment are usually divided into personal equipment (protective clothing), manual equipment (fire tools), adapters and accessories for pumps and helicopter cooperation, mechanical equipment (pumps, chainsaw, etc.), machines (divided in 4 different categories according to overloaded mass and type of driving licence needed), as stated by Sulli and Marchi (1995a; 1995b).

Different cost calculation elements where asked in the questionnaire:

- Initial investment (*P*, €);
- Undepreciated value (*S*, €);
- Actualization rate (i_a, pure number);
- Economic life (*N*, years);
- Productive time (*H*, h y^{-1} or km y^{-1} for wheeled machines);
- Housing (*Sh*, € y^{-1});
- Repair (*R*, € y^{-1});
- Fuel (*B*, € y^{-1});
- Lubricants (0.15**B*, € y^{-1});
- Taxes and insurances (*IT*, € y^{-1});
- Tyres (*T*, € y^{-1}).

Adapting existing information in the literature (Miyata 1980; Hippoliti and others 1980; Pettenella and Cutolo 1987; Sartori and Galletto 1992; Cross 1998; Edwards 2001; Amman 2004; ASAE EP 496.2 2004), a general formula was defined to calculate unit costs (*C*) of all the equipment used during fire-fighting operations. Referring to the equipment category, different cost elements can be considered or not. In the following general formula all the cost elements are considered.

$$C = \frac{(P \cdot i_a) - S}{N \cdot H} + \frac{R + Sh + (1{,}15 \cdot B) + T + IT}{H}$$

Estimates were made for each equipment category and averages for the Veneto Region and Provinces were then given. A *t*-test was also performed to test the difference between provinces. Helicopters and airplane flight costs per minute refer to what was indicated in specific contracts that the Forestry and Economic Regional Head Office signs periodically with specialized external enterprises. *Table 2* shows some results of the cost evaluation. Elements signed with letter *a* are significantly different from the average with a probability level of 95%.

Table 2 — *Examples from unit costs table for fire-fighting equipments and machines in Veneto Region (Italy).*

Equipment category	Number	Average	Unit scale	VR	VI	BL	PD/RO	TV/VE
Helmets	573	0.77	€ h^{-1}	1.46	0.61	0.67	0.93	0.70
Fire swatters	315	0.41	€ h^{-1}	0.39	0.31	0.31	0.47	0.64
Helicopter nets	9	4.97	€ h^{-1}	3.70	2.49	10.64	3.69	n.d.
Portable water tanks	43	13.90	€ h^{-1}	13.86	12.92	13.80	16.11	11.69
Volume < 3000 l	18	11.31	€ h^{-1}	7.82	11.99	10.93	13.74	n.d.
3000 l < Volume < 8000 l	24	15.14	€ h^{-1}	16.88	13.84	14.32	16.90	11.69
Volume > 8000 l	1	30.83	€ h^{-1}	n.d.	n.d.	30.83	n.d.	n.d.
Fire hoses	794	1.83	€ h^{-1}	2.16	1.88	0.93	2.13	2.27
Adapters and fittings	337	0.24	€ h^{-1}	2.02	0.15	0.23	0.10	0.29
Diameter < 45mm	60	0.17	€ h^{-1}	n.d.	0.05	0.31	0.11	0.22
Diameter = 45 mm	122	0.19	€ h^{-1}	n.d.	0.18	0.23	0.09	0.24
Diameter = 70 mm	57	0.30	€ h^{-1}	n.d.	0.27	0.13	0.08	0.51[a]
Pumps	58	17.99	€ h^{-1}	24.02	17.59	17.86	13.07	14.50
Vehicles cat. 1	21	0.63	€ km^{-1}	0.89	0.61	0.63	0.48	n.d.
Vehicles cat. 2	27	1.06	€ km^{-1}	2.15	2.37[a]	0.72	0.63	0.73

Vehicles cat. 38	5.24	€ km^{-1}	n.d.	3.85	1.03	5.12	6.38
Vehicles cat. 47	0.93	€ km^{-1}	0.65	1.51	0.81	0.39	n.d.
Regional helicopter	32.65	€ min^{-1}					
National civil protection service Canadair	86.10	€ min^{-1}					

It must be underlined that equipment costs are mostly influenced by annual utilization, which can reduce the hourly depreciation rate. It is obvious that annual utilization depends on fire frequency and duration and consequently on related operations. Unit costs listed in *table 1* and *table 2* refer to 2006. A yearly update is possible using the excel-tool, thanks to recalculating factors, specific for each equipment category and personnel, which have been calculated reassessing the data obtained with the questionnaire.

Excel-tool for active fight costs evaluation

All unit costs have been entered in an excel-sheet and a sort of user mask has been created (figure 3). Necessary inputs to run the calculation are:

- province where the fire took place;
- number of P.F.S. operators and F.F. volunteers involved in fire extinguishing;
- fire event duration;
- equipment used (specifying categories with pull-down window);
- hours using each equipment.

Total active fire-fighting costs will be automatically updated in the next GIS-ACCESS tool.

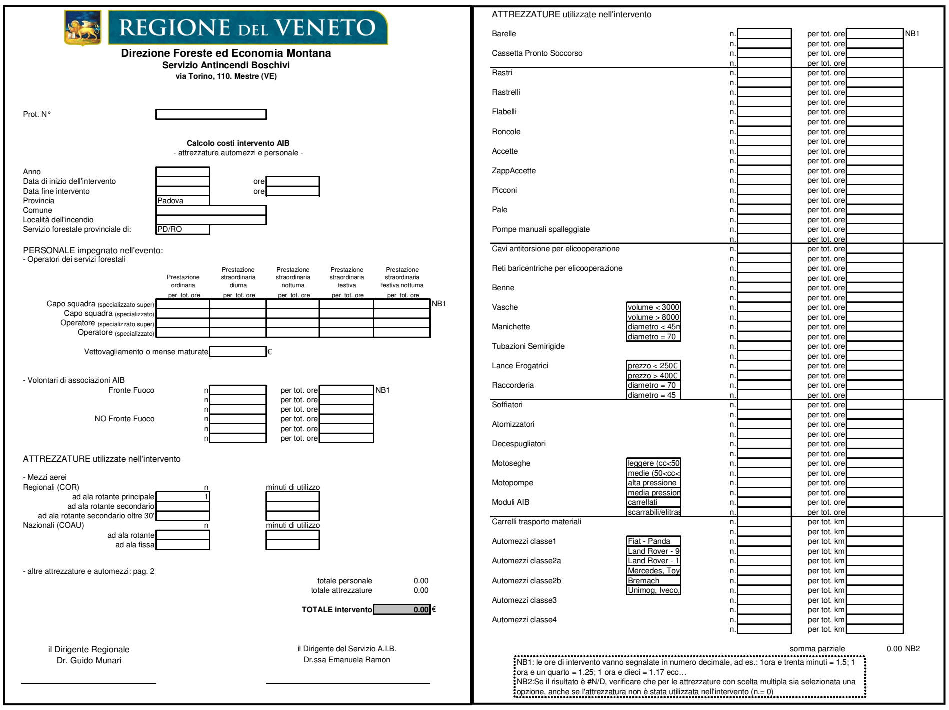

Figure 2— User mask for active fight cost calculation

Methodology for the evaluation of soil and above-ground damage (environmental damage)

The methodology for environmental damage evaluation assesses seven functions linked to the forest, according to its position, category and products (*table 3*). The total value of environmental damage is the sum of the seven functions, deemed the principle ones. Other utilities are characteristic of the forest, such as educational and historic ones, but these aspects are related to the analytic approach and not to the work objective.

Table 3— *Forest functions and benefits.*

Forest function	Benefit
Wood production	Wood products
Non-wood production	Non-wood products (mushrooms, chestnuts, etc.)
Tourism	Recreation chance increment
Hunting	Recreation chance increment
Hydrogeological protection	Reduction of soil erosion and runoff
Protection against climate change (CO_2 uptake)	Health improvement
Nature conservation value	Conservation of genetic inheritance and rare ecosystems for future generations

A regional database was created joining five GIS informative layers (forest cover map, gradient map, tourism value map, protected areas map and administrative limits map) and other sources (*figure 3*). The forest cover map consists of 3,611 patches and each patch contains information about all layers. Furthermore, the computation system is automated by a user friendly interface. The use of local data concerning forest categories and other aspects, like wood annual increment and prices, hunting and tourism value, is a guarantee of estimation accuracy.

In this section every forest function will be described in detail. Two aspects are common to all of them:

- estimation unit is defined like the minimum area where the forest category is homogeneous and it coincides with the forest cover map patches. A unique code defines each patch;
- the patch code is associated to the regional database where the most of inputs to reach the evaluation are stored. Database information is joined to the patch codes.

Georeferenced information was applied in order to minimize the field surveys the customer must collect to run calculations. User has to put six inputs into the computation system (an ACCESS application) to make it run:

1. patch codes;
2. percentage of dead trees;
3. stand age;
4. sylvicultural system;
5. distance from landing;
6. dangerous road length or the length of road where rocks could fall.

Forest Service personnel must survey all the information required in the burnt area. The first field survey will be to measure the fire perimeter using GPS technology. This georeferenced information must be intersected with the forest cover map to get patch codes, using a GIS software.

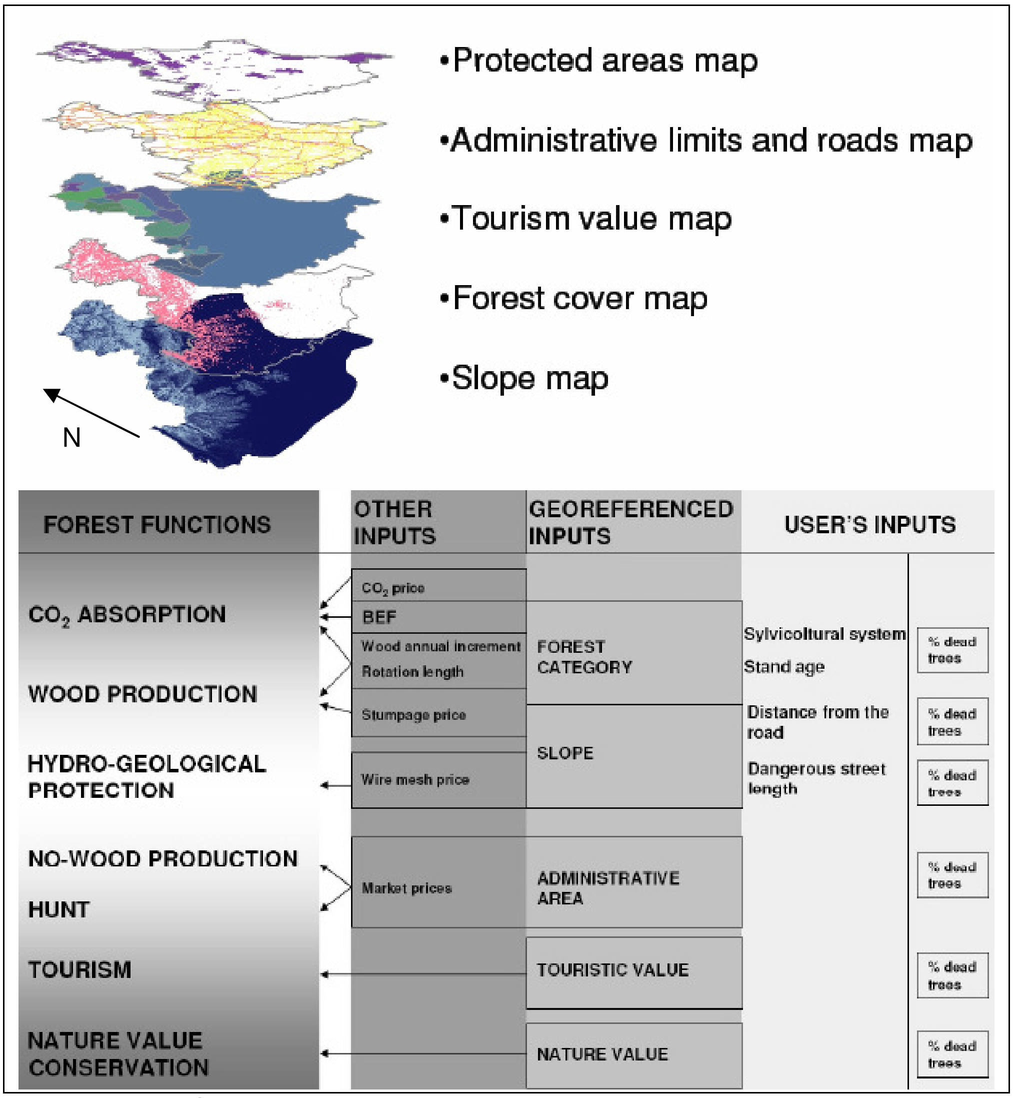

Figure 3— Georeferenced information: forest cover map, slope map, tourism value map, protected areas map and administrative limits map (above); forest functions estimate inputs (below)

Wood production

The timber losses are assessed in terms of market value of the burnt wood volume, taking into account the forest type (tree species composition and corresponding roadside prices) and burnt area accessibility (given by gradient and distance from landing). The costs of felling and logging depend on slope and distance from landing (*table 4*). The subtraction between roadside price and these costs gives the stumpage price, or regional market price.

Table 4— *Standard felling and logging costs (€ m^{-3}).*

Distance from landing (m)	Gradient class		
	≤20 pct	20-35 pct	>35 pct
≤300	15	20	35
300-1500	20	30	
>1500	No direct productive function		

Source: Grigolato S., 2005 (personal communication)

Often forest stands are burnt before having reached the end of the rotation time. In this case, stumpage value must be discounted by the number of years before the rotation time. The damage to wood production function is computed by the following:

$$WPD = Area * Volume * \frac{P_r - C}{(1+r)^m} * Mortality$$

Where:

WPD = wood production damage (€); *Area* = burnt area (ha); *Volume* = commercial maturity volume of timber (m^3 ha^{-1}); P_r = roadside price (€ m^{-3}); *C* = felling and logging costs (€ m^{-3}); *r* = discount rate; *m* = years to rotation time; *Mortality* = percentage of dead trees. *Mortality* of trees is representative of fire intensity.

In order to calculate the *Volume* variable as precisely as possible, a regional analysis of timber annual increments and usual rotation age was done, consulting the *Veneto Region Inventory Database* (2005). A mean annual increment was assessed for every forest category, both high and low forest (when existing). *Volume* results from the following formula:

$$Volume = Ia * R$$

Where:

Ia = timber annual increment (m^3 ha^{-1} y^{-1}); *R* = rotation time (y).

As regards roadside price P_r, this depends on forest category composition and on sylvicultural system. Prices will be referred to lumber or firewood production according to high or low forest.

Non-wood products

Non-wood production availability decreases after fire and is characterized by extreme variability in space and time. The most frequent products in the Veneto region are mushrooms and sweet chestnuts, although other products, like truffles, are found in very localized places. The biggest problem in the assessment of non-wood production is the lack of information on how much is the yearly yield from the forest. Consequently, it is sometimes necessary to find alternatives to the market value approach. As a proxy for mushrooms values we used the value of harvesting permits sold by local municipalities. This approximation appears reasonable considering that most mushrooms harvesters get a recreational benefit from this activity, more than an effective financial one. The formula used to assess lost mushroom production is:

$$NWPD = Area * AI * \frac{(1+r)^n - 1}{r * (1+r)^n} * Mortality$$

Where:

NWPD = non-wood production damage (€), in this case mushroom production damage; *Area* = burnt area (ha); *AI* = harvesting rights income, cumulated in one year (€ ha^{-1}) or goods sale annual income; *r* = discount rate; *n* = years of lost mushroom production or lost income from harvesting rights sale, this is considered to be ten years by national regulations; *Mortality* = percentage of dead trees.

The loss in chestnuts production is computed only when fire occurred in sweet chestnut stands, the location of which is known by the forest cover map as a specific forest category. In this case mean annual chestnut production and mean market price are known. A market value approach is applied taking into account stand age and an adequate period of restoration (ten years for Law 353/2000). The formula to compute chestnut production damage is the same as that used for mushrooms, with the only difference being that *AI*, or goods sale annual income, is calculated as:

$$AI = Aprod * P_{ch}$$

Where:

Aprod = annual chestnut production (t ha^{-1}); P_{ch} = sweet chestnuts market price (€ t^{-1}).

Tourism and recreational activities

Fire can determine a reduction of the number of people visiting an area for recreational purposes. Environmental damage from the reduction of recreational benefits is considered both for areas mainly used for wood production and for recreational utility. The assessments have been made using data from several works focused on tourism trends in last decade in Veneto region (Tempesta, 2004; Da Pozzo and others 2003;) and the following formula has been applied:

$$TD = Area * N_t * V_t * \frac{(1+r)^n - 1}{r * (1+r)^n} * Mortality$$

Where:

TD = tourism damage (€); *Area* = burnt area (ha); N_t = mean number of visitors per year in one hectare; V_t = mean value of one visit (€); r = discount rate; n = years of lost tourism activities in the burnt area; *Mortality* = percentage of dead trees.

The methods estimation choice to assess N_t and V_t was regional situation dependent. This is anyway an applicative example that may be transferred to other regional cases. Both variables have been studied for the major mountain basins, where most forestry cover is present (*Figure 4*). The rest of Veneto region forest has been compared with a low mountain basin using the benefit transfer method.

Two techniques have been applied to assess the mean number of annual visitors (N_t). Statistic data have been considered first. Local tourist offices record arrivals and stays in receptive structures, but this information source explain only 50 percent of the total phenomenon. The second technique consists of *ad hoc* investigations:

- field surveys (counting visitors in sample tourist sites);
- contingent valuation (questionnaires and direct/indirect interviews).

Other indicators can be used to evaluate visitors number if the required precision level is lower, for example number of parking tickets sold and data on local vehicular traffic.

The mean value of the a single visit (V_t) has been assessed by using travel cost and contingent valuation methods.

The period of time during which tourist activities are lost (n) is closely connected to stand mortality rate and burnt area accessibility[6]. Also sylvicultural system has been considered from a tourism restoration perspective. For example, coppice stands damaged by fire recover completely after a period of no longer than one year, hence no loss takes place in those areas.

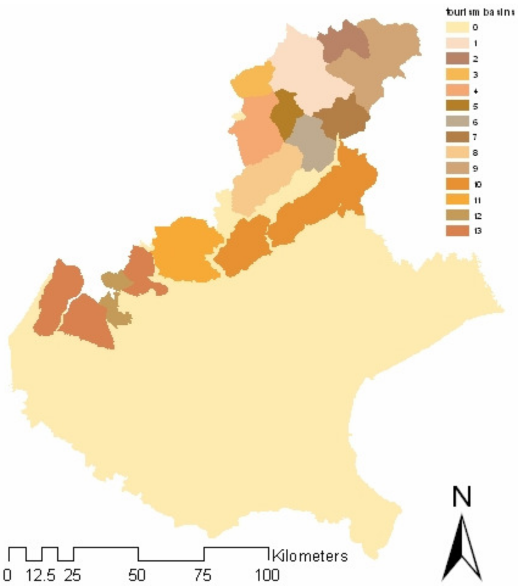

Figure 4— Main tourism basins in Veneto region

Hunting

The environmental damage from loss of hunting potential has been considered from a recreational point of view and not as a loss of marketable production. No quantity ranges were available to assess hunt production, on the contrary willingness to pay for hunting can be estimated by using criteria similar to those given for no-wood products. In this case the number of hunters and annual licence cost have been collected at province level, since these values depend on the range of hunted species in each province. Loss of hunting rights income is computed as:

$$HD = Area * AI * \frac{(1+r)^n - 1}{r * (1+r)^n} * Mortality$$

Where:

HD = potential lost hunting damage (€); $Area$ = burnt area (ha); AI = hunting rights income, cumulated in one year (€ ha^{-1}); r = discount rate; n = years of lost hunting rights sale (national regulations require ten years of hunting suspension); $Mortality$ = percentage of dead trees.

Hydrogeological protection function

The role of the forest in environment protection and consolidation of watersheds is well known. However, soil fertility is hardly affected by high intensity fires because the surface organic layers are leached by precipitations following a fire event (Aylward B., 2004). Damaged forest floors become sensitive to erosion and many problems can involve roading, like big rocks falling.

[6] Time delay in tourism function restoration depends on erosive phenomena connected to the fire effect. Details on time delay computation are given in *Hydrogeological protection* section.

To assess environmental damage from alteration of hydrogeological system two aspects have been considered:

1. loss of soil fertility and restoration time delay;
2. loss of watersheds consolidation (protection given to principal roads against big rocks falling).

Another hypothesis might be pursued, for example estimating the increase of costs to empty streams and catchment areas from ground deposition or the increase of costs to rehabilitate settlements after flooding events. Both alternatives require detailed investigations or are hard to standardize, and erosion from fires is often combined with other factors. In addition, the mean area burnt in Veneto region corresponds to about 5.2 ha and the probability of landslides after fire is very low (Regione Veneto wildland forest fires database, 2007).

Loss of soil fertility is estimated by assigning a time delay *d* to the burnt area, defined as the number of years pioneer species need to colonize the forest floor after fire (Trabaud and Pradon, 1992). The time delay represents a postponement in forest capacity to provide social utilities and is estimated by using a *Gradient-Pburn* model[7], predicting landslides probability in mountain basins. In this study we assume that:

- pioneer species do not colonize burnt areas if landslides are active;
- the area where the fire event takes place is considered a mountain basin;
- the percentage of burnt basin is assessed by the percentage of dead stand.

The model algorithm is as follows:

$$d = \frac{12.98}{1 + e^{2.6765 - (0.02219 * PBURN) - (0.017 * GRADIENT)}}$$

Where:

d = delay (years); $PBURN$ = percentage of burnt area; $GRADIENT$ = mean gradient of burnt area (percent).

The delay *d* must be applied to the forest functions as an additional period of lost function benefit. For example, tourism activities loss period corresponds to time delay and no loss occurs if the time delay is zero, that means fire intensity is low or the burnt area is quite flat. In these conditions landslides do not occur. It has been assumed that *d* can have a maximum value of ten years, when fire burns 70 percent of the stand and the gradient exceeds 40 percent.

Protection against big rocks falling is assessed only when a road section might be involved in rock fall events, i.e. below high gradient hillsides. In this case heavy wire mesh will be laid along the whole road section. Dangerous road length is one of the six inputs the user must enter into the computation procedure. The user must be careful in road length assessment: consolidation financial costs are particularly onerous (average wire mesh unit value is 370 € m^{-1}), so are advisable only when the danger of rocks falling is really high.

[7] The *Gradient-Pburn* model has been created using data provided by http://landslides.usgs.gov/research/wildfire/pw-ref.php.

Protection against climate change (Co_2)

Carbon dioxide emissions following the combustion of wood biomass and organic matter, with a consequent increase in the concentrations of greenhouse gases in the atmosphere, involve a cost that can be estimated by referring to market prices of carbon shares (such as the European Union *Emission Trading Scheme*). The price is transparent following implementation of the Kyoto Protocol, with the creation of a market for credits related to "flexible mechanisms" (and in particular, what is known as the *Clean Development Mechanism*), the voluntary creation of a series of compensatory actions on the part of local authorities, businesses and even individual citizens.

The economic value of carbon dioxide emitted by fire must be deemed as a "temporary" loss of protection against climate change. In Italy, forest areas cannot be converted to other uses, hence stand re-growth will restore carbon dioxide lost from timber biomass, back to the initial level. The assessment method is as follows:

1. economic evaluation of carbon dioxide emitted by fire;
2. correction of that evaluation by discounting future benefits to the present time.

The economic value of carbon dioxide is the value of corresponding carbon emitted, calculated as:

$$CO_2 = Area * C * \frac{44}{12} * P_c * Mortality$$

Where:

CO_2 = economic value of carbon dioxide emitted by fire (€); *Area* = burnt area (ha); P_c = price of one ton of carbon[8] (€ t^{-1}); *Mortality* = percentage of dead trees; C = carbon emitted by fire (t ha^{-1}), calculated as:

$$C = Volume * wd * BEF * cf$$

Where:

Volume = wood volume of stand when fire occurred (m^3 ha^{-1}); *wd* = weight density of wood (kg m^{-3}); *BEF* = biomass expansion factor[9] (coefficient of transformation by volume of the wood mass, expressed in m^3, into epigeous arboreal biomass, expressed in t of dry matter); *cf* = carbon rate in one unit weight of biomass (standard value is 0.5).

The environmental damage to absorption of carbon dioxide is then assessed by the following formula:

$$CCD = CO_2 + \left[Area * CO_2 a * \left(\frac{q^d - 1}{r * q^d} - \frac{q^{n+d} - 1}{r * q^{n+d}} * \frac{1}{q^d} \right) \right]$$

[8] P_C can be updated by analyzing the quotations on the websites that monitor share transactions (http://www.pointcarbon.com/, http://carbonfinance.org/, http://carbonfinance.org/). It is advisable to refer to quotations regarding operations in the fields of agricultural and forest land management since they refer to temporary carbon fixation in the atmosphere (for this reason the value of the shares is, *ceteris paribus*, lower).

[9] The data concerning destroyed stock generally refer to the cormometric/ dendrometric wood mass and must therefore be multiplied by an expansion factor (*BEF*) in order to estimate the total loss of carbon stock (http://afoludata.jrc.it/carboinvent/ciintro.cfm).

Where:

CO_2 = economic value of carbon dioxide emitted by fire (€); *Area* = burnt area (ha); $q = r + 1$; r = discount rate; d = restoration time delay (years); n = stand age; $CO_2\,a$ = economic value of carbon dioxide stored each year by stand.

Nature value conservation

Of all the factors considered, the nature conservation role is the most difficult to quantify, as it represents the value attributed to biodiversity. A simplified estimation procedure refers to Italian State Law n. 353 of 2000 which states that when an area burned by fire includes a protected area the total value of the environmental damage, as estimated using conventional methods, can be increased by fifty percent.

The protected areas map shows which forest units may be considered in nature conservation assessment. However, this method does have a shortcoming: quite frequently, in areas of high environmental value the financial losses from lack of wood production, non-wood forest products or hunting are extremely limited and the multiplication coefficient has to be applied to practically insignificant values.

It will be a judge's decision if environmental damage estimation must be increased or not. This work aims to give solid indications about fire compensation by the person responsible, and does not describe specific stand characteristics in detail.

Conclusions

The analysis of forest fire damage costs in N-E Italy, both environmental and fire fighting ones, provides an operative GIS-ACCESS application and automated damage computation procedure. This work is part of the international trend to consider the forest from an economic standpoint and no longer as a timber provider. Climate change and the biodiversity loss alert in the last decade are increasing the significance of the forest role as "impact bearing", also in legal proceedings. A first structure has been fixed for total damage assessment. Many improvements might be made as the investigation progresses and more information becomes available (fire-erosion quantitative relationship, evaluation of biodiversity value, etc.).

The current level of assessment precision provides objective indications for quantifying claims for damage. The ACCESS application is a good system and it has been set to print all the information concerning the forest area burnt. The computation procedure speed should help Forest Service personnel by supplying a user friendly interface.

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