Economic Impact of Forest Damage in an Alpine Environment

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Abstract – The aim of this paper is to evaluate the situation regarding the main types of damage to forests and their respective economic consequences, with reference to a case study in the Italian Alps (Trentino province). Each kind of damage (wind and snow, defoliation, fire and tillage) has been analysed in terms of its impact on four forest functions (production, protection, tourism-recreation and carbon sequestration) and evaluated in monetary terms. Market value was used to estimate the production and carbon sequestration functions, replacement cost method for protection, and contingent valuation for tourism-recreation. Applying desk research on damage caused by the main biotic and abiotic factors to this particular case study led us to estimate a annual damage of about € 1,624,921 equal to 4.71 € per hectare. This can be considered a lower bound estimate of possibly greater damage. Another interesting result that emerged from the evaluation exercise is that the wealth of information produced through monitoring and scientific research in the last twenty years does not readily lend itself to economic analysis.

forest damage / forest functions / interaction between damage and functions / economic valuation / Alpine forests

Kivonat – Az erdőkárok gazdasági hatása alpesi környezetben. A dolgozat célja, hogy összefoglalja az erdőt érő káros hatások főbb típusait és ezek gazdasági hatásait egy hegyvidéki esettanulmányon keresztül (Trentino tartomán y, Olaszország). A tanulmányban minden fontosabb kártípus (szél, hó, levélvesztés, tűz és mezőgazdasági művelés) elemzése és monetáris értékelése megvalósult az erdő különböző funkciói tekintetében (gazdasági, védelmi, rekreációs és széndioxid megkötés). A gazdasági és széndioxid megkötési funkció értékelése a piaci érték segítségével történt, a védelmi funkció tekintetében a helyettesítési érték módszere került alkalmazásra, a rekreációs funkció pénzügyi értékelése a feltételes értékelés módszerével valósult meg. A tényleges esettanulmány tekintetében a biotikus és abiotikus tényezők által okozott kár évente legalább 1,6 millió €, ami hektáronkénti 4,71 €-nak felel meg. A mintaterület értékeléséből levonható tapasztalat az, hogy az elmúlt húsz évben a tudományos kutatás és monitoring során összegyűjtött adatok nem kifejezetten segítik elő a pénzügyi értékelést.

erdőkárok / erdő funkciói / károk és az erdő funkciói közötti kölcsönhatások / gazdasági értékelés / az Alpok erdei

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1 INTRODUCTION

Over the last couple of decades there has been a growing awareness of the necessity to monitor and evaluate the economic and ecological impact of damage to forest ecosystems (Efremov – Sheshukov 2000) in order to implement adequate prevention policies.

Considerable headway has been made in monitoring, both in setting up international cooperation programmes and monitoring networks, and in determining the status, changes and trends in forest condition indicators on an annual basis. The International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests, UN/ECE), which was set up in 1985, represents a milestone in this endeavour. The first Ministerial Conference for the Protection of Forests in Europe (MCFPE 1990) stated the necessity to hone the Pan European Monitoring System. A specific criterion on forest ecosystem health and vitality (Criterion 2) was endorsed by the Lisbon MCFPE in 1998. This was followed by the European Union Directive on National Emission Ceilings for Certain Atmospheric Pollutants in 2001, and the Forest Focus Regulation in 2003.

Despite these measures, the recent report on the condition of forests in Europe (BHF 2006) asserts that 23.3% of trees in Europe are classified as damaged or dead.

The economic consequences of these health conditions are not easy to investigate. Studies tend to focus on the economic impact of a single specific biotic or abiotic agent (see, for instance Lyytikäinen-Saarenmaa – Tomppo 2002 for defoliation by sawfly or Peryron – Bokouma 2001 for windfalls), partly because different evaluation methods are applied for different types of damage, which are often strongly based on hypothesis and may also rely on rough estimates (Peyron – Bakouma 2001).

In spite of these difficulties, this study is an attempt to estimate the economic consequences of the main types of damage found in Alpine forests, with the aim of giving the public decision maker an objective criterion for fine tuning prevention policies. Four selected types of damage (defoliation, fires, wind/snow damage and tillage[1]) have been analysed in terms of their impact on four forest functions (production, protection, tourism-recreation and carbon sequestration) and evaluated in monetary terms. The reference is a case study in the Italian Alps, the small Autonomous province of Trentino (6.207 km^2), where forest covers more than half of the total area.

2 MATERIALS AND METHODS

2.1 Site characteristics/features

2.1 Study site

An evaluation of biotic and abiotic damage to forests was undertaken for the Autonomous Province of Trento (North East Italy). This is a mountainous province, with limited flat areas at the bottom of the valleys, wide-spread terracing and steep mountain slopes. Approximately 60% of the surface area is situated over 1000 m above sea level with more than 50% of the population concentrated in urban areas below 400 m. 56% of the area (345,180 hectares) is covered by forest, prevalently spruce (59.6%), secondarily European larch (17.5%) and silver fir (10.8%). More than 70% of forests are managed according to ten-year plans.

[1] We chose these four types of damage because they are widely recognised as the most common ones.

2.2 Valuation of forest functions

In order to evaluate the impact of each type of damage on the forests of the province, we started by estimating the annual monetary value of the main forest functions: production, protection, tourism-recreation and carbon sequestration. Biodiversity was not considered because, even in physical terms, "at present it is impossible to evaluate everything" (Efremov – Sheshukov 2000, p. 59).

Methods used to estimate the various functions were market value for production and carbon sequestration, contingent valuation for tourism-recreation, replacement cost for protection.

In more detail, timber products were estimated by distinguishing two components for each species (Merlo – Ruol 1994): the "real monetary value" of annual increment actually harvested (utilisation), and the "potential monetary value" of the remaining annual increment that could have been used but which was in fact left as an investment in timber capital. According to Merlo and Ruol (1994) the latter was estimated at 50% of the average timber price.

The replacement cost method, employed to estimate the protection function, considers the possibility of replacing ecological services with man-made systems (Faber et al. 2002). The evaluation is based on the cost of setting up human-engineered systems to substitute the protective function of the forest. In detail, we estimated the costs of the building, amortization and upkeep of naturalistic engineering works. The kind of engineering works we considered - terracing with simple palisade and grass, avalanche barrier racks with chequer-board arrangement, fascines with cuttings – was tailored to the three main level of hazard identified (high/low risk of landslides, high risk of avalanches). We also factored in to this estimate the cost of maintaining the river beds of the main waterways with the construction of check dams and sills. We have used this method because it takes into account both the reconstitution of protective forests and the investment costs to maintain it. The method that considers only the investment costs would have produced a lower value and wouldn't have capture the entire protection value.

A rough estimation of the tourism-recreation value of Trentino forests was undertaken through integrating data of tourism-recreation flows in Trentino forests (for details see Scrinzi et al. 1997) and results of a contingent valuation (Alberini – Kahn 2006; Mitchell – Carson 1989) study carried out on a representative forest of Trentino, the forest of Lavazè (Val di Fassa). A random sample of 724 visitors (response rate 93%) was surveyed. Interviews were carried out during the summer of 2002. Respondents were asked about their willingness to pay an entrance ticket to cover the costs of the naturalistic management (willingness to pay pro-capita was 2.58 €). The scenario explained that the lack of public funds would lead to a modification in the current type of forest management, from selective cutting to clear cutting. This would imply the modification of the recreational experience of tourists (for more details see Notaro et al. 2006).

The carbon sequestration value was first estimated for the forest of Lavazè by quantifying carbon flows in monetary terms (Notaro et al. 2008) and then extended, with due correction, to the entire province. The quantity of carbon contained in trunks, branches, twigs, crowns, dead wood and stumps (Fattorini et al. 2005) was first defined in physical terms, by applying specific estimation methods for plant mass and volume. Fattorini et al. (2005) estimated the above-ground phytomass of a population of trees in a monitoring area using a probabilistic sampling scheme (randomised branch sampling) (Gregoire et al. 1995). The forecast model, seeking to estimate plant mass and volume for each stand and the corresponding total value per surface unit, starts with data from the diameter measurements for all trees and corresponding height measurements for a sample of trees. Results show that, on average, the plant biomass of the spruce and swiss pine populations contain a carbon stock of 217.4 t/ha (Fattorini et al., 2005; Notaro et al., 2008).

The results were re-elaborated on the basis of different conversion factors between tonnes of dry substance and cubic metres of timber, for all the forest stands in the province, ascribing them to the prevailing species. The price per tonne of CO_2 eq. absorbed was as calculated by Lecocq et al. (2004) for the Joint Implementation and Clean Development Mechanism projects in the first five months of 2004 to modulate this price to data collected for the other functions. We did not use prices of carbon markets because we wanted to refer to projects related to the forestry sector. This was determined at 5.52 \$/tCO_2 eq. (equal to 6.79 €/tCO_2 eq., and 24.89 €/tC).

Total and per hectare values for individual functions are presented in *Table 1*. Afterwards the economic impact of each type of damage is estimated and detracted.

Table 1. Use values of Trentino forests

Forest function	Total economic use value (million €/year)	Use value per ha (€)
Timber production	25,97	75.22*
Hydro-geological protection	25,49	73.84[2]
Tourism-recreation (summer season)	13,97	40.47
Carbon sequestration	31,71	91.86

* 46.02 € real value and 29.20 € potential value

2.3 Valuation of forest damage

Forest health and vitality is affected by several external disturbance factors that can be divided into two main macro-categories: abiotic and biotic factors. This second category also included human factors. These abiotic and biotic factors may have positive, neutral or negative impacts on forest ecosystems, the negative impact being considered as damage. In the literature different definitions of forest damage exist. Reimoser et al. (1999, p.48) considers it as "a problem caused by an unwanted condition", while for the WPR (1994) forest damage is the "reduction of tree population in forests caused by acidic precipitation, forest fires, air pollution, deforestation, pests and diseases of trees, wildlife, etc.". In this paper the authors used this second definition, considering the tillage as a reduction of tree population.

In some cases the damage can be attributed with precision to one specific agent (i.e. wind), in other cases signs of damage (i.e. defoliation) may be ascribed to diverse factors, each with a synergistic effect on forest condition. Types of damage will also tend to impact differently on each forest function.

For the above reasons we shall make only partial use of the previous classification, focusing largely on the following **four** observable categories of damage and on their consequences for every single forest function.

- Defoliation caused by biotic agents such as phytophagous insects or root rot, or by abiotic agents such as late frost or drought, deposition of air pollutants or acidification;
- Damage caused by fires, mainly due to intentional or accidental human action and to a smaller extent to natural phenomena;

[2] Considering only the public investment costs, the average value (years 2004-2005-2006) of the protective function of forests in Trentino was 118,027 € (0.34 €/ha).

- Wind and snow damage: the uprooting of whole trees or breaking off of branches due to early or late snow, or tornados. This category includes both natural hazards and the results of poor forest management;
- Tillage: deforestation due to change in land use for building and agricultural purposes, or to create ski runs and other infrastructure.

After having estimated the value of every single forest function, the economic impact of each type of damage was estimated and deducted.

Data were collected throughout the provincial territory regarding surface area and cubic metres of timber affected by the main biotic, abiotic and anthropogenic factors. From the forestry literature we extrapolated the parameters for reducing the value of each function.

a) Defoliation

Defoliation intensity is one of the main parameters used in evaluating forest health since leaves immediately indicate a plant's physiological condition. Causes of defoliation are root fungi, nutritional imbalance, defoliating insects (Kurkela 2002) and other abiotic factors. Starting from the hypothesis that, regardless of cause, any degree of defoliation results in a reduction in photosynthesis, we can deduce that this damage will affect three main forest functions. As well as reduced wood growth and carbon dioxide exchange with the atmosphere,[3] there is also the fact that a large number of yellowing plants (depigmentation) and plants without leaves (defoliation) negatively effects the tourist-recreational function (Lovett 2002). On the other hand, Meier et al. (2005) found that defoliating insect attacks have a negligible effect on hydro-geological protection as long as they do not compromise many specimens.

According to the literature, defoliation effects wood growth, causing a decrease in the productivity of a forest stand proportional to the percentage of defoliation. The Pan-European Monitoring System distinguishes five degrees of defoliation based on percentage leaf or needle loss in individual subjects in the stand (BHF 2006). An average range of timber loss for different degrees of defoliation (*Table 2*) was estimated according to results obtained by Straw et al. (2002) and Petràš (2002). Moreover, data from permanent plots (Level I of the Pan-European Monitoring System) provides us with the percentage of trees defoliated in Trentino. After converting this into hectares of damaged surface, we can end up with an estimate of the economic loss in timber value for each defoliation class.

Table 2. Defoliation classes and reduction in timber increment

Defoliation class	Degree of defoliation	Needle/leaf loss (%)	Loss in volume (%)
0	None	< 10	0-10
1	Slight	11-25	11-20
2	Moderate	26-60	21-30
3	Severe	61-99	31-40
4	Dead	100	100

Source: our elaboration on UN ECE (2004), Straw et al. (2002) and Petràš (2002).

[3] The relationship between defoliation caused by phytophagous insects and carbon dioxide is more complicated. For example, while an intense attack by insects leads to a lower level of carbon dioxide absorption, a high concentration of CO_2 reduces leaf damage caused by defoliating insects (Knepp et al. 2005).

In a similar way to that described for the production function, leaf loss reduces carbon dioxide exchange with the atmosphere due to the diminished photosynthesis (Knepp et al. 2005). Therefore, the procedure adopted is similar to that used to calculate average loss in timber capital, using fixed carbon flow in lieu of increment. The percentages of reduction in carbon sequestration (5% for defoliation class 0; 15% for class 1; 25% for class 2; 35% for class 3) were deduced from the relationship between cubic metre of timber and the percentage of stored carbon per cubic metre (Matthews 1993; Tucker et al. 2004).

Even if it is likely that tourists perceive the increase in defoliation as a disutility, as far as we know no study exists that investigates the functional form of this relationship. Since Gatto et al. (2005) applied a 20% reduction in the presence of a specific defoliation agent, we decide to increase this percentage (30%) in order to take into account the joint effect of more severe defoliation agents and differences in species affected.

b) Fire

Fire impacts most heavily on forest functions because it indiscriminately affects everything in its path and the drastic rise in temperature causes irreversible damage to vegetation, ranging from injury to the destruction of timber (Pettenella 1997). The passage of fire may even destroy the forest floor and fertile topsoil, triggering erosion, jeopardising the stability of mountain slopes (APPA 2004) and leading to a decrease in carbon sequestration.

The effect of fire on tree vegetation varies according to botanical species (passive pyrophyte or active pyrophyte species) and the nature of the fire. Type of fire are: forest floor fire when the organic ground layers burn slowly, low or grazing fire when it burns the layers of grass and shrubs below the tree canopy, high or crown fire when the fire reaches the tree crowns and spreads from crown to crown (Mazzoleni – Aronne 1993). In every case timber extracted is damaged with, at best, depreciation in value or, at worst, total loss of the wood (Pettenella 1997). In our case study, since most are crown fires, we hypothesised a total timber loss, zero tourism-recreation and zero hydro-geological protection value for the area crossed by fire. The effect of fire on carbon function is a short term slowdown in carbon sequestration due to the vegetation's alteration and/or destruction estimated by Fattorini et al. (2005) at 13.6 tCO_2/ha.

c) Wind and snow damage

Freak weather events can cause forest trees to fall. Heavy early or late snow or very high winds are climatic events that facilitate tree fall and therefore upset the hydro-geological balance (Andreatta 2005). Such phenomena lead to a loss of hydro-geological protection, tourism and recreation, and cause timber depreciation (Nieuwenhuis – Fitzpatrick 2002). However, a positive effect on biodiversity has been noted since "windthrow stimulates arthropod biodiversity in forests" (Wermelinger et al. 2003, p. 79).

Wind and snow damage lead to a total loss of potential value because forced utilisation converts timber capital into real value. Consequently, in order to avoid double counting, the loss of potential value was ignored and a reduction in real value of 30% (Nieuwenhuis – Fitzpatrick 2002) was applied to the entire area damaged. This percentage is justified by the fact that, on average in the case studied, timber was extracted quickly and *Ips typographus* attacks were limited. For tourism-recreation we follow Schneider et al. (2006) and assume a 40% decrease in the economic value. Protection and carbon sequestration, and consequently their value, are to be considered temporarily non-existent over the area affected by wind and snow damage. Consequently we detracted the whole value of these functions for damaged hectares.

d) Tillage

Although tillage is largely limited by legislation in the major European countries, it should not be overlooked as the transformation from "forest" to "other land use" completely wipes out all forest functions.

Tillage leads to total loss of the protective, tourism-recreational and carbon sequestration functions over the area in question. The quality and the economic value of timber is not affected, so the real value of the production function remains the same.

Table 3 summarises all these considerations about the intensity of damage produced by biotic and abiotic factors on the economic value of a forest.

Table 3. Effects of damage by biotic and abiotic factors on the economic value of annual flows of forest products and services

Damage/Function	Defoliation	Fires	Wind/snow damage	Tillage
Production	Negative	Negative	Negative	Total loss
Protection	Negligible	Negative	Total loss	Total loss
Tourism-recreation	Negative	Total loss	Negative	Total loss
Carbon sequestration	Negative	Negative	Total loss	Total loss

The calculation methods applied in this case study, to translate a biological complexity into economic terms, use large scale simplifications and assumptions based on *Table 3*. For example assuming total loss for carbon sequestration function is clearly a simplification of a dynamic process. At the time of tillage only the carbon sequestration flow is lost[4]. Carbon remains stored in wood products but will return to the atmosphere according to the durability of the products: in a short period of time for fire wood, in a longer one for furniture (Gower 2003). Moreover the effects of forest fire on timber depend on intensity and types of fires. In some circumstances forest fires destroy the wood completely, in other circumstances the damages are only superficial and limited. Defoliation has a negligible effect on hydrogeological protection of forest - in cases of slight and moderate degree of defoliation - while severe defoliation can compromise the effect of canopy cover as a physical screen which intercepts precipitation and holds onto a certain fraction of it preventing single drops from reaching the bare soil (Piussi 1994).

3 RESULTS AND DISCUSSION

a) Defoliation

The main causes of defoliation in Trentino's forest ecosystems can be traced to attacks by the pine processionary caterpillar (*Thaumetopoea pityocampa*) (about 4,200 ha in 2000-2001), by larch bud moths (*Zeiraphera griseana*) (defoliation of over 3,800 ha in 1999-2000) and by spruce rust (*Chrysomyxa rhododendri* and *abietis*) (no more than 30% defoliation). During the period 1990-2001 a total of 3,442 m^3 of timber was felled for health reasons, equal to 286.83 m^3 of timber per year (Salvadori et al., 2002). Overall, the last 13 years monitoring of the 18 permanent plots (Level I) located in Trentino Alto-Adige showed average levels (class 2, 3 and 4) of defoliation on 6.7% of all trees (Salvadori et al. 2003). If the plots correctly represented the total forested areas, this would equal a damaged area of 23,127 ha.

[4] As we were interested in calculating annual values we refer only to flows.

Assuming that the quantity of timber harvested will remain constant along lines laid down in the ten-year management plan, independently of defoliation, the reduction in value almost only concerns the potential value. Considering the loss in timber for classes 2, 3 and 4 *(Table 2)*, we used a total weighted mean of 35% for the three classes. At a potential value of 29.2 €/ha the total loss is equal to € 236,358.

Similarly, for carbon sequestration we employed an average reduction of 25% in the value of the function for all hectares suffering damage. In this way the total loss is € 531,112 *(Table 4)*.

Table 4. Economic evaluation of defoliation damage

Forest function		Hectares class 2-3-4 defoliation	Reduction in value per ha damaged (%)	Economic value of damage (€/year)	Incidence of damage on value of single functions (%)
Production	Real		0	0	-
	Potential		35	236,358	2.34
Protection			0	0	-
Tourism-recreation			30	280,785	2.01
Carbon sequestration			25	531,112	1.67
Total		23,127		1,048,255	

In order to calculate effects of defoliation on tourism-recreation, the value was reduced by 30% (Gatto, 2005), resulting in a monetary loss of 280,785 € per year. Finally, consequences on hydro-geological protection were not measured because they can be considered negligible. The various causes of defoliation have lead to an estimated annual loss in value of around € 1,048,255.

b) Fire

For the decade 1991-2001 there was a progressive reduction in the number of fires, except for variations associated with climate trends and with a peak during the early nineties, levelling off at 359.34 ha of forestland crossed by forest fires yearly, or 0.1% of the forests in the province (APPA 2004).

The economic loss associated to the productive function, € 16,537 in real value and € 10,493 in potential value *(Table 5)*, derives from the product of the value per hectare of timber by the number of hectares burnt. The same procedure was used for tourism-recreation and protection. For estimating the economic effect of fire on carbon dioxide exchange we applied the previously mentioned values. The passage of fire produces an annual loss of carbon sequestration of € 33,183.

Table 5. Economic evaluation of fire damage

Forest function		Hectares effected by fire (ha)	Reduction in value per ha damaged (%)	Economic value of damage (€/year)	Incidence of damage on value of single functions (%)
Production	Real		100	16,537	0.10
	Potential		100	10,493	0.10
Protection			100	26,534	0.10
Tourism-recreation			100	14,542	0.10
Carbon sequestration			–	33,183	0.11
Total		359.34		101,289	

c) Wind and snow damage

Trees felled by strong winds, and to a lesser extent by snow, are the main source of forced utilisation and timber loss in the province of Trento, where 36,842 m^3/year of forced utilization has been registered for the period 1991-2001 (Salvadori et al. 2002). Given the growing stock for forests in the province (202 m^3/ha), we can estimate that the average area affected per year is equal to 182 ha. The value of the damage was calculated by detracting the full value of all the functions except production and tourism recreation. A 30% reduction was applied to the real value of production and, as previously mentioned, no reduction was considered for the potential value. A 40% reduction was assumed for the tourism-recreational function following Schneider et al. (2006).

The most part of the economic loss due to wind and snow is in the production function (€ 426,409) *(Table 6)*.

Table 6. Economic evaluation of damage from wind and snow

Forest function		Hectares of fallen trees (ha)	Mc of accident timber	Reduction in value per ha damaged (%)	Economic value of damage (€/year)	Incidence of damage on value of single functions (%)
Production	Real			30	426,409	2.68
	Potential			0	0	-
Protection				100	13,467	0.05
Tourism-recreation				40	2,952	0.02
Carbon sequestration				100	16,753	0.05
Total		182.38	36,842		459,581	

d) Tillage

An average of about 67 hectares of forest in the province of Trento was tilled per year over the decade 1991-2001 (APPA 2004). These figures enable us to calculate an annual loss of € 15,796 linked to tillage related factors *(Table 7)*.

Table 7. Economic value of damage from tillage

Forest function		Hectares tilled (ha)	Reduction in value per ha damaged (%)	Economic value of damage (€/year)	Incidence of damage on value of single functions (%)
Production	Real		0	0	0.00
	Potential		100	1,959	0.02
Protection			100	4,956	0.02
Tourism-recreation			100	2,716	0.02
Carbon sequestration			100	6,165	0.02
Total		67.12		15,796	

Adding up the four different types of economic damage we end up with an estimated annual damage of about € 1,624,921 equal to 4.71 €/ha. Considering the lack of data on wildlife damage, this result can be considered a lower bound estimate. If biodiversity had been considered, the final result may have been different because its value is likely to increase noticeably with respect to other flows of environmental benefits (Leslie 2005), but we cannot predict the magnitude of this change.

If we look in detail at the breakdown of this damage, we find that defoliation counts for 65% of lost forest value, and wind and snow damage for 28%. Damage from fire and tillage cause only 6% of the loss.

The order of importance is different if we consider only production *(Table 8)*. Here the main cause of economic damage is wind and snow, whereas defoliation counts for about half of it. This is what is normally reported by forest experts who tend to think mainly in terms of production when judging the seriousness of damage.

Table 8. Economic value of damage on timber and non-timber functions (€/year)

Forest function	Economic value	Defoliation damage	Damage from wind and snow	Fire damage	Damage from tillage
Production	25,967,144	236,358	426,409	27,030	1,959
Protection	25,489,005	-	13,467	26,534	4,956
Tourism-recreation	13,969,435	280,785	2,952	14,542	2,716
Carbon sequestration	31,706,530	531,112	16,753	33,183	6,165
Total		1,048,255	459,581	101,289	15,796

It is interesting to note how the relationship between damage to timber and non-timber functions differs according to damage type. While wind and snow damage weighs more heavily on timber production, the other three kinds of damage preponderantly affect non-timber services.

Pondering on the overall effects of forest disturbance means fully recognising the multi-functional role of forests and realizing the increasing societal demand for non-timber services. On the other hand, it also implies that forest managers must take into account that their decisions may affect the production of timber and non-timber services in a very different way. Without going further into this issue, we shall mention just two aspects. The currently dominating monocultural and even-aged forest structure seems to be more vulnerable to windthrow and other damaging agents (Lekes – Dandul 2000) and failure to tend forests provokes stress in plants, identifiable by a rise in defoliation level (Nicolotti et al. 2005).

4 CONCLUSIONS

It is clearly perceived at a European level that "disturbances have a considerable impact on forestry" and that this impact is likely to increase for at least two reasons: first of all a rise in both total forest area and total stand volume, implies that a "larger resource may be damaged", secondly changes in climate seem to increase the intensity and frequency of storms and contribute to a deterioration in forest health (Schelhaas et al. 2003; UN Economic and Social Council 2003). Moreover, not all European forests are as well managed as in the case study area presented here.

Nevertheless, trying to quantify the economic impact of different forest disturbances proves to be a real challenge. The wealth of information produced in Europe through twenty years of monitoring and scientific research does not readily lend itself to economic analysis. The format in which damages are published in monitoring reports varies greatly (share of standing stock damaged, volume that has actually been removed from the forest, area crossed by fire). Furthermore, the huge amount of information on the occurrence of disturbance, collected at the national level and available for consultation in the Database on Forest Disturbance in Europe, is not immediately usable for economic analysis (Schelhaas et al. 2003).

An evaluation exercise such as that carried out in this study has to resort to numerous hypotheses, due to the lack of data usable for economic purposes. For small areas, such as the one analysed here, this also happens because the few empirical studies generally deal with a single biotic or abiotic factor, or because we are not certain that the areas studied or the plots monitored are truly representative of a wider area. In addition, when estimating the reduction in price due to fires, wind and snow damage and health factors, we had to approximate data supplied by the limited number of studies available, in order to adapt them to our specific case.

However, as our discussion shows, an overall economic estimate of damage to timber and non-timber functions allows us to build a more precise picture of the effects of the different disturbance factors in play, drawing attention also to the reduction in externality production. This knowledge may also facilitates the fine tuning of adequate prevention policies.

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REFERENCES

ALBERINI, A. – KAHN, J.R. (2006): Handbook on Contingent Valuation. Edward Elgar Publishing, Cheltenham, UK.

ANDREATTA, G. (2005): Problemi di instabilità meccanica in popolamenti forestali della regione alpina. [Mechanical instability in alpine forest stands: causes and possible remediations.] *Forest@* 2: 166-171. (in Italian)

APPA (2004): Rapporto sullo stato dell'ambiente 2003. Provincia Autonoma di Trento. Assessorato all'Urbanistica e Ambiente, Trento.

BHF (2006): The condition of forests in Europe. 2006 Executive Report. UN/ECE, Geneva and Brussels.

EFREMOV, D.F. – SHESHUKOV, M.A. (2000): Ecological and economic evaluation of the consequences of catastrophic fires in the Russian Far East: the Khabarovsk territory example of 1998. IFFN 22: 53-62.

FABER, S.C. – COSTANZA, R. – WILSON, M.A. (2002): Economic and ecological concepts for valuing ecosystem services. Ecol Econ 41: 375-392.

FATTORINI, L. – GASPARINI, P. – NOCETTI, M. – TABACCHI, G. – TOSI, V. (2005): Observation and forecast models for above-ground tree and shrub phytomass in the forest stands of Trentino. Studi Trent. Sci. Nat. Acta Biol. 81: 75-121.

GATTO, P. – BATTISTI, A. – ZOCCA, A. – BARRENTO, M.J. – BRANCO, M. – PAIVA, M.R. (2005): The economic evaluation of integrated pest management strategies: a case-study in Setùbal Peninsula, Portugal. 6th International Conference of the European Society for Ecological Economics, 14-17 June 2005, Lisbon.

GOWER, S.T. (2003): Patterns and mechanisms of the forest carbon cycle. Annu. Rev. Environ. Resour. 28: 169-204.

GREGOIRE, T.G. – VALENTINE, H.T. – FURNIVAL, G.M. (1995): Sampling methods to estimate foliage and other characteristics of individual trees. Ecology 76: 1181-1194.

KNEPP, R.G. – HAMILTON, J.G. – MOHAN, J.E. – ZANGERL, A.R. – BERENBAUM, M.R. – DE LUCIA, E.H. (2005): Elevated CO_2 reduces leaf damage by insect herbivores in a forest community. New Phytol 167: 207-218.

KURKELA, T. (2002): Crown condition as an indicator of the incidence of root rot caused by Heterobasidion annosum in Scots pine stand. Silva Fenn 36: 451-457.

LECOCQ, F. (2004): State and Trends of the Carbon Market 2004. Development Economics Research Group, World Bank based on data and insights provided by Natsource LLC and PointCarbon, 37.

LEKES, V. – DANDUL, I. (2000): Using airflow modelling and spatial analysis for defining wind damage risk classification (WINDARC). Forest Ecol Manag 135: 331-344.

LESLIE, A. (2005): Qu'attendrons-nous des forets. OIBT Actualités des forets tropicales 13: 14-16.

LOVETT, G.M. – CHRISTENSON, L.M. – GROFFMAN, P.M. – JONES, C.G. – HART, J.E. – MITCHELL, M.J. (2002): Insect defoliation and nitrogen cycling in forests. BioScience 52: 335-341.

LYYTIKÄINEN-SAARENMAA, P. – TOMPPO, E. (2002): Impact of sawfly defoliation on growth of Scots pine *Pinus sylvestris* (Pinaceae) and associated economic losses. B Entomol Res 92: 137-140.

MATTHEWS, G. (1993): The carbon content of trees. Forestry Commission Technical Paper 4, 21.

MAZZOLENI, S. – ARONNE, G. (1993): Introduzione all'ecologia degli incendi. Liguori Editore, Napoli.

MEIER, F. – ENGESSER, R. – FORSTER, B. – ODERMATT, O. (2005): Situazione fitosanitaria dei boschi 2004. Istituto federale di ricerca per la foresta, la neve e il paesaggio WSL, Birmensdorf, 22.

MERLO, M. – RUOL, G. (1994): Ipotesi di remunerazione dei servizi pubblici offerti dai beni silvo-pastorali: un'analisi economico-finanziaria. Genio Rurale 4: 9-16.

MITCHELL, R.C. – CARSON, R.T. (1989): Using Surveys to Value Public Goods: the Contingent Valuation Method. Resources for the Future, Washington D.C.

NICOLOTTI, G. – GONTHIER, P. – RETTORI, A. – CELLERINO, G.P. (2005): Fitopatie quale causa di riduzione della funzione ecologica degli alberi. [Decrease of the ecological function of trees due to fungal diseases.] Forest@ 2: 85-91. (in Italian)

NIEUWENHUIS, M. – FITZPATRICK, P.J. (2002): An assessment of stem breakage and the reduction in timber volume and value recovery resulting from a catastrophic storm: an Irish case study. Forestry 75: 513-523.

NOTARO, S. – GIOS, G. – PALETTO, A. (2006): Using the Contingent Valuation Method for ex ante service innovation evaluation. Schweizerische Zeitschrift für Forstwesen, 157: 507-512.

NOTARO, S. – PALETTO, A. – RAFFAELLI, R. (2008): The economic valuation of non-productive forest functions as an instrument towards Integrated forest management. In: Cesaro L, Gatto P, Pettenella D (eds.): The Multifunctional Role of Forests: Policies, Methods and Case studies, EFI Proceedings 55: 301-312.

PETRÁŠ, R. (2002): Reduction of timber value from damaged spruce stand after their dieback. Journal of Forest Science 48: 80-87.

PETTENELLA, D. (1997): La contabilità ambientale delle risorse forestali: un'applicazione all'analisi degli incendi boschivi. Genio Rurale 2: 41-51.

PEYRON, J.L. – BAKOUMA, J. (2001): First Economic Valuation of 1999 Windfalls in France. International IUFRO Symposium The Economics of Natural Hazards in Forestry, Solsona 7h-10h June 2001.

PIUSSI, P. (1994): Selvicoltura generale. [General Silviculture.] UTET, Torino, Italy. (In Italian)

REIMOSER, F. – ARMSTRONG, H. – SUCHANT, R. (1999): Measuring forest damage of ungulates: what should be considered. Forest Ecology and Management 120: 47-58.

SALVADORI, C. – MARESI, G. – BARBIERO, R. (2002): Stato fitosanitario delle foreste trentine Anno 2001. Provincia Autonoma di Trento, Istituto Agrario di San Michele all'Adige, Trento, 29.

SALVADORI, C. – TAIT, D. – VALENTINOTTI, R. – CONFALONIERI, M. – MINERBI, S. – AMBROSI, P. (2003): Stato delle chiome e deposizioni atmosferiche nei boschi del Trentino Alto Adige. Linea Ecologica 35: 51-57.

SCHELHAAS, M.J. – SCHUCK, A. – VARIS, S. (2003): Database on forest disturbance in Europe (DFDE). Technical description. European Forest Institute, Internal Report 14, 44.

SCHNEIDER, J. – VYSKOT, J. – KUPEC, P. – MELICHAROVÁ, A. – FIALOVÁ, J. – SMÍTKA, D. (2006): Wind calamity damages to functions of forest in High Tatras National Park. Zbornik radova, Jahorina - NP. Sutjeska, 05-08: 397-403.

SCRINZI, G. – FLAMMINJ, T. – CUTRONE, A. – FLORIS, A. (1997): Un modello di valutazione quantitativa della pressione turistico-ricreativa sulle risorse forestali. Esempio di applicazione al territorio della provincia di Trento. ISAFA 96/4.

STRAW, N.A. – ARMOUR, H.L. – DAY, K.R. (2002): The financial costs of defoliation of Scots pine (Pinus sylvestris) by pine looper moth (Bupalus piniaria). Forestry 75: 525-536.

TUCKER, S.A. – NEBEKER, T.E. – WARRINER, M.D. – JONES, W.D. – BEATTY, T.K. (2004): Effects of artificial defoliation on the growth of cottonwood: simulation of cottonwood leaf beetle defoliation. In: Connor KF (ed.), Proceedings of the 12th biennial southern silvicultural research conference, Gen. Tech. Rep. SRS-71, Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 169-171.

UN ECONOMIC AND SOCIAL COUNCIL (2003): Progress in implementation: forest health and productivity. Report to the Secretary-General, Geneva, 13th March 2003, E/CN.18/2003/5, 1-17.

WERMELINGER, B. – DUELLI, P. – OBRIST, M.K. (2003): Windthrow stimulates arthropod biodiversity in forests. In: Mason, F.; Nardi, G.; Tisato, M. (eds.) Dead wood: a key to biodiversity. Proceedings of the International Symposium “Dead wood: a key to biodiversity”, 29th-31st, May 2003, Mantova, Italy, Sherwood 95, Suppl. 2: 79-82.

WPR (1994): Encyclopedia of World Problems and Human Potential, 4th Edition, Vol.1: World Problems K.G. Saur, Union of International Associationi, Munchen.