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Sandra Notaro

Alessandro Paletto

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Dott. Luciano Andreozzi
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Dipartimento di Economia
Università degli Studi di Trento
Via Inama 5
38100 TRENTO ITALIA

Natural disturbances and natural hazards in mountain forests: a framework for the economic valuation

NOTARO Sandra[a*], PALETTO Alessandro[b1]

[a]*Department of Economics, University of Trento, Via Inama 5/I, 38100 Trento (Italy).*
[b]*National Council for Agricultural Research - Forest Monitoring and Planning Research Unit (CRA-MPF), P.za Nicolini 6, 38100 Trento - Villazzano (Italy).*

*Corresponding author. Tel. +39 0461 882158; fax +39 0461 882222. E-mail address: sandra.notaro@unitn.it (S. Notaro)

Abstract

This paper focuses on the economic aspects of the protective role of forests against natural hazards, developing an estimation methodology applicable on a local scale. We identified the main variables that influence on a local level those forest attributes involved directly or indirectly in protection with the aim of zoning forests in homogeneous areas in terms of the level of protection they offer.

Applying the replacement cost method a monetary value of the protective function can be estimated for homogeneous zones. The zoning permits the cost of replacement works to be calculated precisely according to the characteristics of the territory in each zone.

The methodology was tested in the province of Trento (North East Italy) in an area where forests serve multiple functions and where the social objectives are intimately linked to those of indirect protection of the mountain slopes and direct protection of human activities.

The estimation of the protective function of mountain forests enables environmental concerns to be included in economic decision-making by integrating economic and ecological approaches. It could be useful as a criterion for ranking different forest management options, i.e. forest management approaches based on the principle of close-to-nature forestry with management forms that focus on the productive function of forests. Accordingly it could enable forest managers to build consensus around management forms that take into account natural hazards and natural disturbances.

[1] This paper is the results of authors' common reflections. However the single paragraphs have been written as following: Sandra Notaro wrote 1, 2.2, 2.4, 3, 4 and Alessandro Paletto wrote 2.1, 2.3, 2.3.1, 2.3.2, 2.3.3.

1. Introduction

The most important ecological and economical function of mountain forests is to protect soil, slopes and human activities from hydro-geological damage (Merlo and Rojas Briales, 2000). There have been many ecological studies that have attempted to quantify the importance and dynamics of the protective function of forests (Brang, 2001; Bebi et al., 2001) however few have considered the economic aspects and have reported varying results due to their different methodological approaches. Despite these differences almost all the authors attribute a higher economic value to this function than to the production (timber and non-timber) and recreational values of the forest (Marangon and Gottardo, 2000; Goio et al., in press).

In order to fully comprehend what is involved in the protective function of a forest and which estimation techniques are better tailored to its economic valuation we need to break it down into types of function and the natural dangers it helps to prevent. During the third Ministerial Conference for the Protection of Forests in Europe (MCPFE - Lisbon, 1998) it was decided that it is necessary to distinguish between indirect protection, which amounts to prevention of soil erosion, and direct protection from natural damage which impacts on people and their activities. The latter can be further subdivided into main types of natural hazard (Motta and Haudemand, 1999; Berger and Rey, 2004): (i) rockfalls, (ii) snow slippage and avalanches, (iii) soil erosion and (iv) landslides.

Forests protect from rockfalls due to the presence of trees with solid trunks to act as obstacles to rolling masses (Dorren et al., 2005) and with root systems capable of holding back the rocks and at the same time accelerating their breakdown (via root exudates and small roots penetrating cracks in the rocks) (Stokes et al., 2005). This function is mostly affected by the number of large trees and their distribution over the area (Schönenberger, 2001). Regardless of this, it has been shown how the protective function of a forest is greatly weakened by the fall of individual trees and events where trees collapse en masse[2] (Hétu and Gray, 2000; Stoffel et al., 2005).

[2] When individual trees fall the volume of land involved is less than 5 m^3 and there is no interaction between the trees, while the mass collapses are phenomena for which the volume of land in movement is more than 5 m^3 (Berger et al., 2002).

The detachment of the snow cover is partially prevented in forests due to its interception by the foliage on the trees, especially evergreens (Rixen et al., 2007), but also because of the reduced sunlight and low temperatures that tend to increase the stability of the snow layer (Montesi et al., 2004).

The type of natural hazard for which forests are the most important protective measure is soil erosion. Tree roots provide a porous structure to the soil and anchorage which allow the soil to hold a greater quantity of water while the foliage catches precipitation (Berretti et al., 2007).

Deep landslides[3] are only partly affected by vegetation while the morphology and profile of the land play a decisive role. In any case, a multilayered woodland structure with dense undergrowth and elevated canopy cover is the most ideal combination of features to reduce the risk of triggering deep landslides (Stierlin et al., 1994; Kräuchi et al., 2000).

On the basis of these preliminary considerations the importance of the protective function of mountain forests becomes clear as does the necessity to combine economic approaches to the ecological ones in order to provide assistance in the planning and management of forests. The economic valuation of forest functions allows forest managers to make conscious decisions, as they can compare the relative importance of each single function in an objective way.

With this aim we have developed, and present in this study, a methodology for the economic valuation of the protective function of forests at the stage of forest management plan.

We think this method is particularly suitable for valuing the protective function of forests as it combines real ecological and economical data, since the unfamiliarity with ecosystem functions inherent in the indirect use category challenges the reliability of stated preferences methods (Contingent Valuation, Choice Modelling).

The paper is developed in three sections after this introduction. Section 2 describes the methodology and the characteristics of the forest where the method was tested, section 3 shows the results and finally section 4 concludes.

[3] Landslides can be divided into deep landslides and superficial landslides depending on whether the depth of soil involved in the slip is greater or less than 2 m (Berretti et al., 2007).

2. Materials and Methods

2.1 Study area

The study was carried out in the eastern Italian Alps in the municipality of Folgaria in the Trentino-Alto Adige region. The forest under study is known as the Valdastico forest (45° 55’ N, 11° 08’ E), and is entirely in the mountains, covering an area of 269 ha and at an altitude ranging from a minimum of 620 m to a maximum of 1,350 m. The climate of the zone is cool, temperate and mild continental. The average temperature in January is 1 °C with 30-50 mm of precipitation and in July it is 22 °C with an average precipitation of 90-105 mm. The average number of rainy days per year is 106 with an average of 1,300 mm of precipitation per year (Lavarone station), and the average snow per year is 35-55 mm.

2.2 Economic approach

The methodology we used was designed to provide a simple and rapid tool for economic valuation of the protective function of forests at the forest planning stage (focal stage of study). A tool of this kind will differ from those used in studies carried out on much larger scales (national and regional) in terms of the kinds of variables considered and the degree of detail achieved.

Economists have developed different methods for estimating monetary values for environmental non-marketed goods. Most of the methods rely on economic welfare theory.

The following estimation methods can be used to evaluate the protective function of forests (Notaro and Paletto, 2004; Merlo and Croitoru, 2005):

- Regeneration Cost, which refers to the costs required for planting, growing and maintaining a wood, using equipment and techniques available at the time of the estimate.
- Avoided Cost method, which is based on calculating the probable damage in the absence of forest protection (Freeman III, 2003).
- Replacement cost (RC) method, which is based on the cost of replacing the protective function of a forest with man-made substitutes. This cost can be used as a proxy of the economic value of the function itself, as it can be interpreted as an estimate of the benefits flowing from measures taken to avoid damage (Dixon et al., 1996).

- Contingent Valuation method, based on preferences expressed by real or potential consumers. Individuals are asked directly about their willingness to pay for the protective function of forests (Alberini and Kahn, 2006; Carson 2004; Mitchell and Carson 1989).
- Choice Modelling focuses on the value that people confer on changes in attributes of the good (Adamowicz et al., 1994; Kanninen, 2007).

The unfamiliarity with ecosystem functions associated with the indirect use category make stated preferences methods – Contingent Valuation and Choice Modelling - difficult to apply (Nunes et al., 2003; Barbier, 2007). Information bias and misspecification bias are major problems (Barkmann et al., 2008). When stated preferences methods are inappropriate the RC method can be an option. It can provide a view from an ecosystem management prospective (Hougner et al., 2006), as RC estimate shows the cost that society would sustain if the environmental service were no longer available.

The Replacement cost method is a cost based approach (Swinton et al., 2007) – falling within the framework of cost-effectiveness analysis (Herfindahl and Kneese, 1974) - that uses market prices as the opportunity cost to value environmental services. The basic premise of the RC method is that the cost of replacing the environmental service is no greater than the benefits accruing from the environmental good. If not, the RC method "misrepresents willingness to pay or willingness to accept valuation concepts" (Farber et al., 2002, p. 389). It also assumes that secondary benefits from the replacement system are nonexistent (Birol et al., 2006).

The Replacement cost method is generally applied in the economic literature for the estimation of indirect use values, such as regulation functions (De Groot et al., 2002), however, it is not able to capture the full value – that is all services and goods - of natural resources.

Replacement cost can only be a valid measure of economic value provided three conditions are met (Shabman and Batie, 1978; Bockstael et al., 2000; Freeman III, 2003).

1. that the replacement system provides functions that are equivalent in quality and magnitude to the natural function;
2. that the human-made system is the cheapest cost alternative way of performing this function;
3. that individuals in aggregate would be willing to incur the replacement costs if the natural function were no longer available.

To a certain extent our application does meet these conditions. The human-engineered system we chose provides the same direct and indirect protection functions as forests. From all the alternatives we chose the least expensive method to replace the protection function. As for the third condition, we have no information on aggregate willingness to pay for this function. We can only say that at the public level there is a deep awareness of the importance of the protective function of forests, as the different Ministerial Conferences for the Protection of Forests in Europe demonstrate.

RC methods present advantages and disadvantages. Although it is usually easier to calculate the cost of producing benefits than the value of the benefit itself and less economic data and resources are needed with respect to other methods, expenditure for replacement is not always a reliable measure of ecosystem services benefits and man-made systems do not generally produce the same benefits as natural services. Moreover conservative estimates are usually obtained with the RC method, since the replacement system usually only represents a portion of the value of the environmental good and also because perfect man-made substitutes are difficult to implement (Haugner et al., 2006).

The replacement cost method is best applied to detailed analyses focussed on a defined area for which there is abundant information available on the local ecology and tree parameters. In the present study the replacement cost method was applied in two phases:

- Phase 1: measuring an adequate range of variables for analysing the ecological and protective characteristics of each forest compartment in the Valdastico forest and estimating the relative contribution that each of these makes to protection from natural disturbances;
- Phase 2: selection of the optimal forest substitute measure, chosen on the basis of the previously assigned level of protection together with characteristics of the terrain, and its conversion into an economic measure.

2.3 Variables

Three macro categories of variables were taken into account when deciding what level of protection to assign to each of the nine forest compartments and these were linked to the following main characteristics: stand characteristics (forest canopy cover, vegetation composition, natural regeneration, vertical stand structure and dominant species), site characteristics (gradient, soil organic matter and soil depth) and vocational categories or functions.

$$P = f(C_{s\tan d}, C_{site}, C_{function}) \tag{1}$$

Where:

P = level of forest protection;

C_{stand} = stand characteristics;

C_{site} = site characteristics;

$C_{function}$ = vocational categories/functions.

The choice of variables emerged from the literature and information arising from the management plan. For this reason the list of variables is not intended to be exhaustive, but simply the best compromise between the economic valuation and forest planning.

According to some authors in the field of forest management the potential level of risk that may arise from hydrogeological disorders can be evaluated according to a synthetic parameter defined as "potential mechanical stability". Potential mechanical stability takes into consideration three main variables (Del Favero et al., 2000): soil depth, expressed as three categories of depth (<40 cm, 40-80 cm, >80 cm); the root system of each species associated with the possible existence of solid obstacles preventing the root system from developing in the normal way; the structural tendencies of each compartment which was a synthesis of the relationship between the thickness of each tree in the compartment together with the length and form of its branches. In order to provide an exhaustive evaluation of the protective function of a forest some authors suggest the following structural variables should be included (Bebi et al., 2001; Chauvin et al., 1994; Berretti et al., 2004): canopy density, dominant height, basal area, regeneration density, density of herb layer, volume and distribution of deadwood (coarse woody debris), percentage of gap and tree species composition. Recent studies concerning the type of silviculture chosen for promoting natural evolutionary processes and ecological stability in protection forests highlighted three key variables (Motta and Haudemand, 2000; Dorren et al., 2004): diverse composition of species, natural regeneration and forest structure.

2.3.1 Stand variables

Looking at the variables we chose, forest canopy cover can be defined as the proportion of the forest floor covered by the vertical projection of the tree crowns (Avery and Brukart, 1994) and represents an important ecological indicator used as a measure of stand density (Gill et al., 2000) and for predicting woody plant composition, tree volume or potential forage production, as well as for the evaluation of forest pest damage (O'Brien, 1989). In this study we defined 5 classes of forest canopy cover each with a different degree of soil cover (very dense = 83-100%, dense = 65-82%, medium density = 47-64%, sparse = 29-46%, very sparse = 10-28%). This was in order to assess 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).

The variable of vegetation composition consisted of recording the mix of tree species in a given population in order to have a measure of the different degree of precipitation interception and soil compaction afforded by the different root systems. There is no consensus in the literature as to how the composition of species affects the forest ecosystem stability (Bengtsson et al., 2000), even though it has been demonstrated that mixed forests are more resistant to perturbations and more resilient after disturbances than single species forests (Dorren et al., 2004). In this study we included three main classes of vegetation composition: (i) population where 60% or more of the trees are of only one species, (ii) population where 80% or more are of two species, (iii) population where conditions are different from the above two and therefore has a greater mix of species.

One further parameter that concerned the vegetation was the dominant species, which looked at the characteristics of a single species. When we take into account the effect of intercepting atmospheric precipitation by the tree foliage we can see that there is a substantial difference between light demanding species with their less dense foliage and shade tolerant species whose foliage will hold more precipitation, and conifers that can hold more than broadleaves because the rain drops coalesce more slowly on the pine needles (Piussi, 1994). The broadleaf can intercept less precipitation in winter, although this reduction is small in many cases when it is considered that the numerous branches and twigs (diameter < 3cm) are more capable of retaining the precipitation than the leaves are. Also species that have a deep root system are more able to withstand landslips than those with a more superficial root system which are more effective in stabilizing surface erosion. The different root systems of forest trees affect not only the ability of the forest to stabilize landslides but also its capacity to block rockfalls. Empirical evidence has shown that species such as the European beech, characteristically highly branched with deep root systems (Stokes et al., 2006), are more resistant to rockfalls than species such as the silver fir, which possesses few roots even though these are large and long and capable of penetrating between the rocks present in the soil, and the beech is even more effective than the Norway spruce which has a superficial root system with few roots (Stokes et al., 2005). Nevertheless conifers with superficial root systems, like the Norway spruce, are particularly effective at preventing snow movement (Hurand and Berger, 2002).

A literature review has revealed two key parameters necessary to allow a protection value to be assigned to a single species: root system and crown type (light demand/shade tolerant, leaves in winter, evergreen/broadleaf). These two parameters together have enabled us to draw up a summary table to provide an overall protection value for each species in terms of the main natural hazards (rockfalls, snow and avalanches, landslides, soil erosion); in this way each of the species present in the Valdastico forest was assigned a value between zero (least ability to stabilize a slip) and 2 (greatest stabilizing ability). The values for the main alpine species are as follows: Silver fir (*Abies alba* Mill.) = 1.5 European beech (*Fagus sylvatica* L.) = 1.25, European larch (*Larix decidua* Mill.) = 1.25, Cembra pine (*Pinus cembra* L.) = 1, Black pine (*Pinus nigra* Arnold) and Scots pine (*Pinus sylvestris* L.) = 1, Norway spruce (*Picea abies* L.) = 0.5.

Another factor to take into account is that of natural regeneration given that this is the primary source for natural stand renewal (Dorren et al., 2004). The fallen tree trunks provide good protection against rockfalls and avalanches, instead when there is a low level of natural regeneration the protective function of the forest decreases (Berger and Rey, 2004). Besides the level of regeneration it is also useful in terms of estimating the capacity of forests to control natural hazards, to know how the trees are dispersed and whether these are distributed across the area under study or if they are confined to groups in clearings (Margreth, 2004). This study considered three different levels of regeneration (absent, low, good) and two levels of distribution on the ground (localized and widespread).

The last variable considered for stand characteristics was the vertical stand structure or rather the stratification of the vegetation in one or more layers according to the growth differences of species in mixed-species, single cohort stands and age differences in multi-cohort stands (Staudhammer and LeMay, 2001).

Besides being an important factor in determining habitat and species diversity (Pommerening, 2002; Mac Arthur and Mac Arthur, 1961) this variable allows a different measure of protection from natural hazards (Dorren, 2004). Even though there are significant differences among natural hazards most authors agree that multilayered stands provide the best solution in terms of protection (Motta and Haudemand, 2000; Kräuchi et al., 2000). In this study we considered three distinct categories of vertical stand structure with an increasing level of protection: monolayered, bi-layered and multilayered.

2.3.2 Site variables

The gradient is a variable linked to the land form and is divided into five groups based on the inclination of the land from the horizontal, each group representing a steeper slope than the previous one: flat, sloping, strongly sloping, steep and very steep. It is clear that as the slope of the land increases the importance of the forest in terms of its protection function also increases, despite the different conditions that are significant for the different types of hazard. As far as avalanches are concerned, a slope of 30° represents the limit above which the risk of one occurring increases (Perzl, 2005); this risk drops again over 50° due to the difficulties in forming a snow cover at this angle, whereas for landslides the greatest risk occurs between 16-37° and for rockfalls it is usually on slopes over 34° (Brändli and Herold, 2001).

The last two variables we considered concern the soil: soil organic matter and soil depth. These two variables work together to provide different levels of protection from the risk of deep and superficial slips. Leaving aside the inherent differences that exist between the geo-lithic soil matrices – useful when the scale is bigger - we can achieve a more useful measure for valuation in terms of soil erosion if we measure those factors that have greatest influence on the water carrying capacity of the soil, such as the presence of plant litter[4] and organic matter in the superficial layer (Boeken and Orenstein, 2001). Meanwhile deeper soils are associated with greater soil retention and protection from superficial erosion which are features of the type of vegetation that thrives on them.

[4] Plant litter: dead plant material of small size lying loose on the ground (Facelli and Pickett, 1991).

2.3.3 Vocational variable

The vocational category simply indicates the principle function that the forester ascribes to each forest compartment. This qualitative assessment is based on a series of important management and silvicultural considerations which are also important for an accurate economic valuation. Bearing this in mind we decided to assign a different weighting to each principle function ranging from the least protective to the most, in that way we were also able to take into due consideration how certain functions (timber production and winter tourism) exceeded the capacity of the ecosystem to maintain the properties needed for its protective function (Führer, 2000). In accordance with other authors the principle forest functions we considered were the following (Pearce, 2001): direct protection, indirect protection, timber production, non-timber production, tourist-recreation and ecological.

2.4 Calculation of the classes of protection and their relative economic value

In the final analysis of each compartment, on the basis of the data reported in the management plan for each of the variables described above, we calculated an overall protection value derived from the sum of the values assigned to each variable. The values can theoretically range from 0 to 20, with the lowest associated with single species forests, monolayered, occupying flat land and managed for production, whereas the highest values were associated with mountain forests close to areas of human habitation and characterized by a multilayered vertical stand structure and a mix of many species as well as a widespread and high level of natural regeneration.

The conversion of the values obtained into economic terms was achieved by hypothesizing the substitution of the forests with naturalized engineering works which would have different impacts according to the level of protection assigned. This method is based on the concept of passive protection, which refers to technical engineering (Berger and Rey, 2004) particularly indicated, according to Rey (2003) and Berger and Renaud (1994), for soil erosion and rockfalls. For simplicity we considered four main classes:

- Class A: land requiring a low level of protection for which grassing is the intervention of choice;
- Class B: land requiring a medium level of protection for which it is necessary to apply hydro-seeding;
- Class C: land requiring a medium to high level of protection for which the most appropriate form of action would be to cut terraces;

- Class D: land requiring a high level of protection where it will be necessary to substitute the forest with a simple palisade or in more extreme cases with a double palisade.

For each class we worked out the total costs of carrying out and maintaining the different natural engineering options and combined these to reach a yearly cost per unit area (ha) for each compartment as well as for the forest as a whole.

3. Results and discussion

When we applied the methodology described to the Valdastico forest we found that this combination of variables revealed substantial differences between individual compartments. In total seven compartments were found to provide medium protection and two gave medium to high. This result can be easily explained by the fact that although the forest is in a mountainous area it does not contain compartments with extreme conditions where human activities need protection nor does it have flat areas with low protection.

Table 1: Stand and site coefficients

Compartment n°[5]	Stand characteristics				Site characteristics			
	Canopy cover	Vegetation compos.	Dominat species	Vertical stand structure	Natural regen.	Gradient	Soil organic matter/Soil depth	Total
2	0.5	2	0.5	2	0.5	1.5	1	8
3	1.5	1	0.5	1	1.5	1	1	7.5
4	1.5	1	0.5	2	2	1	1	9
5	1.5	1	1.25	1	2	1	1	8.75
6	1.5	1	0.5	1	1.5	1	1	7.5
92	1.0	2	0.5	1	1	1	1	7.5
93	0.5	2	0.75	2	0	2	0	7.25
94	0.5	0	0.75	2	0.5	1.5	0	5.75
95	0.5	1	0.75	0	0.5	2	0	4.75

Partial results concerning the stand and site characteristics have been combined in Table 1, whilst the complete results which also contain the vocational category are reported in Table 2. It can be observed that the compartments classified by the forester as directly (compartments 2, 93 and 94) and indirectly protective

[5] The compartments are indicated using the same number of the management plan.

(compartments 92 and 95) have final values that are more relevant than those concerning production or recreation.

Table 2: Stand, site and vocational category coefficients

Compartment	Stand + site coefficient	Vocation category coefficient	Total
2	8	4	12
3	7.5	0	7.5
4	9	0	9
5	8.75	0	8.75
6	7.5	0	7.5
92	7.5	3	10.5
93	7.25	4	11.25
94	5.75	4	9.75
95	4.75	3	7.75

Using the coefficients below we were able to estimate the yearly value per hectare of forest and consequently a total value for the protective function of the Valdastico forest. The cost of implementing natural engineering systems was calculated on the basis of total setting up costs and periodical maintenance costs to provide an annual quota, using an environmental discounting rate of 2%[6] and an operational lifespan ranging from 8 years for grassing to 20 years for a simple palisade.

$$A = C \cdot r \big/ (1 + r)^t \qquad (2)$$

Where:

A = annuity

C = total setting up and maintenance costs (€);

r = environmental discounting rate (%);

t = time (number of years).

[6] As we were evaluating an intangible service we used an environmental discounting rate instead of a social time preference rate. This discount rate is taken from Sáex and Requena (2007) and Weitzman (1999).

Our calculations reveal an annual value per hectare of € 284.74 and the total value obtained for the whole forest is € 76,377 (Table 3). This value is in line with the value arrived at in other studies carried out in the Italian Alps, even if the scale of the investigation was rather different. Notaro and Paletto (2004) estimated a per hectare annual value of € 186.9 for all protective[7] forests in the province of Trento. Goio et al. (in press) also estimated a per hectare per year value of € 212.19 for the same area.

Table 3: Protective value of the Valdastico forest

Level of protection	Bio-engineering works	Unit cost	Economic value per year/ha (€)	Surface (ha)	Total economic value per year (€)
A	Grassing	0.85 €/m^2	170	0	0
B	Hydro-seeding	1.2 €/ m^2	240	202.30	48,552
C	Cutting terraces	20.94 €/lm	418.8	66.44	27,825
D	Simple palisade	32.22 €/lm	644.4	0	0
Total			284.15	268.74	76,377

4. Conclusion

Research into valuation methodologies in order to quantify in monetary terms the protective function of forests is indispensable to alert forest managers and political decision makers to the importance of this function and not to downgrade it, particularly in mountain areas, in favour of other functions or interests. With the prospects of a forest management preparing to maintain more or less artificially the stationary equilibrium (Bormann and Likens, 1979), according to Führer (2000) it is necessary to intervene with corrective management measures or to adjust the planned forest function to the capacity of the ecosystem; it is exactly on this latter point that economic valuation can assist planners in making choices that will improve the stand composition.

The estimation of the protective function of a forest could be useful as a criterion for ranking different forest management options, in particular forest management approaches based on the principle of close-to-nature forestry with management forms that focus on the productive function of forests.

[7] The definition and classification of protective forests in Trentino is given by the Servizio Geologico e Servizio Foreste of the Autonomous Province of Trento.

Beyond this consideration is the fact that the forest has many functions whose utilities cannot be all maximised simultaneously and it also has different kinds of beneficiaries (i.e. landowners, local people and tourists) who all have conflicting ideas on how the forest should be managed.

Participation in forest management makes it possible to help provide more information on the aims and interests of the stakeholders, thereby improving environmental planning by more accurately forecasting the results of a given policy (avoiding undesirable consequences), and detailed analysis of the trade-offs between the various objectives resulting in greater acceptance of the decisions made (avoiding possible resistance) thereby facilitating the process (Chevalier, 2001). It is in this context that economic valuation tools achieve their full potential, in their support role to expert technical diagnosis when negotiating participants' assessments. To give a value to the diverse functions a forest carries out means providing a way to compare forests in terms of the relative importance of these various functions and to consider objectively the distribution of costs and benefits which arise from a management decision between the various stakeholders. Compensations for sustainable management practices performed in order to maintain non-productive forest functions can be also calculated.

In particular the estimation of the protective function of a forest could enable forest managers to build consensus around management forms that take into account natural hazards and natural disturbances.

From the technical viewpoint the replacement cost method lends itself particularly well to forest planning for its ease of application, however it does require detailed information on the physical and biological features of the resource, which unfortunately is not always available.

Our method of assigning a level of protection according to the variables used for forest planning presents an undeniable advantage since it does not require *ad hoc* measures in its application and may in the future be integrated into the technical support tools available to managers involved in forest planning. Its most obvious limitation is in designating a protection value to compartment larger than 10 ha where the internal heterogeneity will be difficult to translate into economic values, instead producing an average value for the whole compartment. A second drawback is the subjectivity involved in choosing the best man-made replacement for the forest as individual cases can vary greatly giving rise to a very wide range of values.

Nevertheless, despite these limitations this methodology can be a valuable aid when making choices in forest management, with its capacity to simplify the decision making process in highly complex situations.

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