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The evaluation of forest crop damages due to climate change. An application of Dempster–Shafer method

Iacopo Bernetti, Christian Ciampi, Claudio Fagarazzi, Sandro Sacchelli*

Dept. of Agricultural and Forest Economics, Engineering, Sciences and Technology, 18, Piazzale delle Cascine, I-50144 Florence, Italy

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ABSTRACT

In order to assess damage risk caused by climate change in forest areas, Dempster–Shafer theory of evidence and fuzzy measures were applied to develop a framework for the estimation of economic forest damage. According to the definition of risk supported by the Intergovernmental Panel on Climate Change, a function of hazard and resilience lines of evidence was defined. The results of the hazard and resilience assessment were used to develop an economic framework based on Faustmann studies. The evaluation model, implemented through a spatial analysis procedure, was carried out linking Faustmann formula with hazard and resilience raster maps. The model permitted to estimate in monetary terms two possible costs to be supported: the first one is expressed as the expected damage to the forest crop on the basis of the current obtainable woody assortments and the second one referred to the potential expenses to pay in order to mitigate the risk. Finally, the framework was tested on an area of central Italy (Tuscany region).

Introduction

Research on the possible impact of climate change on forests in Europe and the development of adaptation and mitigation strategies started in the early 1990s; since then, assessment on climate change, its impact and consequences on natural resources management have been the focus of continuous research efforts (EFI et al., 2008). Among the known effects of climate change there are alteration

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* Corresponding author.
E-mail address: sandro.sacchelli@unifi.it (S. Sacchelli).

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in trees growth and productivity (Kauppi and Posch, 1988; Loustau et al., 2005), variations in forest area and competition between species (Solomon, 1986; Lexer et al., 2002) and damage variation caused by natural disturbances (Flannigan et al., 2000).

Several methodologies were implemented to assess hazard and resilience in forest sector. One promising evaluation of these two variables has been provided by Nitschke and Innes (2008). In their research a meta-modelling analysis was developed to incorporate the strength of many smaller models into a framework that considers natural disturbances, floral and faunal species and species habitats.

A wide review on modelling forest ecosystem disturbances and on natural hazard assessing were developed in recent works of Seidl et al. (2011) and Hanewinkel et al. (2010a), respectively. From these studies it is possible to depict several examples of methodologies that can be applied to describe harm and adaption. Seidl et al. (2011) classify the models according to disturbances typology (event-based or regime-based) in: (i) statistical, (ii) static or dynamic process-based, (iii) vegetation or landscape dynamics and (iv) plant physiology models. Hanewinkel et al. (2010a) divide methods to model risk in experimental (e.g. mechanistic model) and empirical (both analytical and output oriented models).

Despite the intensive research efforts in the above topics, in climate change scenario the precise evaluation of economic losses with high territorial detail is a difficult task. Specifically, the main aspects to be taken into account are: (1) the impact assessment varies widely depending on the simulation model applied, the climate scenario investigated and the geographic and ecological characteristics of the crop; (2) there is considerable uncertainty concerning the interactions between vulnerability and adaptation ability of forest ecosystems.

The main objective of this study is to give a preliminary assessment on innovative kind of economic analysis in climate change forest sector, in particular: (i) to evaluate the risk of vulnerability and the probability of resilience of the forests through probabilistic and subjective estimation and (ii) to estimate the financial consequences of climate change by way of the calculation of both the hazard damage and the value of risk mitigation in forest stands. The applied procedure implemented land expectation value (LEV) calculated by Faustmann approach and Dempster–Shafer theory of evidence (DS).

As a matter of fact several authors (e.g. Buongiorno, 2001) demonstrated that the Faustmann formula is able to incorporate biological and economic risks. The methodology chosen to carried out the research (DS theory of evidence) permits to overcome the limits of Bayesian approach in an uncertain framework as for the climate change one.

DS theory was already used in environmental sector in different topics. Several studies define land cover estimation and land cover monitoring techniques carried out through the use of DS theory (see e.g. Cayuela et al., 2006; Comber et al., 2004). This theory was also introduced in climate change uncertainty evaluation (Raje and Mujumdar, 2010; Lou and Caselton, 1997). In different researches DS technique was applied in forest sector; some examples concern: (i) ways to measure sustainability of forest management and to operationalise it in terms of utility maximisation in land use strategies (Varma et al., 2000); (ii) definition of uncertainty in forest management and silvicultural decision (Ducey, 2001) and (iii) provision of practical tool in order to estimate stand regeneration maps (Mora et al., 2010). Actually, according to authors knowledge, DS theory of evidence has never been used for economic evaluation of forest under climate change conditions.

Methodological framework

The adopted methodological framework is summarized in Fig. 1. According to international literature risk hazard to climate change and resilience of forest crops was defined. Then, based on experts' knowledge, the factors (criteria) defining hazard and resilience were analysed, evaluated through a fuzzy methodology and linked to a Geographic Information System (GIS). The use of Dempster–Shafer (DS) approach permitted to aggregate all criteria in three indicators of subjective probabilities defined, according to DS theory, as: belief of hazard, belief of resilience and uncertainty.

Finally expected loss caused by climate change was estimated by linking subjective probability and land expectation values.

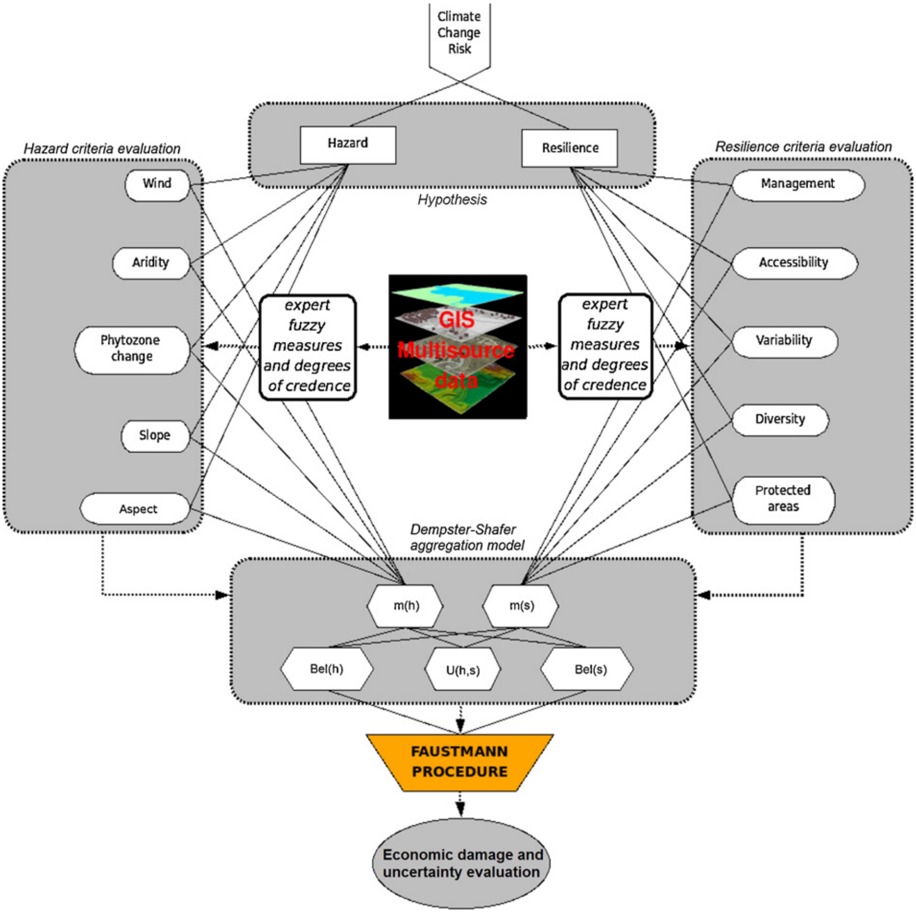

Fig. 1. Flow chart on methodological framework.

Climate change, vulnerability and adaptation capability

Resilience is defined as the ability of a forest to react to external environmental changes, maintaining a certain degree of ecological stability, both in term of species composition and maintenance of the structure. *Hazard* represents the degree of risk of destruction and/or damage of an area. In this research the present value of variables that potentially have a greater influence on the hazard degree was related with the possibility of a climate change, according to: (i) average speed of wind, (ii) yearly cumulative precipitations and (iii) yearly average temperatures. Future value of these climatic variables are based on A2 scenario of the Hadley Centre Met Office Climate Modelling 3 (Hadcm3) developed by Intergovernmental Panel on Climate Change and re-elaborated for Tuscany region (Moriondo et al., 2010).

According to the national and international literature (Carraro et al., 2007; EFI et al., 2008) the following indicators are chosen for the evaluation:

- Resilience
  - Management interventions on the forest crops (expressed as a percentage of forest surface with management interventions);
  - Accessibility to the forest areas for the management intervention;

  - Presence of protected areas;
  - Ecological diversity;
  - Landscape diversity.
- Hazard
  - Wind, as number of yearly extreme events;
  - Aridity (based on De Martonne index);
  - Slope;
  - Aspect;
  - Change in phytoclimatic zone (based on Pavari classification).

Theory of evidence

Research for new methodologies dealing with subjective probabilities and with the resulting uncertainty (mainly as an alternative or a revision to Bayesian approach) was intensified over the last 50 years. In forest economic and policy sector, a variety of new approaches for this topic have been proposed (e.g. Hildebrandt and Knoke, 2011; Gadaud and Rambonilaza, 2010). An important issue in the climate change assessment can be represented by the difficulty uncertainty evaluation; in a decision problem-solving framework, uncertainty could be accessible and useful to decision-makers. As expressed by Patt and Dessai (2005) "*the literature in behaviour economics provides many examples of how people make decisions under conditions of uncertainty relying on inappropriate heuristics, leading to inconsistent and counterproductive choices*". Therefore an in-depth analysis able to relate risk management evaluation and uncertainty is a necessary policy tool.

The methodological framework applied in this paper for the climate change consequences estimation derives from these following methodologies: (i) fuzzy set theory, in which the uncertainty is associated with vague (typically linguistic) variables (applied to climatic research in Scherm, 2000); (ii) Dempster–Shafer theory of evidence (DS), that aims at going beyond the limits of a probabilistic formulation (Bayesian approach) (Lou and Caselton, 1997).

The Bayesian formulation represents the starting point of the plausibility notion treatment in DS theory: the two approaches share the idea that the plausible reasoning is a type of uncertain reasoning because it is carried out by using sources that give information characterized by a degree of reliability but not of certainty. Unlike the Bayesian probabilities, DS theory does not need complete information in the space of the events; thus, this theory allows the use of two different values in order to express the credence in a specific proposition, or the credence in its negation.

In this study two propositions (called lines of evidence) were defined: hypothesis h = vulnerability of the geographic localization and hypothesis s = resilience of the localization. The "non-singular" hypothesis $[h,s]$ represents the value of localizations that are at the same time vulnerable and resilient. The concept of DS probability p differs from the concept of Bayesian probability because for two hypotheses A_1 and A_2 in the DS theory we will have $p(h)+p(s)+p(h,s)=1$ and thus $p(h)+p(s)<1$, while in Bayes $p(h)+p(s)=1$. The remaining $p(h,s)$ represents the contribution to uncertainty. The evaluation of the hypothesis is based on the concept of *Basic Probability Assignment* (BPA). The BPA represents the contribution that a certain factor (a_i) gives as a support for a specific hypothesis (for instance the vulnerability of a stand). The assessment of BPA is based on the combination of fuzzy functions on environmental and socio-economic variables and linguistic evaluators which were used in the model (expressed as a degree of belief). The evaluators were given by experts as oral terms (Bentabet et al., 2000); model formulation was explained in the following formula:

$$BPA(a_i, x) = \mu_{linguistic}(a_i) \cdot \mu_{a_i}(x_{a_i}) \tag{1}$$

with $\mu_{linguistic}(a_i)$ assessment through a fuzzy linguistic evaluator of the contribute in forest crops damage – in climate change scenario – of variable a_i and $\mu_{ai}(x_{ai})$ assessment through a membership function of the environmental effect of the variable a_i on the localization x.

The aggregation for the hypotheses "hazard to climate change" and "resilience to climate change", following the DS aggregation, can be done for pairs of evidence, on the basis of their joint probabilities (orthogonal sum – Shafer, 1976). For two basic probability assessment $BPA(a_i,x)$ and $BPA(a_j,x)$ (for example i = ecological diversity and j = landscape diversity) the orthogonal sum is:

$$BPA(a_i, a_j) = \frac{BPA(a_i, x) \cdot (1 - BPA(a_j, x))}{1 - BPA(a_i, x) \cdot BPA(a_j, x)} \tag{2}$$

All factors are progressively aggregated in pairs to calculate the mass probability of hazard $m(h)$ and the mass probability of resilience $m(s)$. The aggregation of the two hypothesis falls in the case of lines of evidence marked by conflict and thus it is carried out by normalizing the sum of the jointly probabilities not in conflict:

$$\begin{aligned} Bel(h) &= \frac{m(h) \cdot (1 - m(s))}{1 - m(h) \cdot m(s)} \\ Bel(s) &= \frac{m(s) \cdot (1 - m(h))}{1 - m(h) \cdot m(s)} \\ U(h, s) &= Bel(s) - (1 - Bel(h)) = \frac{(1 - m(h)) \cdot (1 - m(s))}{1 - m(h) \cdot m(s)} \end{aligned} \tag{3}$$

$Bel(h)$ and $Bel(s)$ are belief of hazard and belief of resilience measures; $U(h,s)$ belief interval represents the uncertainty degree of location, deriving both from occurrence of high hazard and high resilience in the same area.

Evaluation of the economic damage

Once Dempster–Shafer methodology was applied to the two lines of evidence and the results were aggregated, the quantification of the economic damage that climate change can cause up to the year 2036 was calculated.

The basic element for that definition is the application of the Faustmann formula, which in its foundation is defined as follows:

$$F = \frac{S_f - R + \sum S_t \cdot (1 + r)^{f-t}}{(1 + r)^f - 1} - R + \frac{a - e}{r} \tag{4}$$

with S_f net stumpage value of final cut, R regeneration cost, S_t stumpage value of thinning interventions, r discount rate, f rotation, t age of the thinning of the forest crop, a annual revenues and e annual expenses. The Faustmann formula is a stand-level economic model that was originally conceived for pure even-aged stands. For the current case, land expectation value (LEV) is used as a proxy for the assessment of the perceived utility by the owner for the use of the forestry crops. This formula was implemented through a GIS procedure of spatial analysis (Bernetti et al., 2009a).

The proposed method uses the concept of subjective expected utility variation in order to try to quantify in monetary terms the expected damage due to climate change. The theory of subjective expected utility (Savage, 1954) combines an utility function and a subjective probability distribution.

Based on the maps of the hazard and of the vulnerability degree of the Tuscany forest it is possible to apply the Faustmann formula results in order to quantify in monetary terms two possible expected utility variations: the first one expressed as the expected damage to the forest crop (on the basis of the current timber assortments obtained – Eq. (5)) and the second one referred to the expected expenses, to be supported in order to try to protect forest from damages (Eq. (6)).

$$EUV(damage) = F \cdot Bel(h) \tag{5}$$

$$EUV(adaptation) = \left(\frac{e_a}{r} + \frac{\sum P_t \cdot (1 + r)^{f-t}}{(1 + r)^f - 1} \right) \cdot (1 - Bel(s)) \tag{6}$$

with $EUV(damage)$ expected utility variation caused by the risk of crop damage, F capitalization value of forest crops from Faustmann formula, $EUV(adaptation)$ utility variation caused by the adaptation cost, e_a cost for the annual adaptation actions (viability maintenance, fire surveillance, monitoring of the effectiveness of management options, etc.), P_t costs of mitigation actions at age t (e.g. thinning to avoid overstocked stands susceptible to increased mortality from drought, insects, disease and wildfire) (Anderson and Chmura, 2009).

The rational strategy of the forest owner is the maximization of his utility and thus the minimization of its variation (in our case always negative). Then the *strategic behaviour* (or *strategic cost*) derives from the minimization of the two previous expected utility variations:

$$strategic \quad behaviour = \min\{EUV(damage), \quad EUV(adaptation)\} \tag{7}$$

Study area and data

The model developed for the quantification of the economic damage due to climate change refers to forest crops of the Tuscany region, localized in central Italy. In this region, forest surface reaches about 1,150,000 ha, with a strong variability both in terms of species composition and geomorphological conditions. The main important forest formations are the ones characterized by prevalence of deciduous broadleaved (79%), followed by evergreen broadleaved (13%) and conifers (8%). The main silvicultural system is coppice (Regione Toscana, 2008).

The evaluation model was implemented through a spatial analysis procedure applied to raster maps with a resolution of 75 m × 75 m. The georeferred data used in the work were linked to the characteristics of the regional forests as for both the managerial aspects directly influenced by the human activity and the variables not depending on direct interventions, such as climatic changes and morphological peculiarities.

The first part of the study considered the normalization and the weights evaluation of the variables set (criteria) for each line of evidence.

These criteria were chosen through a fuzzy Delphi procedure (Cheng, 1999), which was carried out with the contribution of eight experts of the forest sector, in order to define several parameters of the analysis model, by means of an iterative questionnaire. The survey considered managers of the Consortium of Mountainous Areas, of the State Forestry Corps and of forest academic staff.

The questionnaire made possible to obtain needed parameters for the creation of the values of environmental effects (fuzzy maps) $\mu_{a_i}(a_i)$ and of the importance of variable a_i in climate change scenario (degree of credence) $\mu_{linguistic}(x_{a_i})$; these values were necessary to calculate the basic probability assignments (Eq. (1)).

The experts' opinions were described by parameters and linguistic terms which can be expressed in trapezoidal (or triangular) fuzzy numbers. The possibility of comparing different indicators among each other (such as the presence of managed areas and the landscape diversity) necessarily requires a normalization (re-classification of the factors in a range between 0 and 1, that is minimum and maximum probability that the factor contributes to the event, respectively). Table 1 shows the fuzzy function parameters used in normalization of hazard and resilience indicators.

The fuzzy linguistic operators are strictly related to the fuzzy logic functions (Chen and Hwang, 1992). These represent a methodology which allows to get to a numeric quantification of qualitative opinions given by the experts of the sector for particular decisional processes, through an evaluation done on specific functional shapes. Thus, with a fuzzy linguistic operator we can turn the verbal evaluation (i.e. high influence of a variable on the line of evidence "hazard") into a number, maintaining the intrinsic uncertainty of the expert estimation. Chen and Hwang identified 8 scales of linguistic terms. The conversion scale adopted for each evaluation (Fig. 2) was chosen by experts in the process.

The evaluation of the other variables was then implemented through a linguistic term sets derived from Scale 2 of the Chen and Hwang as it is showed in Tables 2 and 3. The linguistic terms were converted into crisp values (high: 0.808; medium: 0.5; low: 0.192) using a fuzzy ranking method.

The Basic Probability Assignment (BPA) maps were obtained through the product of each fuzzy map and the relative degree of credence. This last degree derives from the numeric quantification ascribed to each variable through a fuzzy linguistic evaluator following the scale 4 of Chen and Hwang (linguistic values: low: 0.115, medium-low: 0.3, medium: 0.5, medium-high: 0.7, high: 0.885). The degree of credence of each variable was defined in Table 4.

To make the consensus of the experts consistent, it was utilized fuzzy Delphi method to adjust the fuzzy rating of every expert and to achieve the consensus condition. In order to aggregate many

Table 1
Definition of the membership functions of fuzzy maps.

Line of evidence	Criteria	Map data	Fuzzy membership	Control point			
				a	b	c	d
Resilience	Management	Percentage of Municipality forest surface with management interventions	Linear increasing	30		70	
	Accessibility	Accessibility to the forest areas for the managing intervention, expressed in terms of "cumulative" difference in heights from the forest viability (m)	Linear decreasing	0		100	
	Ecological diversity	Variety density index	Linear increasing	0		Maximum value in area	
	Landscape diversity	Edge density index	Linear increasing	0		Maximum value in area	
Hazard	Wind	No. of yearly extreme events	Linear increasing	0		Maximum value in area	
	Aridity	De Martonne index	Linear decreasing	15		30	
	Slope	%	Linear increasing	0		100	
	Aspect	Degrees in respect to North (°)	Symmetric	90	180		270

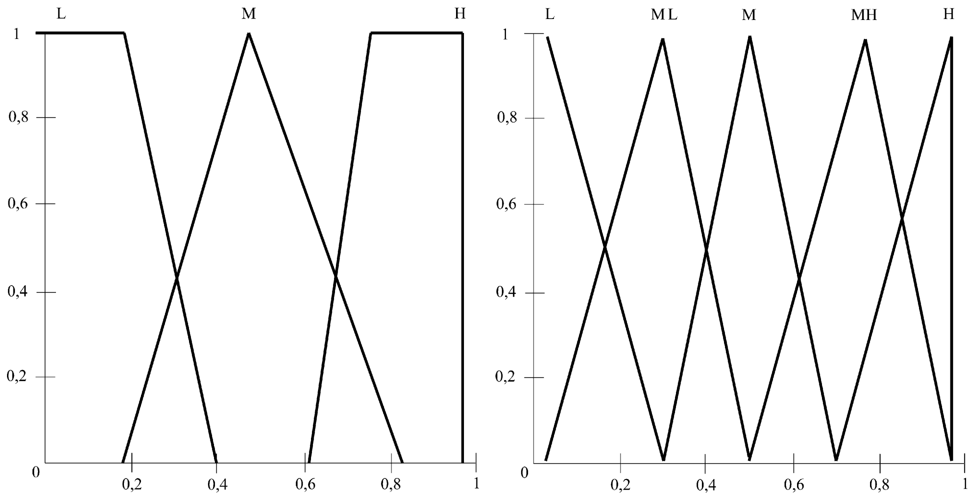

Fig. 2. Scale 2 and 4 of Chen and Hwang.

Table 2
Evaluation of the variable "forests in natural protected areas".

Typology of protected area including forest crops	Definition of linguistic evaluator
National Park	High
Regional Park, National Reserve	Medium
Provincial Park, Regional or Provincial Reserve	Low

experts' opinions, we considered the mean of fuzzy ratings $\mu_{a_i}(a_i)$ and the modal value of degree of credence $\mu_{linguistic}(x_{a_i})$ (Chen and Lin, 1995; Cheng and Lin, 2002). The adopted procedure differs for trapezoidal fuzzy numbers (Cheng and Lin, 2002) and linguistics operator, in particular this phase was carried out as follows:

(a) Aggregation of fuzzy numbers. Step 1: experts provide a parameters for each fuzzy membership function. Step 2: for each expert, first the average of results of step 1 and then, the differences, are found and sent back to the experts for re-examination. Step 3: each expert presents a revised

Table 3
Evaluation of the variable "change of phytoclimatic zone".

Corine Land Cover – CLC IV° level code and description (forests with prevalence of . . .)	Definition of linguistic evaluator		
	From castanetum to lauretum	From fagetum to castanetum	From picetum to fagetum
3111: evergreen oaks and other evergreen broadleaves	Low	Low	Not present
3112: deciduous oaks	Medium	Low	Not present
3113: autochthonous broadleaves	High	High	Not present
3114: chestnut	High	Medium	Low
3115: European beech	High	High	Medium
3116: hydrophilic species	High	High	Not present
3117: exotic broadleaves (locust tree)	High	Medium	Not present
3121: Mediterranean pines and cypresses	Low	Low	Not present
3122: mountain pines	Medium	Low	Not present
3123: Norway spruce and/or silver fir	High	High	Medium
3125: exotic conifers	Medium	Medium	Not present
313: mixed forest	Low	Low	Low
3231: high brushwood	Low	Low	Not present

Table 4
Degree of credence of hazard and resilience criteria.

Line of evidence	Variable	Degree of credence
Resilience	Management	Medium-low
	Accessibility	Medium
	Protected areas	Medium-low
	Ecological diversity	Medium
	Landscape diversity	Medium
Hazard	Wind	Medium-high
	Aridity	Medium-high
	Change of phytoclimatic zone	High
	Slope	Medium
	Aspect	Medium-low

trapezoidal fuzzy number. This process, starting with step 2, is repeated until the successive mean becomes reasonably close.

(b) Aggregation of linguistics terms. Step 1: same as previous. In step 2 the method presented in Chen (1998) is used to deal with fuzzy opinion aggregation for homo/heterogeneous groups of expert, in particular: (i) calculation of the degree of agreement (or degree of similarity) of the opinions between each pair of experts; a method introduced by Chen and Lin (1995) is used for measuring the degree of similarity between trapezoidal fuzzy numbers. (ii) Construction of the agreement matrix. (iii) Calculation of the expert average value of agreement by the use of agreement matrix. (iv) Calculation of the consensus degree coefficient. (v) All parameters are sent back to expert for re-examination. Step 3: each expert provides revised evaluation until consensus degree becomes acceptable.

Results and discussion

Fig. 3 shows the maps and the box-whisker diagrams for the belief of hazard, belief of resilience and uncertainty interval. The box-whisker plots in Fig. 3 show the mean (black line inside the box-whiskers), the first and third quartile and finally, the upper and lower limits reached.

In general the risk of hazard is relatively limited, with an average probability equal to about 0.4. Half of the Tuscany forests present an hazard risk between 0.35 and 0.49. There are also some localizations with a relative higher risk, with an upper whisker equal to 0.71. The values regarding resilient forests to climate change are however relatively low, with a mean value of 0.38 and first and third quartile equal to 0.29 and 0.44, respectively. In this case also the upper limit does not seem high (0.66). The uncertainty interval shows an average value of 0.21 (first and third quartile of 0.18 and 0.24, upper limit 0.32), thus a few Tuscany forests seem to have both high hazard and high resilience evaluation

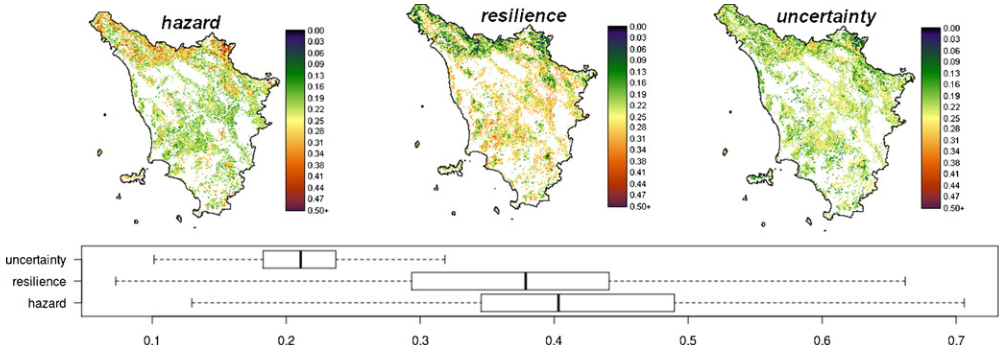

Fig. 3. Belief results.

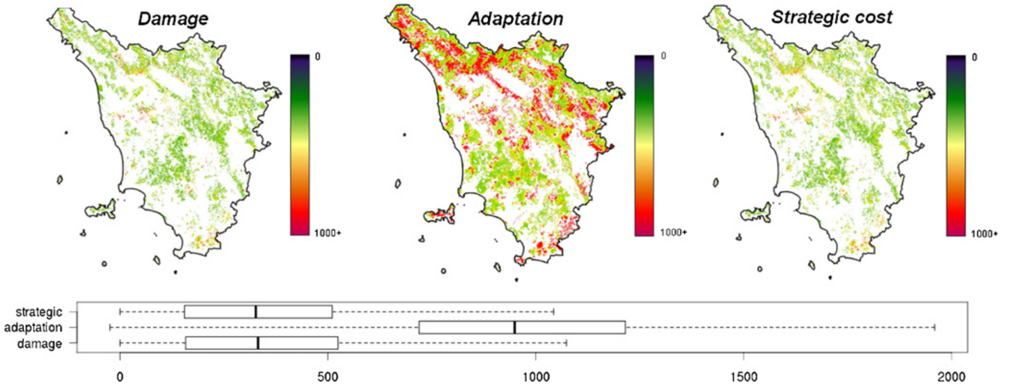

Fig. 4. Expected damage, adaptation cost and strategic cost (€/ha).

in the same area. On the geographic point of view, the forest localizations showing the higher degree of hazard and the lower resilience are situated in the mountainous area of the Apennines (northwest-southeast side of the region), while the Mediterranean forests seem to show, as a whole, a lower risk. These results match with the Italian and international literature on the issue (EFI et al., 2008; Carraro et al., 2007).

Fig. 4 highlights the maps that represent the expected damage, the mitigation cost and the strategic cost.

Results analysis, shows that generally the adaptation cost is higher than the expected damages. The average value of the expected damage is about 332 €/ha, with the first and third quartile equal to 158 and 524 €/ha. The adaptation cost, instead, shows a mean of 950 €/ha (first and third quartile 719 and 1,215 €/ha, respectively). For this reason, the strategic cost comes to be, in the majority of the forest localizations, equal to the expected damage (mean 326, first and third quartile 155 and 510 €/ha). These results point out values close to the ones presented in another recent study carried out by Hanewinkel et al. (2010b) with a similar methodology (LEV reduction calculated with the Faustmann formula) for southwest Germany Norway spruce; the authors calculate an average reductions of LEV equal to 521 €/ha in A2 IPCC scenario.

The strategic cost represented in formula (7) and in Fig. 4, is expressed as a capital value. However, considering several of the basic conditions necessary for the application of the Faustmann formula (i.e. a long time constituted forestry fund and thus characterized by constant revenues and costs, as well as by a permanence in the destination and in the productive conditions), it is possible to hypothesize the presence of regulated and uneven-aged forests in which the strategic cost is reported as present value of annuity. The frequency distribution of this value is represented in Fig. 5.

For the entire regional territory the strategic cost amounts to about 12,500,000 €/year, corresponding to the 33% of the gross product of the silvicultural sector in Tuscany (IRPET, 2008). This reduction can be compared with the one calculated for other sectors sensitive to climatic changes. In the agricultural sector Bernetti et al. (2009b) evaluated reductions between 1930 and 101,718 €/ha for the wine sector and 134 €/ha for the arable lands. Carraro et al. (2007) estimated that, in northern Italy, reduction of the tourist income could vary from a minimum of 17.3% to a maximum of 21.2% (as a function of the scenario and of the considered region). International studies (e.g. Stern, 2007) evaluated that the cost derived from the climatic change is varying between −4% of GDP (that is, net gains) to +15% of GDP; most estimates are still centered around 1% of GDP. Thus, the forest sector (together with the agricultural and the tourist ones) seems to be more sensitive when compared to the economic system in its complexity.

These results may allow not only to estimate a monetary quantification but also to define the localization of the damage. The geographic localization and quantification of hazard, resilience and uncertainty value, permits to downscale results according to optimal administrative and policy decision-level. In our research adaptation and damage costs can be, e.g. estimate at a Provincial level;

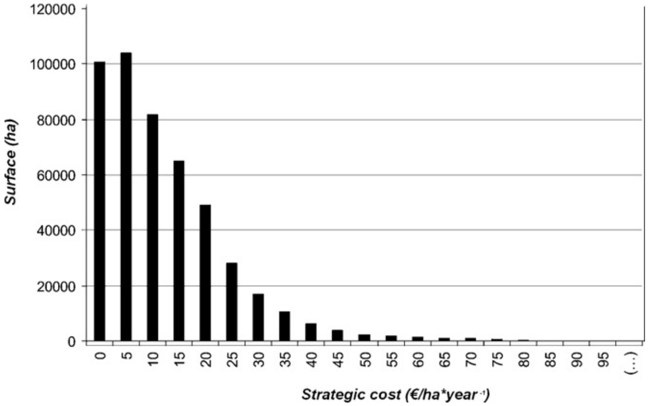

Fig. 5. Annual strategic cost.

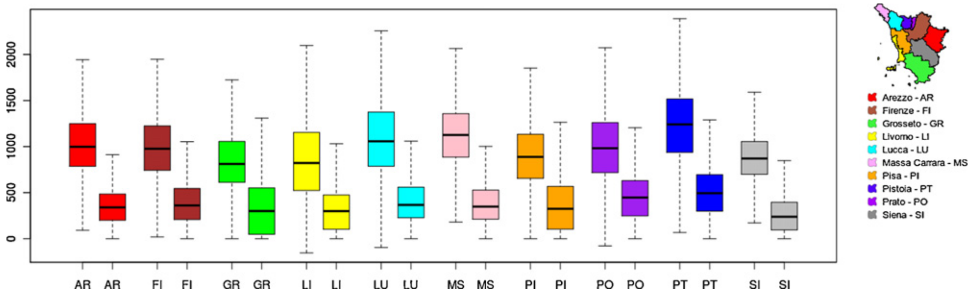

Fig. 6. Adaptation cost (left bars) and expected damage (right bars) for Tuscany Provinces.

as a matter of fact the operative actions regarding the Italian agricultural policy are delegated to the Provinces (NUTS-3 subdivision, according to Eurostat classification) and they are the main local stakeholders, able to address funds in particular agro-forestry sectors. Quantification of adaptation cost and expected damage in Tuscany Provinces is explained in Fig. 6.

Conclusions

The examined Dempster–Shafer approach appears to be a promising alternative for conducting economic analysis in near-ignorance conditions and in an environment of limited data and relevant uncertainty such as the climate change in forestry sector. The fuzzy measure and Dempster–Shafer theories used in this study seem to be efficient tools for data integration and environmental impact assessment.

In particular the application of DS theory proved to be particularly useful from the expert systems viewpoint as a powerful tool for uncertainty analysis; in addition it aggregates all evidential variables in an unique frame of discernment that is an efficient kind of damage analysis in climate change risk conditions. Finally, in environmental decision making sector, it could provide useful guidance for natural resource plans based on the level of probable damage in different locations.

On the other hand the work can be improved in some aspects as follows. Monetary computations in expected utility variation caused by the risk and by the adaptation cost work under the assumption that all prices and costs (timber, labour, interest, regeneration, etc.) are constant over time according to the classical Faustmann model. However in real forestry, timber and input prices are subject to periodic fluctuations and the forecasted forest growth is subject to various disturbances and variations (extreme event, increase in temperature, etc.). Similarly, in Faustmann formula an assumption is that the interest rate is known and constant over the period.

In order to overcome these limits the integration of risk in climate change damage estimation can be achieved also by the addition of a premium to the discount rate (Hanewinkel et al., 2010a). In a study carried out by Knoke and Hahn (2007) simulation approach developed through Monte Carlo analysis was used to introduce risk evaluation in Faustmann formula. Uncertainty related to timber prices can be taken into account by means of stochastic dynamic programming (Lohmander, 2000). On LEV reduction viewpoint other study estimate value close to the ones depicted in this research, e.g. for southwest Germany Norway spruce, the application of Faustmann procedure linked by generalized linear model and single-tree growth simulator defined an average LEV reduction of 521 €/ha vs. 326 €/ha of the present research (Hanewinkel et al., 2010b).

Furthermore the model assumes that also damage and mitigations work perpetually and with constant quantification. In order to consider possible fluctuation of climate change, ecosystem interactions and their consequences on forest crops, process-based approaches can be a solution. Dynamics process in particular landscape and vegetation dynamics or plant physiology models are some suitable examples of these. Finally recent methodological advances have been used to consider highly variable and incomplete and noisy characteristics of most disturbance datasets (e.g., machine learning algorithms such as random forests and artificial neural network) (Seidl et al., 2011).

Further future development of the model could involve the extension of analysis to non-market data in order to achieve a more holistic framework to support decisions in climate change planning.

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