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Uncertainty assessment in climate change scenarios: a methodological proposal for management of forest ecosystem services

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Abstract - The work introduces a method to quantify potential impact of climate change on cultural ecosystem services in forests. The technique of Hesitant Fuzzy Linguistic Term Set is applied to face with the uncertainty due to climate change as well as subjective opinion of forest experts. Two forest management scenario (current practices as well as climate change-oriented silviculture) are investigated for different time horizons. Results highlight the increasing uncertainty on climate change impact evaluation related to longer time horizons. Potential losses connected to current cultural ecosystem services provision are quantified from spatial as well as economic viewpoint. The method is tested for an illustrative example in the Tuscany region - central Italy.

Keywords - climate change-oriented silviculture; cultural ecosystem services; uncertainty evaluation.

Introduction

Sustainable forest management as well as adaptive governance are essential strategies to cope with the vulnerability of forests to environmental change (Cudlín et al. 2013). Among disturbances, climate change (CC) is one of the main threats facing forest stability in the future (Hanewinkel et al. 2011, Seidl et al. 2011). Ding and Nunes (2014) attempted to model the relationship between CC and the provisioning of ecosystem goods and services stressing the cost-effectiveness of nature-based mitigation policies. In recent years, forest science literature has moved from a focus on mitigation to one that includes adaptation with a strong relevance given to the modelling of potential forest reaction to CC (Lawrence and Nicoll 2015). However, current data on the feasibility and effectiveness of adaptation in reducing ecosystem service loss are limited, due to the significant magnitude and speed of global warming. The transient response of forests under CC and the shifting of species were analysed in different studies based on national forest inventories (NFIs) and projection of climate data (Lexer et al. 2002). Scenario modelling (focused on growth as well as vulnerability matrixes) was also applied to assess the potential impact of biotic/abiotic factors on forest ecosystem services (Ray et al. 2017), with a particular emphasis on biodiversity (Felton et al. 2016).

Forests managers have to decide specific strategies to cope with CC in conditions of risk and uncertain results of adaptive measures. Knight (1921) stated how we are in a world of "uncertainty" (unknown probabilities) rather than "risk" (known probabilities). The uncertainty "contributes to great differences of opinion as to the appropriate policy response [to CC], with some experts seeing little or no threat and others finding cause for immediate, extensive action" (Congressional Budget Office 2005). In fact, as confirmed by Lindner et al. (2014), a communication gap often exists between scientists and forest managers for the interpretation of impact scenarios and their implication for forests.

Scientific literature addresses the importance of considering the risk and uncertainty in the assessment of management strategies and policies for adaptation to CC. Nevertheless, there has been limited discussion on specific methods for uncertainty quantification. Markov chain approach was applied to assess the magnitude of uncertainties due to CC and forest management related to carbon storage in Finland forest until 2050 (Vauhkonen and Packalen 2018). Monte-Carlo simulation was applied to evaluate the feasibility of afforesting erodible land in New Zealand, in uncertain climatic condition (Monge et al. 2018).

A useful approach is to explore knowledge and skills of experts to elicit uncertainty due to CC im-

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pact on forest ecosystem services. Thus, the intangibility and vagueness of some modelled parameters can be treated. The experts – using their knowledge – can fill the lack of information to provide a quick and insightful uncertainty assessment, in particular through collective judgment (Donlan et al. 2010, Martin et al. 2012). Different techniques have been applied within this framework: simple interviews, quantitative modelling as well as scenario-building informed by expert knowledge were used to evaluate short to long-term climate driven perturbations in forests (Munji et al. 2014, Price et al. 2012). Cerroni and Douglass Shaw (2012) introduced the exchangeability method to assess the influence of CC on pine beetle impacts in forests. Choice experiments (elicited-choice probability) were also carried out to evaluate public preferences and uncertainty for biodiversity conservation, climate-change mitigation policy and trade-offs in multiple-use land management (Shoyama et al. 2013). Probabilistic (Bayesian) approaches were applied in combination with elicited expert opinion (e.g., Gonzalez-Redin et al. 2019). To overcome the limits of the Bayesian approach, some authors introduced the Dempster-Shafer (DS) theory of evidences (possibilistic approach) in CC impact assessment (Luo and Caselton 1997, Bernetti et al. 2011). In comparison to the "probabilistic" as well as "possibilistic" uncertainty, the so-called "fuzzy uncertainty" deals with ambiguities that are often based on qualitative knowledge. In other words, fuzzy set theory allows for management of uncertainty resulting from: (i) vague definitions (Kangas and Kangas 2004) and (ii) the lack of knowledge about something that cannot be precisely defined or measured (Phillis and Andriantiatsaholiniaina 2001).

In real decisions, the experts express their ideas using linguistic descriptors. In order to deal with the uncertainty regarding the expert subjective assessments, many decision-making models based on linguistic approaches have been developed (Wu and Xu 2016). Zadeh (1975) introduced the concept of "linguistic variable" as *«a variable whose values are not numbers but words or sentences in a natural or artificial language»*. To "translate" linguistic variables into numerical operators, it is necessary to choose appropriate linguistic descriptors.

Among different approaches explained in literature (Rodrìguez and Martínez 2013), here the innovative method of Hesitant Fuzzy Linguistic Terms Set (HFLTS) is applied (Rodrìguez et al. 2014). HFLTS are useful compared to classical fuzzy techniques because they are close to the linguistic structures used by humans to provide their assessment in real-world problems. With HFLTS an interviewed can affirm its subjective opinion even if she/he is not able to assess one single linguistic variable because of indecision (hesitant behavior).

The purpose of this work was to identify a method for the elicitation of expert opinions about the impacts of CC on the supply of forest ecosystem services (in particular, recreational service).

In the present work, the HFLTS were tested for the identification of potential impact of CC in the provision of cultural ecosystem services (CES) for different time horizons. The case study is the Tuscany region (central Italy). The study area was chosen to test the method in a context with strong forest variability in terms of geomorphological as well as vegetational conditions. Furthermore, in Italy the implementation of the EU funds available for particular forestry intervention for CC adaptation (e.g. measures related to Common Agricultural Policy) are delegated to the regions (Eurostat classification: NUTS-2). In synthesis, the main features of the proposed method are: (i) the explicit assessment of the uncertainty related to both impact of CC on CES and elicitation of the individual expert; (ii) the efficient aggregation of the experts' opinions as well as the evaluation of the degree of consensus reached; (iii) the use of natural language in expert evaluations; (iv) the possibility of transforming natural language into cardinal evaluation.

Methodology

The Fuzzy Hesitant Linguistic Term Sets: the elicitation of opinion

The usual approach to define the linguistic descriptors of linguistic variables are the membership functions (Yager 1995, Bordogna and Pasi 1993, Tong and Bonissone 1980). In the membership functions (that can have different forms e.g., triangular or trapezoidal) fuzzy numbers are usually defined in the interval [0,1].

Rodríguez et al. (2012) show how to generate comparative linguistic expressions by using a simplified grammar. It may generate comparative linguistic expressions similar to the expressions used by experts in evaluation problems. The objective is to define a grammar that generates simple but rich linguistic expressions that can be easily represented by means of HFLTS.

Given the set of the linguistic term *S*={*Nothing*, *Very bad*, *Bad*, *Medium*, *Acceptable*, *Good*, *Complete*, *Light improvement*, *Improvement*, *Sure Improvement*} some linguistic expressions can be obtained using the statements *G*={*lower than*, *greater then*, *between … and*}. It might be:

good = {*Good*}

lower than medium = {*Nothing*, *Very bad*, *Bad*, *Medium*};

greater than complete = {*Light improvement*, *Improvement*, *Sure Improvement*};

between medium and good = {*Medium*, *Acceptable*, *Good*}.

Considering the basis of the fuzzy linguistic approach in which the linguistic terms have defined a syntax and fuzzy semantics, it seems suitable that the semantics of the comparative linguistic expressions are represented by fuzzy membership functions. Hence, to build the new fuzzy trapezoidal number representing the fuzzy membership functions of the linguistic terms of the HFLTS, the triangular fuzzy numbers referring to the subset of linguistic terms have been aggregated by using the ordered weighted averaging (OWA) operator (for a complete description of the OWA operator see Yager 1988). Fig. 1 shows some examples of evaluation using HFLTS aggregated by the OWA operato

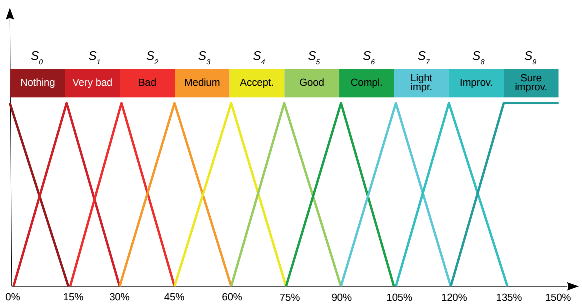

Figure 1 - Some examples of evaluation using HFLTS.

HFLTS are an efficient way to preserve the uncertainty associated with expert evaluations. Fig. 2 shows an example of the growing uncertainty expressed by an expert in evaluating the supply of ecosystem services for a given forest. The effects of CC is considered for increasing periods from the current year. The range of the triangular number is proportional to the uncertainty expressed by the expert.

Aggregation of expert evaluations

Conflict and agreement are typical issues in a group decision environment due to different opinions of the experts. Thus, the aggregation of expert opinion needs a method for quantification of group consensus (Mardani et al. 2018). In this paper, the similarity measure between fuzzy numbers proposed by Lee (2002) is applied.

Let be a positive trapezoidal fuzzy number representing j[th] subjective estimate of expert A and the subjective estimate of expert B. The distance between A and B for the estimate *j* is:

$$d_p(A_j, B_j) = \left(\sum_{k=1}^{4}\left(\left|a_{A,j}^k - a_{B,j}^k\right|\right)^p\right)^{\left(\frac{1}{p}\right)} \quad [1]$$

with *p* metric of distance (p=1 is the distance of Manhattan, p=2 is the Euclidean distance, p=3 is the p-distance and p= distance of Chebyshev). Let *u* be the difference between the minimum and maximum value in the fuzzy linguistic terms set *;* the similarity between A and B for the estimate *j* can be defined as:

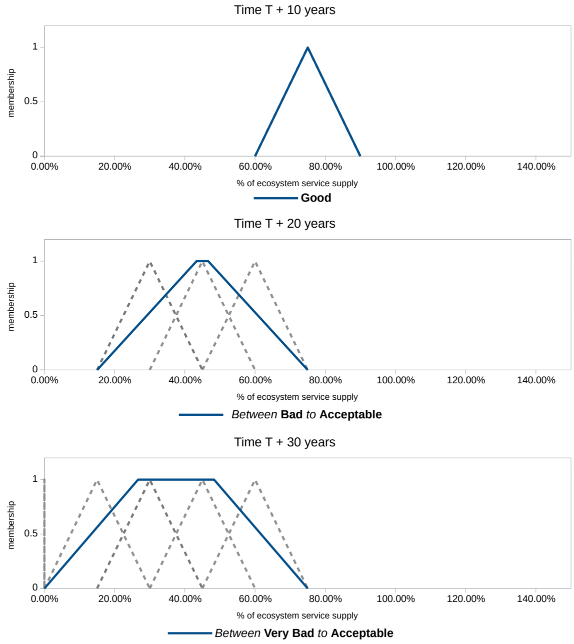

Figure 2 - Example of evaluation through HFLTS with increasing uncertainty.

$$S_p(A_j, B_j) = 1 - \frac{1}{4u^p} d_p(A_j, B_j)^p \quad [2]$$

For all estimates, we computed the average agreement degree *C* of expert E_i for a group of *n* experts (i.e. i = (1,2,...,n) by averaging the degrees of similarity with respect to other experts:

$$C_i = \frac{1}{n-1} \sum_{k \neq i}^{n} \sum_{j=1}^{m} S_p(E_i, E_k) \quad [3]$$

Finally, to calculate the fuzzy number representing the aggregate estimate of the expert group, a weighted average of the *n* estimates is carried out:

$$\tilde{R}_j = \left\{\sum_{i=1}^{n} w_i\, a_{i,j}^1; \sum_{i=1}^{n} w_i\, a_{i,j}^2; \sum_{i=1}^{n} w_i\, a_{i,j}^3; \sum_{i=1}^{n} w_i\, a_{i,j}^4\right\} \quad [4]$$

where w_i represents the aggregation weight of E_i (without considering i-th expert's degree of importance) given by:

$$w_i = \frac{C_i}{\sum_{i=1}^{n} C_i} \quad [5]$$

The value of Group Hesitant Fuzzy Linguistic Terms

The final phase of the method consists in transforming the valuations of the experts formulated as fuzzy numbers, into non-fuzzy values (crisp), keeping the information relative to the uncertainty expressed by the experts. Following the literature (Fenton and Wang 2006) the key concepts that we used for this transformation are the level of confidence and the attitude to risk.

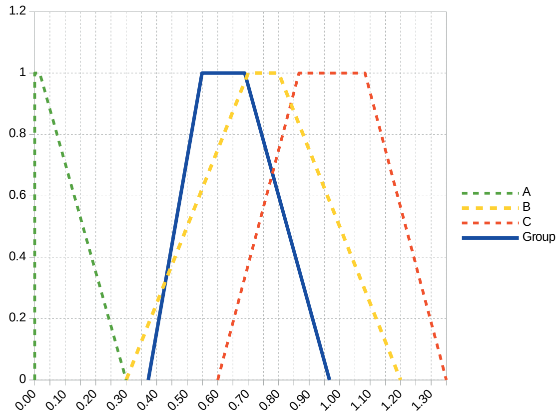

Figure 3 - Example of aggregation of opinion for 3 experts.

In statistics the level of confidence indicates the probability of a certain event. In fuzzy logic the equivalent concept is represented by the α-cut (probabilistic confidence) (Salicone 2007) represented in Fig. 4a. The importance of representing a fuzzy variable in terms of its α-cuts is that the α-cuts of a fuzzy variable and the corresponding levels α can be considered as a set of intervals of confidence: α value close to 0 means that there is a high level of confidence about the phenomenon to be evaluated. In the elicitation of experts we used the confidence level reported in Tab. 1. The effect of more or less high alpha cut values (corresponding to more or less high levels of confidence) is to increase the spread between minimum and maximum expected value in the impact of CC, as shown in Fig. 4b. In other words, the alpha cut confidence level is a complementary way to consider uncertainty with respect to HFLTS: the expert can express the uncertainty regarding a specific assessment (for example the impact of CC on a single forest type) using one or more linguistic terms in defining the HFLTS. Moreover, through the alpha cut the expert can express his level of uncertainty on the whole evaluation problem or on subsets of the whole evaluation problem (for example the impact of CC on all forest types for time horizons more or less far in the future).

Table 1 - Confidence levels.

Confidence level	α value
Absolutely confident	1
Fairly confident	0.75
Neutral	0.5
Fairly non-confident	0.25
Absolutely non-confident	0

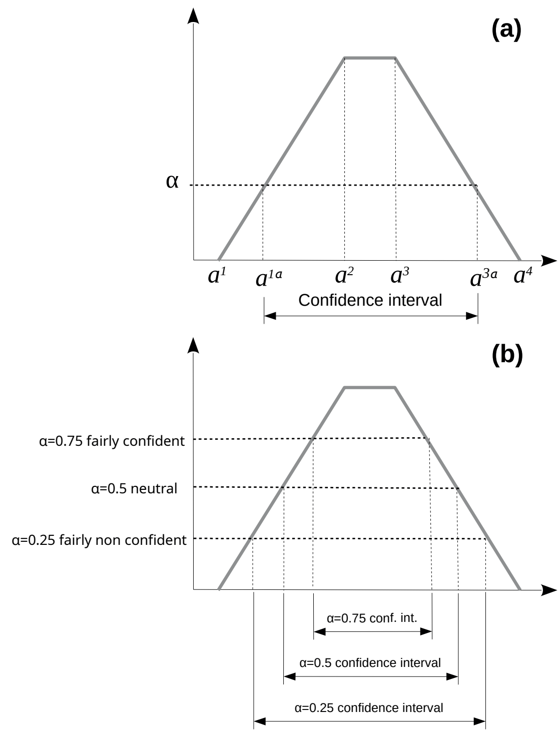

Figure 4 - cut and confidence interval.

Finally, the notion of "risk aptitude" is introduced in the method. Risk aptitude is the behavior of decision-makers, corresponding to trade-off between uncertainty in payoff and expected payoff. As example a risk averse individual seems willing to take on low risks in the hope of even low returns (viceversa for risk seeking individuals) (Tobler and Weber 2014). In decisions under risk, the decision-maker knows with precision the probability distribution of possible outcomes. In decisions under uncertainty, the decision-maker is not provided such information but must assess the probabilities of potential outcomes with some degree of vagueness (Fox and Poldrack 2014). As adaptation decisions often involve considerable uncertainties, stakeholders and decision-makers risk perception may, in some cases, become important. Furthermore, different stakeholders may have different perceptions of the consequences of alternative adaptation measures, reflecting their specific interests in relation to the affected case. This may contain more ambiguity than in other elements of the uncertainty chain (Refsgaard et al. 2013). Risk attitude may have an effect on decision-making, especially in conditions that involve risk and uncertainty (Keil et al. 2000). In addition, decision-makers need to have quantifiable result instead of fuzzy values to be able to use expert evaluations in Cost Benefit Analysis of adaptation measures.

Therefore, the last phase of the method aims to convert the trapezoidal fuzzy number to a unique scalar value (crisp) of the impacts of CC taking into account the uncertainty expressed by the expert group and the risk

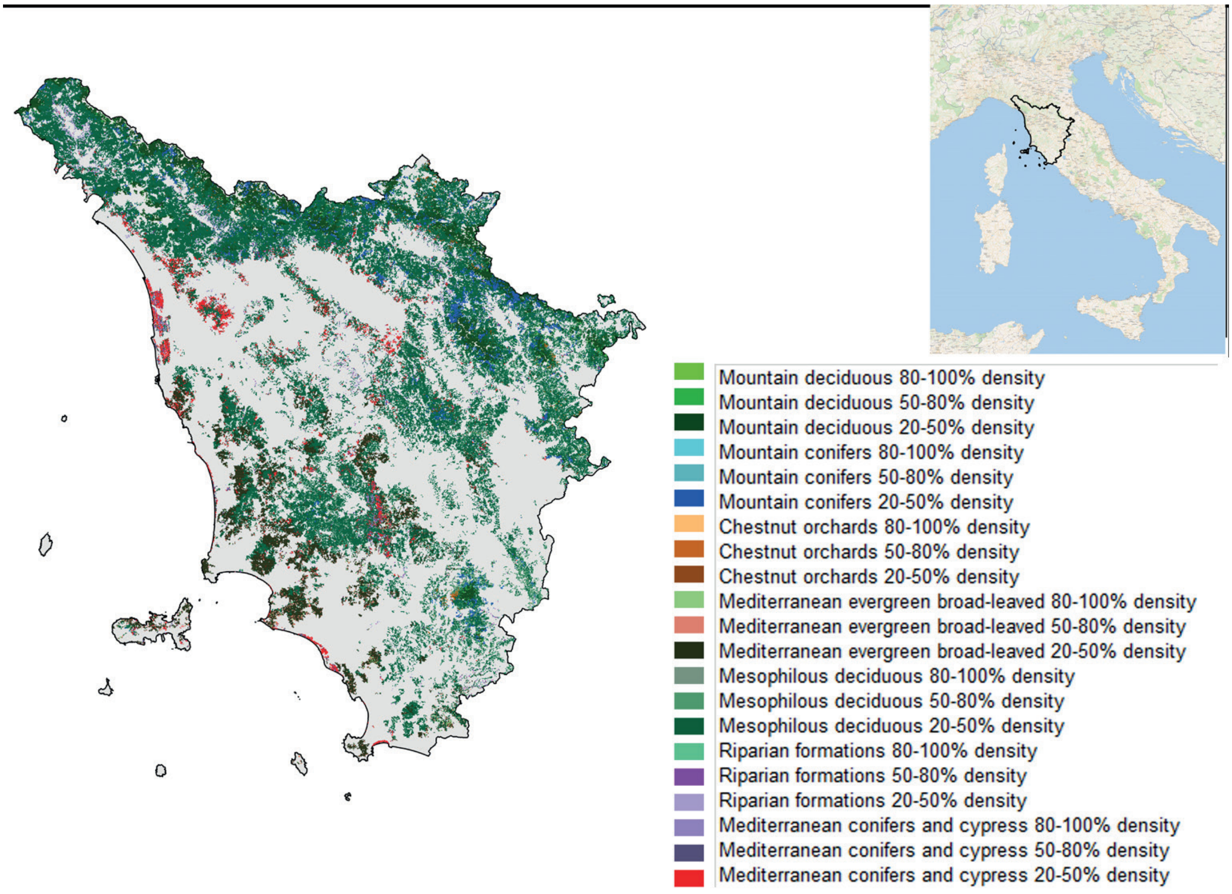

Figure 5 - Study area with forest type and stands density according to maps from Tuscany Region (2018).

attitude of the decision-maker.

The approach proposed by Liou and Wang (1992) was modified to incorporate the confidence level. Given a α-cut trapezioidal numbers representing jth subjective estimate of expert group, the scalar (crisp) value V_j is:

$$V_j = (1-\lambda)\frac{a_j^{1\alpha}+a_j^2}{2} + \lambda\frac{a_j^{3\alpha}+a_j^4}{2} \quad [6]$$

where λ∈[0,1] is an index that represents the degree of risk attitude of a decision-maker. A larger λ indicates a higher degree of risk attitude. More specifically, λ=0.25 represents a fairly risk adverse decision-maker, λ=0.75 represents a decision-maker with a fairly high risk attitude and λ=0.5 represents a neutral decision-maker.

Case study

The method is tested in a preliminary and illustrative case study for the evaluation of the CC impact on CES in the Tuscany region (Italy). The forested area of Tuscany is 1’086’000 hectares, equal to 47% of the regional territory. Forests are mainly composed by deciduous oaks (primarily Turkey oak and downy oak with 414’000 ha), followed by forests with a prevalence of chestnut (177’000 hectares). The mountainous territory is characterized by European beech (76’000 ha), firs (14’000 ha) and black pine (21’000 ha). In the coastal area, holm oak (87’000 ha), Mediterranean scrub (11’000 ha) and Mediterranean pines (e.g., Italian umbrella pine and Maritime pine, 44’000 ha) are widespread (our elaboration on data from Tuscany Region 2018). With regard to the forest management, there is a clear prevalence of coppice (66%) – compared to high forest (34%) – more concentrated in mountainous forests, especially in European beech (INFC 2005). Fig. 5 shows the distribution of forest species in the study region. In this case study, three experts (shortly, A, B, and C) were asked to elicit their opinion about potential impact of CC on CES for forest type reported in Fig. 5. The experts were selected according to their high degree of experience in the analysed topic from both the theoretical and empirical viewpoint. The interviewed A is a university full professor expert in forest economics and recreation monetary evaluation; interviewed B is a university full professor expert in silviculture and forest phytosociology and the expert C is an administrator of a regional forest park. Six scenario were evaluated combining: (i) the presence/absence of adaptation to CC (current practices or CC-oriented forest management); (ii) evaluation of three time horizons at T+10, T+20 and T+30 years with T current year. Taking into account current practices, a typical and widespread

Table 2 - Numbers of terms used in experts evaluations.

			Number of terms				Uncertainty (average of used terms)
Expert	*Adaptation*	*Horizon*	*1*	*2*	*3*	*4*	
A	With	T+10	20	1	0	0	1.05
		T+20	20	1	0	0	1.05
		T+30	0	20	1	0	2.05
	Without	T+10	8	8	5	0	1.86
		T+20	9	11	1	0	1.62
		T+30	9	11	1	0	1.62
B	With	T+10	3	17	1	0	1.90
		T+20	0	10	11	0	2.52
		T+30	10	11	0	0	1.52
	Without	T+10	10	4	7	0	1.86
		T+20	0	10	4	7	2.86
		T+30	10	4	7	0	1.86
C	With	T+10	11	10	0	0	1.48
		T+20	2	19	0	0	1.90
		T+30	3	16	2	0	1.95
	Without	T+10	0	11	5	5	2.71
		T+20	1	9	11	0	2.48
		T+30	2	9	8	2	2.48

forest treatment for Tuscany coppices is clear cutting with standards. This type of intervention is mainly focused on productive services. Firewood is the main assortment, in particular in oak, European beech and other broadleaves coppices. Small dimension timber poles are also produced in coppices (e.g., in chestnut stands). High forests are usually managed with clear or strip cutting on small surfaces. Roundwood and other assortments can be obtained from these interventions. CC-oriented forest management scenario involves mixed and specific interventions seeking to increase stand stability and resilience to CC as reported in scientific literature (Lidner et al. 2008, Hemery 2008, Brang et al. 2014, Sohn et al. 2016, Sferlazza et al. 2017). Among CC-oriented practices focused on recreational activities, conversion from coppice to high forest, reforestation as well as low intensity and selective thinning can be suggested. In general, a species-based and structural diversification of the forest should be promoted also maintaining accessibility and fruition of stands.

One of the potential strengths for the proposed method is the relationship between the evaluations with the monetary value of CES. To verify this statement, the results of the case study are applied to the map of CES' economic value (focused on recreational aspects) calculated by Bernetti et al. (2013). This map considered the total value of tourism in regional protected areas, the value of hunting and mushroom gathering as well as the impact of the tourist spending on the local economy.

The map of the economic impact on CES is obtained by multiplying the perceived impact due to CC – here computed – with the current recreational value from Bernetti et al. (2013).

Results

The combination of seven forest types, three density classes, two adaptation scenarios and three time horizons lead to a total of 378 evaluations. All experts declared that they were "Fairly confident" (α=0.75) for the time horizon T+10, "Neutral" (α=0.5) for the horizon T+20 and "Fairly non-confident" (α=0.25) for the horizon T+30. Output shows how the uncertainty defining each HFLTS - measured by the number of terms in Tab. 2 - increases

Table 3 - Consensus evaluation.

	Exp A	Exp B	Exp C	Total (weights)
Exp A	-	0.80	0.92	0.86
Exp B	0.80	-	0.85	0.82
Exp C	0.92	0.85	-	0.88
Overall	-	-	-	0.86

Table 4 - Percentage of residual supply of CES by forest type.

Forest type	With adaptation T+10	With adaptation T+20	With adaptation T+30	Without adaptation T+10	Without adaptation T+20	Without adaptation T+30
Mediterranean evergreen broad-leaved 80-100% density	67%	61%	56%	58%	49%	42%
Mediterranean evergreen broad-leaved 50-80% density	67%	61%	56%	63%	53%	43%
Mediterranean evergreen broad-leaved 20-50% density	75%	63%	55%	73%	61%	51%
Mesophilous deciduous 80-100% density	67%	61%	52%	58%	49%	41%
Mesophilous deciduous 50-80% density	67%	61%	52%	63%	53%	42%
Mesophilous deciduous 20-50% density	75%	63%	55%	73%	61%	51%
Chestnut orchards 80-100% density	62%	56%	47%	58%	49%	41%
Chestnut orchards 50-80% density	64%	58%	50%	66%	55%	46%
Chestnut orchards 20-50% density	73%	63%	55%	73%	61%	51%
Mountain deciduous 80-100% density	62%	61%	50%	53%	49%	37%
Mountain deciduous 50-80% density	62%	61%	52%	63%	59%	46%
Mountain deciduous 20-50% density	69%	58%	55%	69%	55%	53%
Riparian formations 80-100% density	75%	63%	60%	73%	61%	56%
Riparian formations 50-80% density	75%	63%	60%	73%	61%	56%
Riparian formations 20-50% density	75%	63%	60%	73%	61%	56%
Mediterranean conifers and cypress 80-100% density	62%	54%	47%	53%	42%	39%
Mediterranean conifers and cypress 50-80% density	62%	56%	47%	60%	49%	42%
Mediterranean conifers and cypress 20-50% density	72%	56%	50%	69%	59%	52%
Mountain conifers 80-100% density	67%	58%	51%	63%	49%	41%
Mountain conifers 50-80% density	73%	63%	55%	69%	57%	46%
Mountain conifers 20-50% density	75%	67%	58%	73%	65%	55%
Average	69%	61%	54%	66%	55%	47%

with the increase of the time horizon for all three experts. From the scenario viewpoint, adaptation measures reveal less uncertainty than projection without measures (Tab. 2); assertions for T+10 interval are less hesitant in respect to T+20 and T+30 (a few differences are revealed for these two time horizons). Finally, experts B and C express in all the assessments greater uncertainty than the expert A (Tab. 2). In general, the three experts reveal a certain agreement in their perception probably due to a common background. Differences in elicitation are presumably dependent on current specialization as well as professional activities of the interviewed.

Tab. 3 shows the results of the consensus evaluation among the experts. The total consensus is 0.86. Brunelli et al. (2014) fix the acceptable level of consensus at 0.7; therefore, a result of 0.86 can be considered satisfactory. The major differences in evaluations were between experts A and B and the greater agreement between experts A and C. The overall weights are therefore quite similar to each other.

Tab. 4 shows the supply percentage of CES, compared to the current value (T+0 year) for all 21 typologies of forest. Results were aggregated with a neutral attitude about the uncertainty (λ=0.5 in eq. [6]). Average residual supply of CES decreases from 69%, to 61% and 54% in case of adaptation measures (for T+10, T+20 and T+30, respectively). CES delivery percentage is 66%, 55% and 47% without adaptation strategies. When adaptation strategies are applied, the greater decrease of CES provision is highlighted for Mountain deciduous at T+10 as well as Mediterranean conifers and cypress at T+20. At time T+30 the above forest types with the Chestnut orchards are the most impacted. The trend is similar in case of adaptation absence, with a strong impact for Mountain deciduous at T+30 (63% of CES reduction). In general, low level of impact are stressed at T+10 for Mediterranean evergreen broad-leaved, mesophilous deciduous, chestnut orchards, riparian formations and Mountain conifers. Mountain conifers and riparian formations are less impacted at

Table 5 - Confidence intervals by forest type.

	With adaptation					
	Minimum T+10	Maximum T+10	Minimum T+20	Maximum T+20	Minimum T+30	Maximum T+30
Mediterranean evergreen broad-leaved 80-100% density	54%	79%	50%	76%	45%	75%
Mediterranean evergreen broad-leaved 50-80% density	54%	79%	50%	76%	45%	75%
Mediterranean evergreen broad-leaved 20-50% density	64%	84%	53%	78%	46%	71%
Mesophilous deciduous 80-100% density	54%	79%	50%	76%	41%	71%
Mesophilous deciduous 50-80% density	54%	79%	50%	76%	41%	71%
Mesophilous deciduous 20-50% density	64%	84%	53%	78%	46%	71%
Chestnut orchards 80-100% density	49%	74%	45%	71%	36%	66%
Chestnut orchards 50-80% density	54%	74%	48%	73%	41%	66%
Chestnut orchards 20-50% density	64%	79%	53%	78%	46%	71%
Mountain deciduous 80-100% density	49%	74%	50%	76%	41%	66%
Mountain deciduous 50-80% density	49%	74%	50%	76%	41%	71%
Mountain deciduous 20-50% density	59%	79%	48%	73%	46%	72%
Riparian formations 80-100% density	64%	84%	53%	78%	51%	77%
Riparian formations 50-80% density	64%	84%	53%	78%	51%	77%
Riparian formations 20-50% density	64%	84%	53%	78%	51%	77%
Mediterranean conifers and cypress 80-100% density	49%	74%	45%	65%	36%	66%
Mediterranean conifers and cypress 50-80% density	49%	74%	45%	71%	36%	66%
Mediterranean conifers and cypress 20-50% density	60%	81%	45%	71%	42%	66%
Mountain conifers 80-100% density	54%	79%	45%	76%	40%	70%
Mountain conifers 50-80% density	64%	79%	53%	78%	46%	71%
Mountain conifers 20-50% density	64%	84%	58%	78%	51%	71%
	Without adaptation					
	Minimum T+10	**Maximum T+10**	**Minimum T+20**	**Maximum T+20**	**Minimum T+30**	**Maximum T+30**
Mediterranean evergreen broad-leaved 80-100% density	42%	80%	37%	74%	33%	70%
Mediterranean evergreen broad-leaved 50-80% density	50%	81%	42%	73%	34%	71%
Mediterranean evergreen broad-leaved 20-50% density	64%	84%	53%	78%	46%	66%
Mesophilous deciduous 80-100% density	42%	80%	37%	74%	33%	64%
Mesophilous deciduous 50-80% density	50%	81%	42%	73%	35%	65%
Mesophilous deciduous 20-50% density	64%	84%	53%	78%	46%	66%
Chestnut orchards 80-100% density	42%	80%	37%	74%	33%	64%
Chestnut orchards 50-80% density	55%	81%	45%	75%	40%	65%
Chestnut orchards 20-50% density	64%	84%	53%	78%	46%	66%
Mountain deciduous 80-100% density	37%	75%	37%	74%	30%	60%
Mountain deciduous 50-80% density	50%	81%	50%	76%	40%	65%
Mountain deciduous 20-50% density	59%	84%	45%	75%	46%	72%
Riparian formations 80-100% density	64%	84%	53%	78%	51%	72%
Riparian formations 50-80% density	64%	84%	53%	78%	51%	72%
Riparian formations 20-50% density	64%	84%	53%	78%	51%	72%
Mediterranean conifers and cypress 80-100% density	37%	75%	29%	66%	31%	63%
Mediterranean conifers and cypress 50-80% density	46%	77%	37%	74%	35%	65%
Mediterranean conifers and cypress 20-50% density	59%	84%	50%	76%	47%	66%
Mountain conifers 80-100% density	50%	81%	37%	74%	33%	64%
Mountain conifers 50-80% density	59%	84%	48%	78%	40%	65%
Mountain conifers 20-50% density	64%	84%	58%	78%	51%	66%

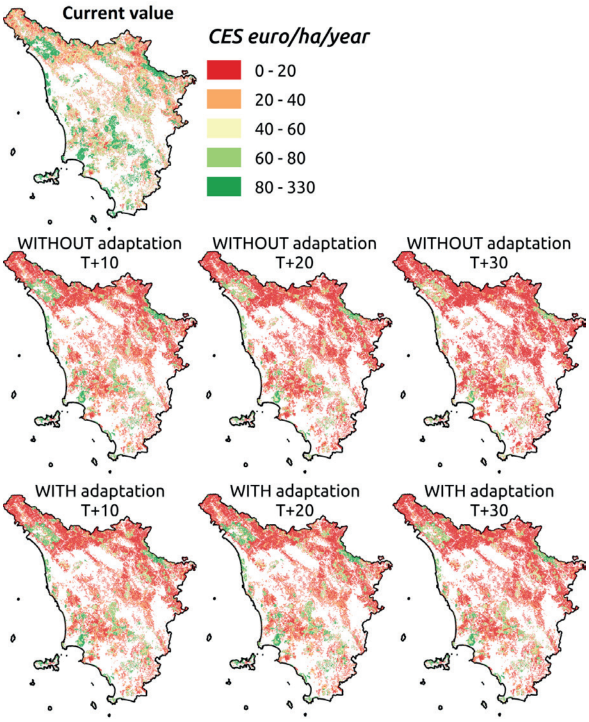

Figure 6 - Changes in supply of cultural ecosystem services (CES).

T+20 and T+30, respectively.

Highly dense stands seem to be more impacted in all scenario. In particular - without adaptation strategies - class density has a strong weight in decreasing of CES delivery for conifers (both Mountainous and Mediterranean ones) and other forest types (e.g., Mediterranean evergreen broad-leaved). Forest experts probably perceived the risk due to extreme climatic or biotic events such as pathogen infestation or storm for young or highly dense stand of conifers as well as fire risk in not-managed Mediterranean woodlands. The application of adaptation strategies stands out the importance of average climatic modification. In fact, density highlights a certain influence for types such as Chestnut and Mountainous conifers, more sensible to temperature and precipitation modification in respect to other forest important for CES delivery.

Tab. 5 shows the confidence intervals of the evaluations for forest type, time horizon and presence/absence of adaptation. The results show that silvicultural adaptations reduce uncertainty about the effects of CC on CES. This assertion seems to be particularly true for the longer time horizon (T+30).

Fig. 6 shows the evolution of the monetary value of recreational ecosystem services. The maps show that with the adaptation measures the loss of monetary value decreases in the three time horizons in respect to scenario without adaptation. From monetary viewpoint total potential losses in case of adaptation strategies are 94’497’200 €/year, 110’221’800 €/year and 134’036’800 €/year for T+10, T+20 and T+30 scenario, corresponding to 36%, 42% and 52% of total value at T+0. Without adaptation, losses increase at 115’483’400 €/year, 141’065’300 €/year and 164’069’800 €/year (45%, 54% and 63% of total value) for the three time horizons.

Discussion

Preliminary results highlight how – according to expert opinion – the most impacted forest types seem to be the Mountain deciduous, the Mediterranean conifers and cypress as well as the Chestnut orchards. Climatic projection and scenario agree with prediction of increase in average temperatures and decrease of average annual precipitation, with an augmented frequency as well as impact of extreme climatic events. The combination of the above factors seems to be critical for mountainous species (e.g., European beech), Chestnut and conifers characterized by tree instability in case of extreme events (in particular for currently widespread unmanaged artificial stands such as cypress forest). Mediterranean conifers are strongly impacted due to sensitivity to CC and due to high current value for CES delivery (as example in case of Italian umbrella pine stand near to seacoast). Outputs reveal a lower impact for other forest types probably due to small weight in CES delivery (e.g., for Mediterranean evergreen broad-leaved and riparian formations) or efficiency of CC-oriented silvicultural practices (e.g., for mesophilous deciduous and mountain conifers). Results suggest intervention aimed at reducing stand density from high to medium-low class, to decrease the risk of extreme biotic and abiotic impacts. Uncertainty increases with length of the time horizon and decreases in case of adaptation strategies application. Average elicited residual value of CES provision is equal to 69%, 61% and 54% with adaptation strategies at T+10, T+20 and T+30, respectively. The comparison with residual economic value (64%, 58% and 48%) highlights how the impact seems to be concentrated in forest types with relevant recreational function. As matter of fact, Mediterranean conifers are concentrated in coastal areas with higher inhabitant-density as well as touristic pressure; mountain deciduous (e.g. European beech) are among the most frequent species in National as well as regional parks in the Apennines. The trend is similar for the three scenario without adaptation strategies but with a greater differences between residual CES provision and residual economic values (about 10% higher), probably due to sensitivity to CC for forest types with high CES economic value.

In order to emphasizes spatial variation in CES delivery according to scenario, a focus on a representative area with high monetary values for CES (“Foreste Casentinesi, Monte Falterona e Campigna” national park) is carried out. Figure 7 shows

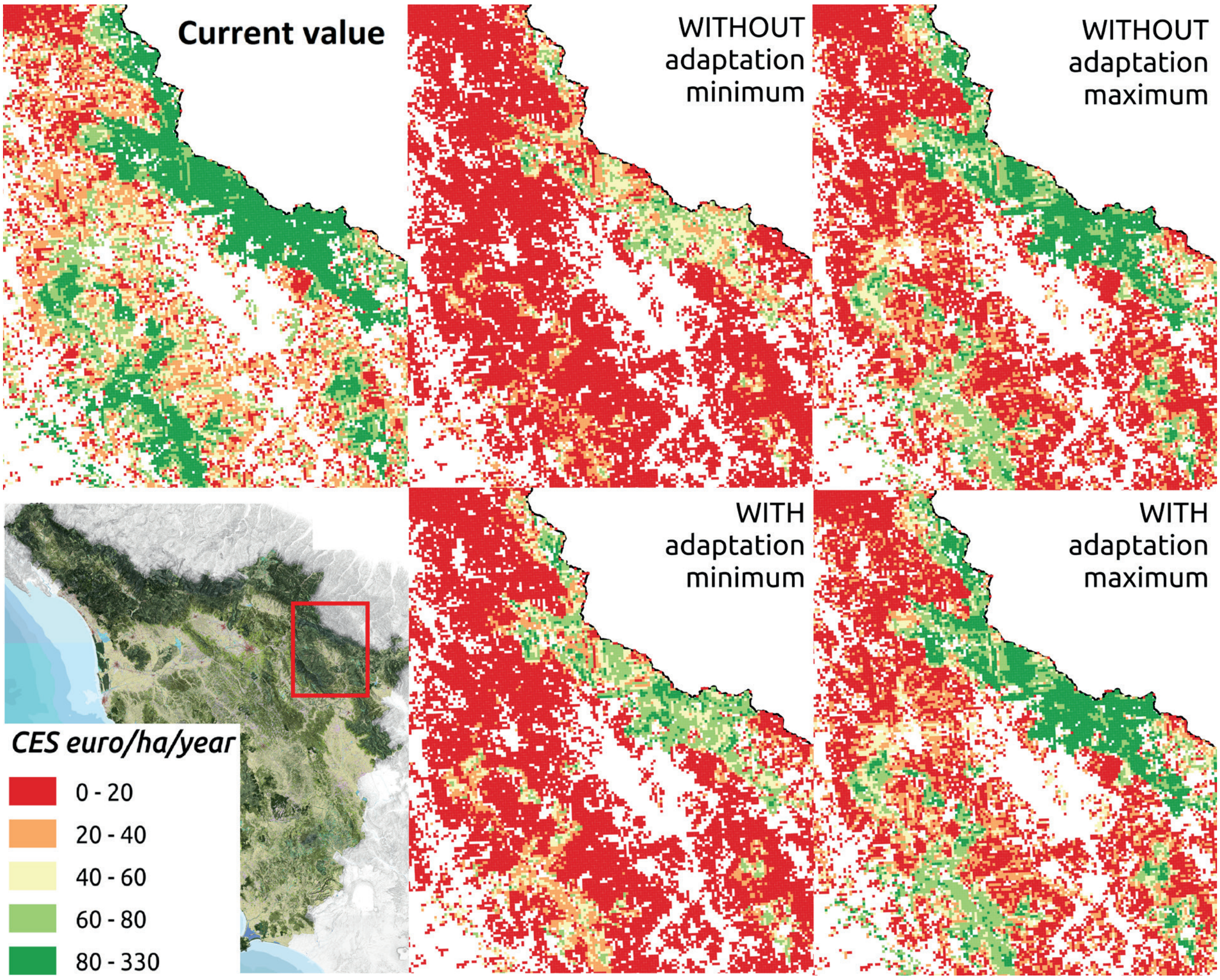

Figure 6 - Confidence intervals in CES delivery: focus on "Foreste Casentinesi, Monte Falterona e Campigna national park.

how the usefulness of silvicultural adaptation measures - in this area but this assertion can be extended to other protected areas in Tuscany - is evident. The map highlights a strong variation in confidence intervals for the T+30 time horizon. According to experts' opinion the adaptation measures reduce the uncertainty on the impact of CC in forests with high recreational value, mainly in the minimum (pessimistic) value of the confidence interval.

Conclusion

The main innovation of the proposed method is the application of the Hesitant Fuzzy Linguistic Term Set (HFLTS) technique for the expression of opinion in CC scenario. Strengths of HFLTS are the quantification of opinion consistency in case of aggregation of different evaluations and the opportunity to compute the level of uncertainty through the confidence intervals of the evaluations. Kangas et al. (2018) reported how the accuracies in ecosystem services assessment is highly influenced by several sources of uncertainty. The authors suggest quantifying this uncertainty and take it into account in the decision-making for forest management. Among different methods to quantify uncertainty in forest ecosystem services analysis (e.g. Bayesian approach; Grêt-Regamey et al. 2013) HFLTS allows to manage the indecision of experts about future and uncertain events such as CC. HFLTS improves communication of results to policy-makers and forest managers. In this way, practical intervention and adaptation strategies can be associated to monetary quantification of expected damages, spatial localization as well as uncertainty in the results, allowing for calibrated management practices.

This work is an explorative early study; the low number of involved experts could be considered as a limit. However, the method only represents the kernel of a more complex decision support system applied to the management of forest adaptation measures. An additional weakness of the HFTLS is connected to the length of interviews. Compared to other probabilistic evaluations (e.g., Bayesian network or Dempster-Shafer approach) with HFLTS the number of elicitations for each expert (126 in our case study) derives from the Cartesian product of variables (i.e., forest type, density, adaptation scenario and time horizon). This aspect can cause a lack of attention of the interviewed during elicitation also depending on the number of items in the applied scale; the investigation of methodologies allowing for quantification of the degree of experts' reliability is suggested in future analysis.

From preliminary results, it seems plausible to concentrate particular attention to forest types with high risk of CES reduction. As example, a focus on suitable silvicultural intervention to mitigate CC impact should be promoted for Mountainous broadleaved and Mediterranean conifers.

Additional future methodological improvements of the work could follow these directions:

- the modelling of expert evaluations regarding the effect of geographical variables (elevation, aspect, slope, etc.) that influences the supply of ecosystem services in CC scenario;
- the evaluation of impacts according to CC scenarios of the IPCC (2014) reports;
- the evaluation of a complete set of ecosystem services;
- using the results of expert evaluations within a multi-criteria analysis in conditions of risk and uncertainty to support forest planning.

In conclusion, the tested technique integrated with the suggested improvements could be an effective decision support system for forest management in complex and uncertain scenarios.

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