Highlights

- The risk of wolf attacks in Umbria's municipalities has been assessed.
- The risk map constructed shows that a high number of municipalities are at high risk.
- AHPSort II, a new risk classification sorting method based on AHP, has been developed.
- It requires far fewer pairwise comparisons than its predecessor, AHPSort.

Sorting municipalities in Umbria according to the risk of wolf attacks with AHPSort II

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ABSTRACT

In Italy, the recent wolf expansion process is the result of a series of historical, natural, ecological and conservation related factors that have characterized the Italian environmental context during the last few decades. The difficulties in broaching the environmental management of the wolf species have increased economic conflicts, mainly with livestock farmers. To facilitate and pacify the debate, an assessment of the risk of wolf attacks on livestock farms in Umbria's municipalities needed to be carried out. For this assessment, AHPSort II, a new multi-criteria sorting method for a large number of alternatives, has been developed. This is used for sorting the alternatives into predefined, ordered risk categories. It requires far fewer comparisons than its predecessor, AHPSort. This sorting method can be applied to different environmental problems that have a large number of alternatives. In our case study, AHPSort II requires only 1.4% of the comparisons that would have been required by AHPSort. Combined with clustering, only 0.54% of the comparisons are required. The resulting map shows that a high number of municipalities are at risk, especially those near protected areas.

Keywords: Multi-criteria Decision Analysis, risk analysis, AHPSort, sorting method, wolf, livestock predation

1. Introduction

Sustainability, risk, quality, environmental or ecological indicators are all based on a large variety of criteria. As a consequence, Multicriteria Decision Analysis (MCDA) has been widely used as it provides a structured, transparent, and reliable indicator (Cinelli et al., 2014). In particular, in order to aggregate tangible and intangible criteria into a unique score, the Analytic Hierarchy Process (AHP) was introduced by (Saaty, 1977). The first step, in using this method, is to structure the problem by identifying the alternatives to evaluate and the criteria on which the alternatives are to be evaluated (Ishizaka and Labib, 2011). Then the criteria and the alternatives are evaluated

pairwise in a matrix. This is the cornerstone of the method, where the decision-maker concentrates their effort on only two elements at a time. Experimental evaluations have demonstrated that the pairwise comparison process is more accurate than a direct evaluation of preferences (Millet, 1997; Whitaker, 2007). AHP has found several applications with regard to environmental management problems (De Felice and Petrillo, 2013; Durberry and Sinclair, 2002), transport sustainability (Campo and Yagüe, 2008), land suitability for cultivation (Chen et al., 2015), water quality assessment (Chiang and Jang, 2007), and the evaluation of racecourses (Blake et al., 2003).

Although AHP has been applied in numerous situations with impressive results (Forman and Gass, 2001; Ho, 2008; Kumar and Vaidya, 2006; Liberatore and Nydick, 2008; Omkarprasad and Sushil, 2006; Sipahi and Timor, 2010), it can also present some problems. In particular, incorporating a large number of alternatives requires an overwhelmingly high number of pairwise comparisons. For example, to compare 100 alternatives, $(100^2 - 100)/2 = 4950$ comparisons are required. If the decision-maker takes only one minute to reflect on each comparison, the process would require 82 hours and 30 minutes, which is about three and half days without interruption. This reflection time should further be multiplied by the number of criteria. This task is therefore not feasible; the expert would become tired, annoyed and lose concentration during this long process. Moreover, AHP has been developed for ranking and selection problems, but it is not adapted to sorting problems. AHPSort (Ishizaka et al., 2012) is a sorting method based on AHP that retains AHP's advantages but reduces the problem of the high number of comparisons. Unfortunately, if the set of alternatives, criteria, and limiting or central profiles analysed are high, the number of comparisons required is also still high. Therefore, as we discuss in this paper, AHPSort II has been developed to overcome the problems with big data, as presented in this case study for evaluating the risk of wolf attacks in Umbria (Italy).

AHPSort II has been complemented by a Geographical Information System (GIS). The GIS is a powerful tool to process spatial and non-spatial data, to overlay different layers or maps and to visualise their combined results (Grosfeld-Nir et al., 2007). This MCDA and GIS combination has already been used for producing land evaluations (Chen et al., 2015), evaluations of environmentally sensitive areas (Soylu and Akyol, 2014), eco-city evaluations (Greco et al., 2006), sustainable environmental monitoring (Zionts and Wallenius, 1976), landscape eco-risk (Geoffrion et al., 1972), and well-being city maps (Ishizaka and Nemery, 2013). In this paper, the integration of AHPSort II and a GIS provide a spatial decision support system offering a risk map of wolf attacks. The economic damage inflicted on livestock farmers, the support of the environmentalists and conservationists for the wolf, and the potential wolf interactions between hunters and wild prey

populations, are all elements that contribute to keeping the wolf at the centre of the continuous debate. The return of the wolf in regions from which it had disappeared for centuries has caused worries and protests from local communities alarmed at possible episodes of predation against domestic livestock (Bisi et al., 2007; Meriggi and Lovari, 1996). It is therefore important to determine which areas are at risk. This study highlights that a high number of municipalities are at risk, especially if they are near a protected area.

2. The status of wolves in Italy

In Italy, the decline of the wolf (*Canis lupus L.*) population started in the 1800s (Boitani, 1992). Wherever humans settled, they persecuted the large predators because of their threat to livestock and as competitors for game species. Administrations even paid bounties to kill them, either by shooting, trapping, or poisoning them. These bounties provide reliable data to support the conclusion that the direct persecution was the primary reason for the decline in the wolf population (Breitenmoser, 1998). Habitat fragmentation, through the destruction of forests, the expansion of cultivated land and roads, was also another substantial reason for its decline (Breitenmoser, 1998; Jaeger et al., 2005; Kaartinen et al., 2005).

The wolf population was at its lowest level around the 1970s, when (Zimen and Boitani, 1975) estimated that there were approximately 100 wolves distributed throughout fragmented areas in Central and Southern Italy – i.e. Abruzzo, Basilicata, and Calabria (Fig. 1). The wolf species survived only in areas where there were consistent flocks (as in Abruzzo, Maremma, and the Southern Apennines) or relict populations of ungulates (as in the forests of the Tosco-Romagnolo Apennines) (Randi et al., 2000).

Fig. 1. Distribution of the wolf in Italy in 1900, 1973 and 1994 (Jaeger et al., 2005).

Since the end of the 1970s, the wolf has been legally protected in Italy, with the prohibition against targeting wolves with poison coming into effect in 1976, and in Europe through the Bern Convention in 1979 (Valière et al., 2003). In the late eighties, the wolf population recovered rapidly in Italy (Fabbri et al., 2007; Marucco and McIntire, 2010). The wolf has never been the subject of reintroduction, repopulation or introduction programmes in Italy or in Europe, in contrast to North America. The recent expansion of the species is the result of a series of historical, natural, ecological, and conservation related factors that have characterized the Italian environment in the last decades and to which the wolf has adapted (Bocedi and Bracchi, 2004). In particular, wild ungulates recovered consistency in their population, in part due to their massive reintroduction (Glenz et al., 2001). Roe deer, red deer, wild boar, fallow deer, and mouflon repopulated the mountains and hills rapidly when they were left free from domestic livestock. The presence of all these natural prey for the wolf encouraged its revival without direct intervention by humans (Bocedi and Bracchi, 2004). The present distribution of the wolf population in Italy (Fig. 2) covers the entire Apennine chain, from Aspromonte to the Maritime Alps (Meriggi et al., 2011).

Fig. 2. Distribution range of wolves in 2004 (Meriggi et al., 2011).

As wolves propagate and kill prey, including species that humans hunt and farm, wolf-human conflicts expanded and intensified as a result of the increase in the wolf population (Graham et al., 2005). The increasing costs of the compensations paid to farmers have forced some regional administrations to reduce or even eliminate these compensations (e.g. Calabria) (Boitani et al., 2010). A report by Berna and Marchi (2014) stated that the compensations are often not enough to cover all the economic consequences, as:

- the economic damage caused by predation concerns not only the loss of the predated animals and their attached market value. It also includes indirect economic losses, such as veterinary fees for the care of injured animals or eventually euthanasia, abortion, termination of milk production, fear of going out to pasture and therefore subsequent maintenance of the animals in the stable (thus wasting feed and time), an increase in the stress experienced by the livestock, compromised health status, and reduced reproduction;
- the value of the damages includes the loss by predation and also the time necessary to replace the predated animals;
- indirect damages arise from the mode of disposal of the carcasses, requiring their removal from the company authorized by the local health authorities, the costs of which are paid by the farmer;
- damages are not adequately compensated – i.e. not according to the real market value;
- the payment of damages does not occur for a minimum of two years due to the excessive bureaucracy and the inadequacy of the available public funds.

The purpose of this analysis is to depict the risk of wolf predation on farm livestock, and in particular cattle, sheep, goats and horses, in the Umbrian municipalities. It is important to understand the risk of wolf predation on livestock in order to properly manage any potential human-wolf conflict.

3. Methodology

Sorting methods are used to assign alternatives to predefined classes. The classes are defined in an ordinal manner based on the decision-makers' preferences. AHPSort is a variant of AHP designed to sort problems (Ishizaka et al., 2012). The necessity for developing a new methodology – AHPSort II (section 3.1) – lies in the fact that applying AHPSort becomes difficult when the number of alternatives considered is high (section 3.2).

3.1. Description

The new method, AHPSort II, is based on nine steps. As any MCDA method, all required inputs in all steps are provided by the same decision-maker. It is a modification of AHPSort, with the first four steps being the same:

Problem definition

- 1) Define the goal, the criteria $c_j, j = 1, \dots, m$ and the alternatives $a_k, k=1, \dots, l$ with respect to the problem.
- 2) Define the classes $C_i, i = 1, \dots, n$, where n is the number of classes. The classes are ordered and are given a label (for example, excellent, good, medium, poor).
- 3) Define the profiles of each class. This can be done with a local limiting profile lp_{ij} , which indicates the minimum performance needed for each criterion j to belong to a class C_i , or with a local central profile cp_{ij} , which is given by a typical example of an element belonging to class C_i based on the criterion j . We need $j \cdot (n - 1)$ limiting profiles or $j \cdot n$ central profiles to define each class.

Evaluation

- 4) Evaluate pairwise the importance of the criteria c_j and derive the weight w_j with the eigenvalue method of the AHP.

$$A \cdot p = \lambda \cdot p \quad (1)$$

where:

A is the comparison matrix;
p is the priorities/weight vector;
 λ is the maximal eigenvalue.

- 5) Select for each criterion j a small number of representative points s_{oj} , $o = 1, \dots, rp_j$, that are well distributed on the scale of each criterion.
- 6) Compare in a pairwise comparison matrix the representative points and the limiting or central profiles. In this step, it is possible to use clusters to further reduce the number of pairwise comparisons (section 3.3). From the comparison matrices, derive the local priority p_{oj} for the representative points and the local priority p_{ij} of the limiting profiles or central profiles with the eigenvalue method in Eq. (1).
- 7) If the alternatives a_k belong to the interval of two consecutive representative points s_{oj} and s_{o+1j} , we can derive the local priority p_{kj} as follows:

$$p_{kj} = p_{oj} + \frac{p_{o+1j} - p_{oj}}{s_{o+1j} - s_{oj}} \cdot (g_j(a_k) - s_{oj}) \quad (2)$$

where:

- s_{oj} and s_{o+1j} are two consecutive representative points on criterion j ;
- p_{oj} and p_{o+1j} are the local priorities of the two consecutive representative points;
- $g_j(a_k)$ is the score of the alternative a_k on criterion j ;
- p_{kj} is the local priority of a_k

For example, Fig.3 depicts 10 representative points on the horizontal axis (i.e. 100, 200, ..., 1000) along with their calculated local priorities on the vertical axis. The whole piecewise linear priority function is then drawn by connecting these points (bold piecewise linear line). If the value of the alternative to be evaluated is 850, the local priority can be graphically found by reading the created graph.

Fig.3. Example of how to find the local priority of alternative a_k using Eq. (2).

Assignment to classes

- 8) Aggregate the weighted local priorities, which provide a global priority p_k for alternative k , (Eq. (3)) and a global priority lp_i for the limiting profile or cp_i for the central profiles (Eq. (4)).

$$p_k = \sum_{j=1}^m p_{kj} \cdot w_j \quad (3)$$

$$lp_i \text{ or } cp_i = \sum_{j=1}^m p_{ij} \cdot w_j \quad (4)$$

The comparison of p_k with lp_i or cp_i is used to assign alternative a_k to a class C_i :

- (a) Limiting profiles: If limiting profiles have been defined, alternative a_k is assigned to the class C_i which has an lp_i just below the global priority p_k . See Fig. 4(a).

$$p_k \geq lp_1 \Rightarrow a_k \in C_1$$

$$lp_2 \leq p_k < lp_1 \Rightarrow a_k \in C_2$$

...

$$p_k < lp_{n-1} \Rightarrow a_k \in C_n$$

Fig. 4. Sorting with limiting profiles (a) and central profiles (b).

(b) Central profiles: The limiting profiles can be deduced by $(cp_i + cp_{i+1})/2$. The alternative a_k is assigned to the class C_i which has the nearest central profile cp_i to p_k – see Fig. 4(b). In the case of there being an equal distance between two central profiles, the optimistic assignment version allocates a_k to the upper class, while the pessimistic assignment version allocates a_k to the lower class.

$$p_k \geq cp_1 \Rightarrow a_k \in C_1$$

$$cp_2 \leq p_k < cp_1 \text{ AND } (cp_1 - p_k) < (cp_2 - p_k) \Rightarrow a_k \in C_1$$

$$cp_2 \leq p_k < cp_1 \text{ AND } (cp_1 - p_k) = (cp_2 - p_k) \Rightarrow a_k \in C_1 \text{ in the optimistic version}$$

$$cp_2 \leq p_k < cp_1 \text{ AND } (cp_1 - p_k) = (cp_2 - p_k) \Rightarrow a_k \in C_2 \text{ in the pessimistic version}$$

$$cp_2 \leq p_k < cp_1 \text{ AND } (cp_1 - p_k) > (cp_2 - p_k) \Rightarrow a_k \in C_2$$

...

$$p_k < cp_n \Rightarrow a_k \in C_n$$

9) Repeat steps 5 to 9 for each alternative to be classified.

Fine tuning

10) As AHPSort II uses linear approximation in (2), it is important to have a fine tuning to check the alternatives that are just above and below the limiting profiles with AHPSort, to have an exact classification. If they have the same classification as AHPSort, then the AHPSort II classification is correct and the process is terminated. Otherwise, the next

alternatives above or below the first checked alternative needs to be also classified with AHPSort until the classification is equal to the AHPSort II classification.

3.2. Number of comparisons

The high number of comparisons is a well-known problem of AHP. In fact, with l alternatives, $\frac{l \cdot (l-1)}{2}$ pairwise comparisons are necessary for each criterion considered. The increase in the number of comparisons is quadratic. For m criteria, the total number of pairwise comparisons is:

$$m \cdot \frac{l \cdot (l-1)}{2} \quad (5)$$

In AHPSort, the number of comparisons is reduced. The b limiting or central profiles need first to be compared between themselves: $\frac{b \cdot (b-1)}{2}$. Then, the l alternatives are compared to the b profiles. Finally, this is repeated for all m criteria:

$$m \cdot \left[\frac{b \cdot (b-1)}{2} + (b \cdot l) \right] \quad (6)$$

However, the number of comparisons is still high for a high number of alternatives and limiting profiles.

In AHPSort II (section 3.1), the number of pairwise comparisons does not depend on the number of alternatives, but only on the number of profiles b and representative points rp_j . The representative points – the number of which may vary according to the criterion j – and the b profiles are pairwise compared for each criterion:

$$\sum_{j=1}^m \frac{(b+rp_j) \cdot (b+rp_j-1)}{2} \quad (7)$$

where: rp_j = number of representative points for criterion j

m = number of criteria

b = number of profiles

To illustrate the advantages of this new method in terms of reducing the number of pairwise comparisons asked of the decision-maker, Table 1 shows the number of evaluations that the case study of this paper would require.

Table 1 Number of pairwise comparisons for AHP, AHPSort and AHPSort II.

Data			
No. of alternatives l	No. of criteria m	No. of limiting profiles rp_j	No. of representative points on criterion j
92	9	3	(8, 8, 8, 5, 8, 13, 9, 7, 6)
Calculation			
Method	AHP (5)	AHPSort (6)	AHPSort II (7)
Number of pairwise comparisons	37674	2511	515

3.3. Clustering to reduce of the number of entries

The cluster and joining point method is a useful technique with matrices of high rank, when the number of pairwise comparisons becomes overwhelming (Ishizaka, 2012). It is based on four steps:

- For each criterion, the representative points and limiting or central profiles are selected (section 3.1).
- Representative points and limiting or central profiles are divided into clusters. Psychologists have observed that it is difficult to evaluate more than seven elements (Saaty and Ozdemir, 2003). Therefore, it is recommended to build clusters that do not contain more than seven elements (Ishizaka, 2012). The last compared element becomes the joining point at the boundary of both clusters (Fig. 5).
- The elements of the cluster are compared in a matrix and priorities are calculated.
- The priorities of the clusters are joined with a common element: “joining point”. This is used for the conversion rate between two clusters.

In problems with very large elements to be compared, the total number of comparisons can number in the hundreds. Clusters split high-order matrices, which decreases the dimensions. The total number of comparisons is given by:

$$\sum_{j=1}^m \left(\sum_{i=1}^{cl_j} \frac{(b_{cl_i} + rp_{j_{cl_i}}) \cdot (b_{cl_i} + rp_{j_{cl_i}} - 1)}{2} \right) \quad (8)$$

where: $rp_{j_{cl_i}}$ = number of representative points for criterion j in cluster i

b_{cl_i} = number of limiting profiles in cluster i

m = number of criteria

cl_j = number of clusters on criterion j

b = number of profiles

Fig. 5. Clusters with 11 representative points, rp_j , and 4 profiles, b_i ; dashed line highlights clusters.

Using (8), the number of pairwise comparisons for the problem described in Table 1 is further reduced to 204 comparisons. Details of the calculation can be found in Table 10.

4. Case Study

The risk of wolf attacks on livestock in Umbria was analysed. As we have a high number of municipalities we use AHPSort II, following the methodology described in section 3.

4.1. Problem definition

1) Problem structuring

The problem can be structured in a hierarchy (Fig. 6). The top level has a unique node, which is the goal of the problem: define the risk of wolf attacks on livestock in Umbria. The second level contains the criteria that are used to quantify this risk. Five criteria have been identified and detailed below. Two of the criteria have sub-criteria; this is the third level. The fourth level contains the alternatives: 92 municipalities of the Umbria region. The fifth level is dedicated to the classes where the alternatives are sorted. Four risk classes are defined, separated by three limiting profiles.

Fig. 6. Risk structure.

In what follows, the five criteria and six sub-criteria selected, which determine the presence of wolves or the factors that might favour their presence, are detailed. All the data collected are secondary data.

Number of predated animals. This criterion concerns the losses of domestic livestock caused by wolves, considering the number of cattle, goats, sheep and horses found dead. It indicates that wolves have already attacked animals in this municipality and could possibly continue doing so. This criterion has been divided into three sub-criteria that represent the number of cattle preyed upon, the number of sheep-goats preyed upon, and the number of horses preyed upon. This subdivision is necessary because the number of domestic livestock preyed upon by wolves is different for each analysed species. These secondary data have been provided by “Umbria’s Regional Wildlife Observatory” and the “Sibylline Mountains National Park”. As they have collected data on different areas of Umbria, both databases were then merged by the authors to cover the entire studied region (Table 2).

Table 2 Predation numbers for domestic livestock in Umbria.

	2002	2003	2004	2005	2006	2007	2008	2009	2010
Cattle predated	23	89	84	77	64	67	52	65	56
Sheep/goats predated	224	312	463	622	641	601	735	1020	1043
Horses predated	17	42	25	31	19	10	15	18	25

Source: Data collected by Umbria’s Regional Wildlife Observatory

Presence of wolves. This criterion concerns the number of wolves reported as being present on Umbrian territory. It represents direct observations of wolves being present. The data were furnished by “Umbria’s Regional Wildlife Observatory” and the “Sibylline Mountains National Park”. As they have collected data on different areas of Umbria, we then merged both databases to cover the entire studied region. The reports were obtained by gathering the data on howls heard, induced howls, sightings, corpses, releases, camera traps, excrement, wolf tracks and radio collars. It is necessary to specify that it is impossible to undertake a census of the number of wolves living in a specific territory because they are very elusive animals that limit their activities to the night hours and areas less frequented by humans.

Number of live animals (domestic livestock). This criterion reports the number of cattle, sheep, goats and horses in the regional territory in 2014. This criterion is essential in order to understand where the predators might be attracted by livestock farms. This criterion is divided into three sub-criteria: the number of cattle, the number of sheep/goats, and the number of horses. This subdivision is done because some species are more attractive than others for the wolves. The data were found at the National Livestock Register – Teramo (Italy). In Umbria, the livestock sector has seen a diminution of the number of livestock farms and associated living heads in the last decade (Table 3).

Table 3 Trend in numbers of livestock farms and living heads in Umbria in the period 2000–2010.

	Umbria					
	Farms			Living heads		
	2000	2010	$\Delta\%$	2000	2010	$\Delta\%$
Cattle	3,553	2,687	-32.2%	62,994	60,527	-4.1%
Sheep/goats	4,555	1,719	-165.0%	156,116	110,292	-41.5%
Horses	1,699	1,382	-22.9%	8,251	6,647	-24.1%

Source: General Agricultural Census – ISTAT (www.istat.it)

Protected areas. The creation of new parks and protected areas has guaranteed the restoration of favourable environmental conditions for wolves, creating at the same time “shelter zones”. These protected areas have a ban on hunting and a higher presence of ungulates (e.g. roe deer, red deer, wild boar, fallow deer, mouflon, etc.). Therefore, they can be considered an amplifying risk factor that may increase the probability of predation (Mattiello et al., 2012). Umbria has eight protected areas that cover circa 7,5% of the region (www.regione.umbria.it/ambiente/parchi-nazionali-e-regionali) (Fig. 7).

Fig. 7. Protected areas in Umbria

Population density. This criterion considers the municipalities of the region that have a low population density (inhabitants per square kilometre). A lower human presence in the territory leaves more uncontrolled space to the predator (Cozza et al., 1996; Meriggi et al., 1991; Pickett et al., 2011), which entails a higher risk of predation. The data were collected for the 15th Census of Population and Housing 2011 by the Italian National Institute of Statistics (ISTAT) and is available on the following website: www.istat.it. Table 4 contains the data for all criteria.

Table 4 Data on each criterion for all municipalities.

Municipality	No. of predated animals (2002–2010)			No. of wolves (2002–2010)	No. of live animals (2014)			Protected areas	Population density
	Cattle predated	Sheep/goats predated	Horses predated		Living cattle	Living sheep/goats	Living horses		
Acquasparta	1	44	0	1	334	1172	155	0.0	60.3
Allerona	2	422	2	10	148	3086	47	39.5	22.1
Alviano	0	2	0	0	114	211	36	11.3	61.5
Amelia	7	113	0	0	1145	2164	312	0.0	90.5
Arrone	11	67	9	2	264	432	85	11.9	68.3
Assisi	4	139	4	11	3323	2372	339	30.0	150.5
Attigliano	0	0	0	0	321	100	2	0.0	192.6
Avigliano Umbro	0	8	0	0	167	241	35	0.0	50.4
Baschi	0	8	0	0	179	197	59	24.9	40.9
Bastia Umbra	0	4	0	0	367	33	126	0.0	796.5
Bettona	0	0	0	1	384	56	100	0.0	96.7
Bevagna	0	0	0	0	581	1731	151	0.0	91.9

Calvi dell'Umbria	0	112	0	0	757	1201	114	0.0	40.8
Campello sul Clitunno	47	42	5	2	145	2001	48	0.0	50.3
Cannara	0	16	0	0	679	297	169	0.0	133.9
Cascia	12	73	1	30	1710	3200	109	0.0	18.0
Castel Giorgio	0	115	0	0	89	3842	11	0.0	51.7
Castel Ritaldi	0	6	0	0	116	1276	115	0.0	148.3
Castel Viscardo	0	79	0	0	10	71	18	0.0	115.4
Castiglione del Lago	0	58	0	0	1377	4883	156	23.4	76.1
Cerreto di Spoleto	7	28	3	14	234	899	35	0.0	14.7
Citerna	0	0	0	2	626	208	40	0.0	150.4
Citta della Pieve	0	21	0	1	409	1024	181	0.0	70.5
Citta di Castello	6	560	0	38	796	4296	523	0.0	103.8
Collazzone	0	45	0	3	320	1727	118	0.0	62.9
Corciano	0	0	0	0	531	123	200	0.0	332.6
Costacciaro	74	111	14	8	815	184	46	53.0	30.6
Deruta	0	0	0	0	644	276	109	0.0	219.6
Fabro	7	85	1	0	711	1122	74	0.0	84.7
Ferentillo	38	112	8	1	700	458	325	11.9	27.8
Ficulle	0	33	0	0	112	140	58	0.5	26.4
Foligno	3	75	4	13	2176	3149	505	1.2	216.3
Fossato di Vico	1	0	6	2	909	49	94	44.0	83.1
Fratta Todina	0	0	0	0	89	104	29	0.0	107.0
Giano dell'Umbria	0	81	0	0	218	906	57	0.0	85.9
Giove	0	7	0	0	43	305	14	0.0	127.5
Gualdo Cattaneo	0	97	0	3	700	757	300	0.0	65.1
Gualdo Tadino	5	29	2	13	624	941	167	0.0	124.7
Guarda	0	0	0	0	118	122	58	11.1	46.8
Gubbio	83	985	16	42	4901	4961	1029	0.0	62.1
Lisciano Niccone	1	29	0	15	216	65	31	0.0	18.0
Lugnano in Teverina	0	0	0	0	293	134	58	0.0	50.9
Magione	0	19	0	0	294	2336	239	25.0	114.7
Marsciano	0	26	0	3	757	509	191	0.0	116.8
Massa Martana	3	53	2	0	563	1307	119	0.0	48.7
Monte Castello di Vibio	0	0	1	0	159	87	39	2.3	50.4
Monte S.M. Tiberina	0	65	0	13	11	374	58	0.0	16.6
Montecastrilli	0	75	0	0	301	1132	26	0.0	83.2
Montecchio	0	0	0	0	205	162	23	4.9	34.6
Montefalco	0	18	0	0	1248	1096	144	0.0	83.1
Montefranco	0	5	1	0	84	97	24	14.2	127.1
Montegabbione	1	20	0	1	114	488	35	0.0	24.5
Monteleone di Spoleto	26	32	20	5	380	2523	326	0.0	9.9
Monteleone d'Orvieto	0	8	0	0	78	196	60	0.0	62.3
Montone	0	75	0	5	158	797	85	0.0	33.1
Narni	0	91	0	0	1755	5131	519	0.0	101.6
Nocera Umbra	18	148	53	7	806	1019	213	4.9	37.9
Norcia	5	49	0	68	2292	7279	385	56.4	17.9
Orvieto	0	571	0	1	451	4883	317	11.9	74.6

Otricoli	0	0	0	0	65	1937	29	0.0	69.0
Paciano	0	0	0	0	0	12	33	0.0	58.5
Panicale	0	1	0	1	56	1366	111	8.7	72.9
Parrano	1	9	5	0	151	18	145	2.1	14.4
Passignano sul Trasimeno	0	43	0	5	446	1211	77	29.6	70.3
Penna in Teverina	0	0	0	0	374	116	61	0.0	106.6
Perugia	1	168	0	9	2434	6190	799	0.0	369.7
Piegara	0	7	0	3	103	727	50	0.0	38.1
Pietralunga	52	194	7	25	603	601	106	0.0	15.2
Poggiodomo	13	0	1	45	141	363	68	0.0	3.3
Polino	2	21	0	4	77	30	52	0.1	12.0
Porano	0	35	0	0	135	204	30	0.0	145.3
Preci	0	2	0	26	52	2151	88	27.9	9.2
San Gemini	0	56	0	0	156	922	65	0.0	180.8
San Giustino	5	4	2	11	206	229	69	0.0	142.7
San Venanzo	76	254	6	7	844	1299	137	4.0	13.4
Sant'Anatolia di Narco	7	37	0	4	144	222	11	0.0	11.9
Scheggia e Pascelupo	22	57	10	5	197	1157	51	83.9	21.8
Scheggino	2	21	7	0	81	158	82	0.0	13.6
Sellano	1	38	2	9	465	1935	118	0.0	13.0
Sigillo	8	43	2	2	228	180	55	58.2	93.2
Spello	2	0	0	3	830	370	299	10.5	141.2
Spoletto	55	187	11	9	2575	5695	781	0.0	111.1
Stroncone	13	53	7	0	691	1729	144	0.0	69.6
Terni	10	152	9	2	495	2716	532	3.1	529.0
Todi	0	22	0	2	911	1303	284	6.5	76.4
Torgiano	0	0	0	0	111	131	158	0.0	177.8
Trevi	23	58	2	1	1381	1648	167	0.0	119.0
Tuoro sul Trasimeno	0	66	0	9	112	174	97	33.5	68.7
Umbertide	7	237	0	24	955	5709	375	0.0	83.4
Valfabbrica	1	88	0	19	809	2223	90	0.0	37.6
Vallo di Nera	0	0	0	3	16	328	9	0.0	10.6
Valtopina	0	11	0	0	120	307	98	6.1	36.0

2) Definition of classes

Municipalities are sorted into four classes, “low risk”, “medium-low risk”, “medium-high risk”, and “high risk” with respect to the risk that wolves will attack livestock farms in Umbria.

3) Definition of the profile of each class

The limiting profiles have been defined by an expert. He has been studying the behaviour of wolves since his master thesis in 2008 and has published several articles on the subject. He is currently employed by “Ambito Territoriale di Caccia” in Umbria.

Table 5 Limiting profiles.

Criteria	Period	Values of alternatives		Classes of risk						
		<i>min</i>	<i>max</i>	Low	Lp1	Medium-low	Lp2	Medium-high	Lp3	High
1. No. of predated animals	2002–2010									
1.1 Cattle		0	100	< 20	20	20–39	40	40–59	60	≥ 60
1.2 Sheep/goats		0	1000	< 200	200	200–399	400	400–699	700	≥ 700
1.3 Horses		0	60	< 12	12	12–23	24	24–41	42	≥ 42
2. No. of wolves	2002–2010	0	70	< 10	10	10–29	30	30–39	40	≥ 40
3. No. of live animals	31/12/2014									
3.1 Cattle		0	5000	< 1000	1000	1000–1999	2000	2000–2999	3000	≥ 3000
3.2 Sheep/goats		0	7500	< 1000	1000	1000–1999	2000	2000–2999	3000	≥ 3000
3.3 Horses		0	1100	< 200	200	200–499	500	500–699	700	≥ 700
4. Protected areas (%)	2014	0	90	< 10	10	10–29	30	30–49	50	≥ 50
5. Population density (inhabitants/km ²)	31/12/2014	0	800	> 500	500	500–299	300	300–199	200	≤ 200

4.2. Evaluation

4) Weighting of criteria

The criteria were compared pairwise in a matrix (Table 6, Table 7, Table 8) by the expert. The evaluations were then entered into Excel to calculate the weights of the criteria through the eigenvalue method of the AHP (Eq. (1)).

Table 6 AHP matrix for weighting criteria.

Risk of wolf attacks on farm livestock in Umbria	No. of predated animals	No. of wolves	No. of live animals	Protected areas	Population density	Weight
No. of predated animals	1	1	8	5	7	0.424
No. of wolves	1	1	7	3	4	0.333
No. of live animals	1/8	1/7	1	1/3	2	0.056
Protected areas	1/5	1/3	3	1	5	0.140
Population density	1/7	1/4	1/2	1/5	1	0.047

Inconsistency ratio: 0.06

Table 7 AHP matrix weighting the sub-criteria of “Number of predated animals”.

No. of predated animals	Cattle	Sheep/goats	Horses	Weight
Cattle	1	1/8	3	0.125
Sheep/goats	8	1	8	0.796
Horses	1/3	1/8	1	0.079

Inconsistency ratio: 0.04

Table 8 AHP matrix weighting the sub-criteria of “Number of live animals”.

No. of live animals	Cattle	Sheep/goats	Horses	Weight
Cattle	1	1/8	3	0.125
Sheep/goats	8	1	8	0.796
Horses	1/3	1/8	1	0.079

Inconsistency ratio: 0.04

The weights of the five main criteria and six sub-criteria are depicted in Fig. 8.

Fig. 8. Weights in the AHP decision tree.

5) Selection of the representative points

The representative points were selected by the expert. After a careful evaluation of the values that the alternatives assume for each criterion, the expert selected an appropriate number of representative points. These must be selected carefully and in the most representative way. The representative points should be distributed as homogeneously as possible on the scale of each criterion in order to highlight marginal changes between them. For example, for the alternatives with respect to the criterion “number of wolves”, assuming values from zero to 70, Table 9 shows the five representative points and the three limiting profiles selected by the expert.

Table 9 Representative points and limiting profiles for the criterion “Number of reported wolves”.

Criterion	No. of reported wolves					
Representative points	0	20		50	60	70
Limiting profiles		10	30	40		

6) Compare the representative points

In this step, the expert compares the representative points and the limiting or central profiles in a matrix in order to obtain the local priorities. To reduce the high number of pairwise comparisons, we use clusters (section 3.3). Table 10 summarizes the number of representative points and the limiting profiles for each cluster.

Table 10 AHPSort II + Clustering: structure of the clusters and the number of comparisons for each criterion.

Criteria (<i>m</i>)	Representative points	Limiting profiles	Cluster (<i>cl</i>)								AHPSort II + Clustering	
			1		2		3		4		No. of pairwise comparisons using (8)	
			<i>rp_{jcl₁}</i>	<i>b_{jcl₁}</i>	<i>rp_{jcl₂}</i>	<i>b_{jcl₂}</i>	<i>rp_{jcl₃}</i>	<i>b_{jcl₃}</i>	<i>rp_{jcl₄}</i>	<i>b_{jcl₄}</i>		
1. Number of predated animals												
1.1 Cattle	8	3	3	1	3	2	4	0	-	-	22	
1.2 Sheep/goats	8	3	3	2	2	2	3	1	-	-	22	
1.3 Horses	8	3	3	1	3	2	3	1	-	-	22	
2. Number of wolves	5	3	2	2	3	2	-	-	-	-	16	
3. Number of live animals												
3.1 Cattle	8	3	3	1	2	2	4	1	-	-	22	
3.2 Sheep/goats	13	3	3	2	3	2	5	0	4	0	36	
3.3 Horses	9	3	4	1	2	2	4	1	-	-	26	
4. Protected areas (%)	7	3	2	2	2	2	4	0	-	-	18	
5. Population density (inhabitants/km ²)	6	3	4	1	3	2	-	-	-	-	20	
Total number of comparisons											204	

The structure of the clusters for the criterion “Number of wolves” is reported in Fig. 9.

Fig. 9. Clusters for the criterion “Number of wolves”.

Priorities are calculated for the two clusters. Local priorities of the second cluster (Table 12) are linked to the first (Table 11) by multiplying them by the ratio of the scores of joining point 30 in the two clusters: $0.622/0.029 = 21.448$.

Table 11 First cluster “Number of wolves”.

Criterion: No. of reported wolves					
1 st Cluster	0	Lp1 10	20	Lp2 30	Local priority
0	1	1/3	1/4	1/9	0.049
Lp1 10	3	1	1/5	1/7	0.087
20	4	5	1	1/4	0.242
Lp2 30	9	7	4	1	0.622

Inconsistency ratio: 0.09

Table 12 Second cluster “Number of wolves”.

2 nd Cluster	Lp2 30	Lp3 40	50	60	70	Local priority	Priorities linked to the first cluster
Lp2 30	1	1/3	1/7	1/8	1/9	0.029	0.622
Lp3 40	3	1	1/7	1/8	1/9	0.046	0.987
50	7	7	1	1/3	1/5	0.164	3.518
60	8	8	3	1	1	0.343	7.357
70	9	9	5	1	1	0.418	8.965

Inconsistency ratio: 0.08

7) Derive the local priority for the alternatives

This step consists of deriving the local priorities for the alternatives using Eq. (2). An example of how to obtain them is reported below.

The local priorities calculated in Table 12 need to be normalized (Table 13). Fig. 10 shows how the presence of wolves contributes to the risk of predation. We can see two behaviours. The contribution to the risk is low until the number of wolves reaches 40, then the risk increases rapidly.

Table 13 Normalized local priorities of the representative points and the limiting profiles for the “Number of wolves” criterion.

Criterion: "No. of reported wolves"			
Representative points		Local priority (Table 12)	Normalized local priorities
Lp1	0	0.049	0.005
	10	0.087	0.010
	20	0.242	0.027
Lp2	30	0.622	0.070
Lp3	40	0.972	0.109
	50	3.501	0.393
	60	7.323	0.821
	70	8.917	1.000

Fig. 10. Graphic of local priorities.

The local priority p_{kj} of an alternative k that has the presence of 54 wolves is given by Eq. (2), where $s_{o+lj} = 60$, $s_{oj} = 50$, $p_{o+lj} = 0.821$, $p_{oj} = 0.393$ and $g_j(a_k) = 54$:

$$p_{kj} = 0.393 + \frac{0.821 - 0.393}{60 - 50} \cdot (54 - 50) = 0.564$$

4.3. Assignment to classes

In this step, the 92 municipalities are sorted into the respective class (section 3.1, point 8)(a). The municipalities with a score below 0.007 have a low risk, between 0.007 and 0.045 a medium-low risk, between 0.045 and 0.122 a medium-high risk, and 0.122 or above a high risk. The detailed results are given in the supplementary results.

4.4. Fine tuning

In the validation phase, the alternatives classified just above and below the limiting profiles (see supplementary results) are reclassified with AHPSort (Ishizaka et al., 2012) in order to confirm their ranking.

As the problem is unchanged, the problem definition (step 1-3) and the evaluation of the weights (step 4) are the same in both AHPSort methods. Then, the expert is asked to compare each of the 6 municipalities at the limit (Terni, Corciano, Baschi, Ficulle, Costacciaro and Poggiodomo) against the limiting profiles. AHPSort provides the same classification as AHPSort II, apart from Poggiodomo, which is classified medium-high with AHPSort (Table 14).

As the classification of the two methods is divergent, the next municipality in the high risk class needs to be also classified with AHPSort. Scheggia e Pascelupo is also found to be classified in the medium-high risk class with AHPSort. Therefore, the next municipality needs also to be tested. Norcia is classified at high risk from AHPSort and AHPSort II, therefore, the fine tuning can be stopped.

	Risk classes	
Municipalities	AHPsort II	AHPSort
Terni	Low	Low
Corciano	Medium-low	Medium-low
Baschi	Medium-low	Medium-low
Ficulle	Medium-high	Medium-high
Costacciaro	Medium-high	Medium-high
Poggiodomo	High	Medium-high
Scheggia e Pascelupo	High	Medium-high
Norcia	High	High

Table 14: Comparison of the AHPSort and AHPSort II classification

5. Discussion

The geographical representation of the results is shown in Fig. 11, obtained by entering the results in QuantumGIS software. Only two municipalities – Bastia Umbra and Terni – are classified as low risk. The main reason is that they are high-density housing municipalities, and lower predation events have been observed and a low presence of wolves has been reported in these municipalities.

The medium-low risk class includes the highest number of municipalities. The predation events and the reported presence of wolves are generally quite low. These municipalities are situated in hilly and low land. The absence of protected areas (Fig. 7) contributes to lowering the risk.

In a post-analysis with the expert, he confirmed that the municipalities showing high and medium-high risk already have a high incidence of predated sheep and goats and also a high reported presence of wolves. In the case of these municipalities, the presence of protected areas or their proximity to such areas, which create “shelter zones” for wolves, supports the sorting outcome. These municipalities are situated in the mountainous areas of the region, where the availability of wild game is high and the population density is low. All these factors favour the presence of wolves.

On the technical side, the large number of municipalities to be classified has necessitated the development of a new sorting technique: AHPSort II. This new sorting method is based on AHP and therefore retains its advantages, while removing the problem of the high number of comparisons. Our case study would have required 37,674 pairwise comparisons using the AHP method, whereas using AHPSort it requires 2,511 comparisons. To reduce the number of comparisons and the cognitive effort required of the decision-maker, AHPSort II asks the decision-maker to select the representative points and the limiting or central profiles for each criterion. The representative points are the main focus of the method and they must therefore be selected carefully and in the most representative way. Similarly, the definition of the limiting profiles is a sensitive step. These definitions must be done carefully because the entire sorting process depends on it. AHPSort II requires 515 comparisons – 1.4% of the number required by AHPSort. Combined with the clustering technique, the number of comparisons further decreases to 204 (0.54%), which are 37,470 fewer comparisons than AHP. For this task, a 3-hour meeting with the expert was needed. If extrapolated to the number of evaluations required by AHPSort, an excess of 32 hours would have been required.

However, it is to note that AHPSort II needs a fine tuning with AHPSort as it contains some linear approximations. In our case, two municipalities out of the 92 municipalities were misclassified.

Fig. 11. Risk map of the Umbria region.

6. Conclusion

Wolf management is strongly influenced by public opinion and human tolerance of the presence of wolves. The wolf wins support among conservationists and many urban people, but is considered a nuisance in rural areas, where people often consider this predator a threat to livestock and wildlife (Gazzola et al., 2008). Wolf conservation can be successful in the long term only if people are willing to accept free-ranging predators in their area. The design of effective conservation and management plans needs to be informed by an effective decision support system. The developed

geographical information system shows the hotspots that are at risk, which can help the local government in planning conflict mitigation strategies. The local government should focus their efforts and resources on these hotspots when implementing methods to control the wolf. An appropriate response to predation is not limited to ex-post intervention programmes because, although this would satisfy farmers (until the exhaustion of funds), it addresses none of the causes of the problem (Boitani et al., 2010). The response needs to start much earlier, with ex-ante interventions to help the farmers purchase protective devices (i.e. fences) and implement husbandry techniques that will help minimize potential wolf predation. Techniques need to be promoted, and, if necessary, enforced, such as livestock-protection dogs (Gehring et al., 2010; VerCauteren et al., 2012), electric fences, presence of shepherds, night time enclosures, and other good husbandry practices (remove dead and sick livestock from pasture, management of lambing season) (Breitenmoser et al., 2005; Dalmaso et al., 2012).

The main contribution of this paper has been to develop a new sorting method AHPSort II that requires far less evaluations than AHPSort I. The reduction of pairwise comparisons may reduce slightly the precision due to the used linear approximation but in our case study it has produced reliable results with few borderline misclassifications. It is therefore important to have a fine tuning of the borderline alternatives with AHPSort. It is also worth adding that the expert would have felt some measure of questionnaire fatigue if too many questions would have been asked and by consequence the precision would have decreased due to a lack of concentration. A future research project would be to find out experimentally at which number of alternative is it better to switch from AHPSort I to AHPSort II.

It is worth noting that the developed method is sufficiently generic to be used in other regions and also in any application area to support decision-making. Due to the increase in big data sets, it is believed that its usage will increase rapidly.

In a future work, we envisioned implementing this sorting method within a geographical information system (GIS) software package in such a way so as to reduce the number of comparisons that spatial multi-criteria decision problems may require, to automatize the geographical representation, and to obtain the advantages of the MCDA methodology combined with the possibilities offered by the GIS (Massei et al., 2014).

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