

MULTIOBJECTIVE ANALYSIS OF OPEN AREAS INVADED BY FOREST WITH OPEN-SOURCE SOFTWARE: THE CASE OF THE SATURN PROJECT

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ABSTRACT:

In the last decades in Italian mountainous regions, forests are invading abandoned pastures and cultivated surfaces that often played a key ecological role for biodiversity conservation, a complex land-use change phenomenon. To improve sustainable regional planning and management it is increasingly important to quantify the phenomenon and classify those areas according their ecological vocation. This study explores multi-objective and multi-criteria assessment for the identification of the most suitable areas for agricultural purposes between those surfaces that have been invaded by forests. Free and Open-Source Software for Geospatial (FOSS4G) software has been used to carry out the research. The work here presented has been funded by the EIT Climate-KIC SATURN project (2018-2021) and was carried out in the pilot areas of the Province of Trento (Italy). Geospatial data set was georeferenced and managed with GRASS and QGIS and the files were collected combining data freely available at the Autonomous Province of Trento geocatalogue as well as others self-produced during the project. The comparative analysis and methodology were carried out by means of QGIS 3.16 Geographic Information System which has been used to complete the analysis to develop a methodology that can be widely used by territorial operators and Public Administrations. To validate the model and verify the results, on-site inspections were carried out. The developed model can be used in different environmental assessments for territorial planning purposes.

1. INTRODUCTION

In European alpine mountain areas, forests are invading pastures and abandoned cultivated surfaces (Gobbi et al., 2019a, Varga, 2020). This phenomenon is evident in the Trentino region (Italy) where an important land-use change is happening reducing those open areas that are fundamental for ecological purposes and play an essential role in the alpine environment (Sitzia et al., 2017, Tattoni et al., 2017). The role of open areas is very complex as it depends not only on the quality of the individual environments but also on the mosaic formed by the various pieces of the landscape (Gaglio et al., 2017, Cavalcante et al., 2020, Garbarino et al., 2020). Forests planning and land management are key elements in preserving these areas and ensuring the maintenance of the integrity of the ecosystems (Cantiani et al., 2016). Tools for a dynamic investigation of the environment are meant to be essential to support a sustainable planning of the territory. The literature identifies multi-criteria and multi-objective methods for environmental assessment (Geneletti and Van Duren, 2008) since they can examine multiple competing land uses. Different examples can be found in literature, facing similar themes (Pal et al., 2021, Salazar et al., 2021, Valente et al., 2021, Michael Griffel et al., 2022). Through these approaches, different criteria and analysis can be compared both contemporarily and separately. This methodological process provides a more precise and clear classification output than classical multi-criteria analysis.

Our research focuses on former open areas recolonised by forests (FOARF) and has been carried out within the framework of the European EIT Climate-KIC SATURN project (2018-2021)

(Fondazione Edmund Mach, 2019). Three city-regions – the Trentino region in Italy, Birmingham in the United Kingdom, and Gothenburg in Sweden – have been the pilot cases in which the project aimed to strengthen the reconnection between urban and peri-urban environments and integrate natural resources into cities' climate change adaptation strategies. The third main objective was the scale out of the model by creating a broader initiative involving an increasing number of stakeholders (Nikologianni et al., 2020).

The Trentino Hub research team has developed different tools to analyse the landscape using FOSS4G software (Ciolli et al., 2017, Gobbi et al., 2018, Gobbi et al., 2019b, Tattoni et al., 2019, Zatelli et al., 2019a, Zatelli et al.2019b). The assessment method presented here focuses on the use of multi-objective and multi-criteria analyses in identifying the most suitable areas for agricultural purposes or ecological relevance among those surfaces that have been invaded by forests. The analysis of the areas was determined by considering their intrinsic characteristics and their spatial location concerning the territory and started from previous studies on land use in the Autonomous Province of Trento (Italy) (Gobbi et al., 2019a).

2. OBJECTIVE

In this research, a multi-criteria analysis was applied to identify the FOARF areas that are most promising from an agricultural recovery perspective and the ecologically relevant areas. The aim is to identify a method to run a multi-objective analysis, that is the simultaneous comparison of multi-criteria analyses, using

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Geographic Information Systems (GIS) for the aforementioned purpose.

3. MATERIALS AND METHODS

The research has been carried out by means of FOSS4G Geographic Information Systems (GIS). In particular, GRASS (GRASS Development Team, 2022) was used to identify the open areas reinvaded by forest and QGIS 3.16 (QGIS Development Team, 2022) has been used to complete the analysis to develop a methodology that can be widely used by territorial operators and Public Administrations.

Technicians and experts have been involved in the research through focus groups, organised within the SATURN project, to define the parameters considered in the analysis. Other experts have been asked to complete a questionnaire to contribute to designate the parameters' weight.

Through a series of multi-criteria analyses of the agricultural and ecological vocation of a given region, and more specifically of abandoned agricultural areas, it has been possible to create initial assessment maps. The data collection, georeferencing, and standardisation has been the first step. Then, synthesis analyses have been useful to compare the ecological and agricultural aspects and integrating them into synthesis maps, which can be used in the future for land management and planning.

Finally, a series of in-site visits allowed to validate the model and verify the results.

3.1 Context

The research has been conducted during the SATURN project in the Autonomous Province of Trento (Italy) between 2020 and 2021. In particular, the territory that includes the Municipality of Trento, the Municipality of Pergine Valsugana and the Rotaliana Plain (counting seven municipalities in the north of Trento) have represented the case study in which the multicriteria analysis has been tested.

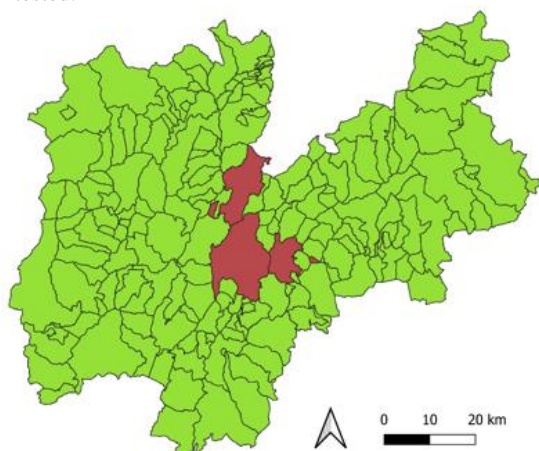


Figure 1. Case study areas in the Autonomous Province of Trento.

The Autonomous Province of Trento is an Italian Alpine Region in Northeast Italy, encompassing about 620,000 hectares with a population of roughly 540,000 people. The geography of the province, which is made up of valleys and high mountains with large percentages of steep slopes, is reflected in the fact that 88% of the municipalities are located at a height of more than 600 meters above sea level. Because of these geographical features, farming has always been challenging, and terraces were built to solve the problem. Nowadays, agricultural machinery is frequently unsuitable for usage in such locations, therefore they

are frequently abandoned in favour of flatter places (Andreola et al., 2021).

More than 50% of Trento's Province surface area is covered by forests, while about 20% is in agricultural use. Residential areas cover about 7% of the surface and roads and infrastructure occupy 3% of Trento's territory (Andreola et al., 2021). The city of Trento, the capital of the region, is located in the Adige Valley. The major watercourses that flow through the city of Trento are the Adige River, which runs through it from north to south, and the Fersina stream, which runs through it from east to southwest. In recent decades, the city has undergone a strong urban expansion toward the hillside hamlets – Cognola, Povo and Villazzano – and northwards. Trento is a tertiary centre, with a high level of industrial activity in the peripheral area of Trento Nord and a large intensive agricultural activity, especially apples and grapes, in the countryside of Trento. In recent years, greater importance has been assumed by tourism. With its 21,564 inhabitants, Pergine Valsugana is the third-largest municipality in Trentino by population. The town is located in the middle of Trentino, 12 km east of the municipality of Trento and occupies the vast basin at the foot of the Teggazzo hill and the valley floor of the Fersina stream. The municipality of Pergine includes several hamlets and villages, which are home to about half of the inhabitants of the municipality. From an economic perspective, Pergine has a tertiary character, with a discrete industrial activity in the area north of the town and a large agricultural activity, represented by apples, grapes, cherries and small fruits, in the countryside on the outskirts of the municipality. The richest and most profitable sector is commerce, but tourism, cultural, sporting and excursion tourism also plays an important role. The third case study is the Rotaliana plain, an aggregation of seven municipalities in the north of Trento. It is an alluvial plain located between the Adige river and the Noce torrent in the northern part of Trentino. It is surrounded on three sides by rock walls, which act as protection against cold winds. In more detail, the municipalities that make up the Piana Rotaliana are Mezzocorona, San Michele, Terre d'Adige, Lavis, Roverè della Luna and Mezzolombardo. In the Piana Rotaliana the cultivation of vineyards is widespread and Teroldego, a wine made from grapes mainly grown in this area, is widely recognised as a characteristic of this territory.

Case study	Surface [ha]
Municipality of Trento	15,785.4
Municipality of Pergine Valsugana	5,430.5
Rotaliana plain	9,465.2

Table 1. Case studies surface.

3.2 Data collection

Initial maps were obtained through automatic land-use classification starting from the orthophotos of 1954 and 2015. By comparing the two, it has been possible to highlight the area of forests' expansions. The map of former open areas recolonised by forest was produced by Gobbi (Gobbi et al., 2019a, Zatelli et al., 2019b). The estimated surface involved in this transformation is approximately 3,416 ha, corresponding to 11.2% of the total surface area of the territory. Most of the maps used for the processing are available and freely downloadable through open cartographic portals or upon request to the local public bodies that kindly collaborated. Other maps were produced during the SATURN project (Nikologianni et al., 2020) or other cited works. WGS 84 is the reference ellipsoid used for map processing and the projection used is UTM (Universal Transverse

Mercator), the municipalities of interest for the project are located in zone 32.

3.2.1 Analysis criteria and constraints: The identified criteria can be divided into two classes: evaluation criteria and constraint criteria. The former serve to assess the different areas in a gradual or net manner, with a change in scale that differentiates the areas. The latter, on the other hand, are urban or environmental constraints, which determine the exclusion of areas for the multi-criteria analysis considered. The criteria used for the ecological and agricultural evaluation can be divided into more than one assessment criteria, which can be used for a scoring classification that identifies the goodness or suitability of an area for a certain aspect and/or the constraints necessary for masking or eliminating areas that are not suitable for assessment. The evaluation criteria can be divided into three categories:

1. Category A: criteria suitable for the evaluation of areas for agricultural restoration
2. Category B: criteria for ecological evaluation
3. Category C: criteria used for ecological assessment and agricultural potential.

Criteria	Assessment Method	Category
Exposure	Calculation of exposure.	A
Dangerousness	Map of identified risks	A
Proximity to the road network	50 m buffer around the road	A
Sunshine/sunshine hours	QGIS Analysis	A
Agricultural area	Fall within a special agricultural zone 1 or 2	A
Proximity to urban centres	Positive (connecting to the grid), negative (pollutants)	A
Terraces	Existing terraces	A
Elevation	DTM assessment	A
Groundwater Pollution	Pollution risk	A
Polluted sites	Presence of polluted areas	B
Classified FOARF positioning	Identifying the location of the areas and associating a scale according to it	B
Ecological network	Assessment of ecological effectiveness as corridors	B
Wildlife biodiversity	Presence of a considerable number of different taxa	B
Protected areas, Natura 2000	Assessment of presence or proximity to protected areas	B
Proximity to water surfaces	50 m buffer around watercourses and lakes	C
Soil fertility	Score based on soil quality	C
Nectariferous	Pollination capacity map	C
Forests	Wooden areas	C
Slope	Slope estimation and scale association.	C

Table 2. Agricultural and ecological evaluation criteria.

For the evaluation of the FOARFs, and more generally for the multi-criteria analysis, in addition to the previously mentioned criteria, constraints have to be taken into consideration for the exclusion of some areas due to physical and political limits. In Table 3 are reported the considered constraints. Constraints are related only to “Category A – criteria suitable for the evaluation of areas for agricultural restoration” because the ecological assessment per se is not subject to limitations. All criteria are analysed separately contemporary to analyse the area according

to ecological and/or agricultural perspectives. Each criterion has been categorised with positive values if related to agricultural aspects or negative values if related to ecological aspects.

Constraint	Category
Area extension	A
Slope	A
Proximity to road network	A
Protected areas, Natura 2000	A
River protection	A
Lake protection	A
Polluted sites	A

Table 3. Agricultural constraints.

Firstly, all criteria were analysed separately to understand all the particularities of the case. A rating scale (0-1) has been assigned to each criterion to compare the results. Moreover, to each criterion, a weight has been assigned from a minimum of 1 to a maximum of 10 according to their relevance. The range has been defined for convenience.

3.2.2 Definition of the parameters weight: The definition of the parameters weight could be affected by the subjectivity as there are no physical or normative limits for the assignment of weights. To limit the incidence of this error factor, a questionnaire has been administered to specific samples of experts and technicians. The results have been analysed to derive parameters weights. The first group was made up of five experts directly involved in the research, instead the second group involved a greater number of both technicians and experts not directly involved. More than 100 answers were collected from this second group.

3.2.3 Definition of the assessment empirical formula: The empirical formula assemble all the criteria for each multi-criteria analysis; its objective is the identification of the areas suitable for agricultural restoration and areas of relevant ecological importance. The empirical formulation was implemented in QGIS, using the MapCalculation functions. Below is the formulation used to calculate the general agricultural importance for the entire territory considered in the analysis (three macro-zones).

$$gai = (8.2 \cdot exp + 8.8 \cdot sun + 7.8 \cdot nec + 8.5 \cdot sf + 6.6 \cdot az + 7.5 \cdot ter + 6.9 \cdot alt) - (8.2 \cdot csph + 7.3 \cdot gp + 7.6 \cdot sl + 8.1 \cdot pr + 7.9 \cdot pw + 6.4 \cdot pba) \quad (1)$$

where *gai* = general agricultural importance
exp = exposure
sun = sunshine
nec = nectariferous
sf = soil fertility
az = agricultural zones
ter = terraces
alt = altitude
csph = csp hazard
gp = groundwater pollutions
sl = slope
pr = proximity to roads
pw = proximity to watercourses
pba = proximity to built-up areas

Once the general constraints are subtracted, the general agricultural level map is obtained. This could prove useful for future projects, as well as for possible future spatial planning. Subsequently, aspects inherent only to FOARFs, formerly open

recolonised areas of interest for restoration, were also considered. Therefore, the general formulation is modified as follows.

$$aiFOARF = (8.2 \cdot exp + 8.8 \cdot sun + 7.8 \cdot nec + 8.5 \cdot sf + 6.6 \cdot az + 7.5 \cdot ter + 6.9 \cdot alt + 7 \cdot wood) - (8.2 \cdot csp + 7.3 \cdot gp + 7.6 \cdot sl + 8.1 \cdot pr + 7.9 \cdot pw + 6.4 \cdot pba) \quad (2)$$

where *aiFOARF* = agricultural importance of FOARF
exp = exposure
sun = sunshine
nec = nectariferous
sf = soil fertility
az = agricultural zones
ter = terraces
alt = altitude
wood = woods
csp = csp hazard
gp = groundwater pollutions
sl = slope
pr = proximity to roads
pw = proximity to watercourses
pba = proximity to built-up areas

By subtracting the areas classified as general constraints and specific constraints for the FOARFs and subsequently cropping it to the FOARFs, the agricultural level map specific to the areas of interest is obtained. The same procedure was also used to produce the ecological maps. Below is the formulation used to calculate the general ecological assessment for the entire territory considered in the analysis (three macro-areas).

$$ea = (8.1 \cdot sf + 9.3 \cdot en + 9.2 \cdot wb + 8 \cdot nec + 8.4 \cdot for + 8.7 \cdot pa) - (5.2 \cdot dep + 8 \cdot pw + 9.3 \cdot ps) \quad (3)$$

where *ea* = ecological assessment
sf = soil fertility
en = ecological network
wb = wildlife biodiversity
nec = nectariferous
for = forests
pa = protected areas
dep = dependence
pw = proximity to watercourses
ps = polluted sites

Subtracting the areas considered as general constraints, we obtain the general ecological level map that can be used for various projects and/or future spatial planning. Subsequently, aspects inherent only to FOARFs, formerly open recolonised areas of interest for the assessment, were also considered. Therefore, the general wording is modified as follows.

$$eaFOARF = (8.1 \cdot sf + 9.3 \cdot en + 9.2 \cdot fb + 8 \cdot nec + 8.4 \cdot for + 8.7 \cdot pa + cpFOARF) - (5.2 \cdot sl + 8 \cdot pw + 9.3 \cdot ps) \quad (4)$$

where *eaFOARF* = ecological assessment of FOARF
sf = soil fertility
en = ecological network
fb = faunal biodiversity
nec = nectariferous
for = forests
pa = protected areas
cpFOARF = classified positioning of the FOARF
sl = slope
pw = proximity to watercourses
ps = polluted sites

By subtracting the areas considered as general and specific constraints for the FOARFs and subsequently cropping them, the ecological level map specific to the areas of interest is obtained.

4. RESULTS

Two different methods have been tested for the multi-criteria analysis, then the three methods have been compared and discussed, two using the QGIS raster calculator and one operating with a script. Through the QGIS raster calculator the ecological assessment and the agricultural assessment have been compared, before separately and then simultaneously.

The first method involves a subtraction between the ecological and agricultural multi-criteria analyses previously normalised and multiplied, for convenience, by 10. Assigning positive values for agricultural and negative values for ecological has no importance from a recovery perspective, it only serves to obtain the union of the two multi-criteria analyses. From the first analysis, it is possible to determine which of the two parameters (ecological or agricultural) prevails over the other for the FOARFs considered. More specifically, the more positive the value, the more the agricultural aspect prevails, whereas the more the value is negative, the more the ecological aspect prevails over the agricultural one.

The second method, starting from the normalised and reclassified maps, uses a hundred-cell matrix obtained by multiplying the agricultural and the ecological values. The result represents the importance of the area under the combined aspects analysed. From the second analysis, it is possible to determine how the two aspects interact with each other.

The value, which can vary between 0 and 100, will be higher for those soils that have both a high agricultural value and a high ecological value. However, this analysis does not discriminate which of the two aspects prevails for the plot and may equal plots with opposite aspects.

The third method has been conducted through a script developed specifically to compare multicriteria analyses performed in raster mode on the GRASS software. Since the output is an image, a spatial distribution of the information and a visualization of the analysis results can be obtained by means of a different colouring according to the value determined by the multi-criteria analysis. The objective is to assign each pixel resulting from the comparison of two multi-criteria analyses a code, instead of a number, and an appropriate colour scale. The script inputs are the individual multicriteria analyses.

In the specific case of this research, the inputs are the multicriteria analyses of agricultural value and ecological value, scaled 0-10. The individual analyses are classified into 10 intervals (0-1, 1-2, 3-4, 4-5...), to limit the calculation time and simplify the work and map reading.

A code has been obtained by combining the two analyses, as the raster cannot contain more than one piece of information besides coordinates. This code, therefore, contains two pieces of information: the agricultural value of the pixel and the ecological value of the pixel.

The code determines a position on the matrix, which is obtained by placing the agricultural value on the x-axis and the ecological value on the y-axis. (coordinates). Once the final maps were obtained, a field visit was carried out in order to validate the model. The choice of the places to visit was made by weighting the characteristics of each of them and selecting areas that were different from each other and representative of each of the 4 categories listed in the previous chapter. The map below shows the location of the areas where the surveys were carried out. Next, the specifications and photographic documentation of every single inspection are reported, grouped according to the macro-areas.

	Coordinate N	Coordinate E	ID
1	46°07'28.90	11°21'96.49	0804
2	46°03'56.11	11°25'91.09	0508
3	46°05'75.73	11°25'10.05	0505/0404
4	46°19'04.65	11°13'93.04	0606
5	46°23'08.69	11°08'75.21	0709
6	46°19'59.88	11°15'77.04	0706
7	46°07'07.38	11°15'35.86	0804
8	46°04'15.14	11°09'97.34	0508/ 0507
9	46°07'01.12	11°18'97.40	0402

Table 4. In-site visits localisation.

5. DISCUSSION

Three multi-criteria analysis have been compared during the analysis, the first related to agricultural aspects and the second to ecological aspects. This analysis can be carried out for both general and specific maps drawn up on individual FOARFs. From the first analysis, it is possible to determine which of the two parameters (ecological or agricultural) prevails over the other for the FOARFs considered. More specifically, the more positive the value, the more the agricultural aspect prevails, while the more negative the value, the more the ecological aspect prevails over the agricultural aspect.

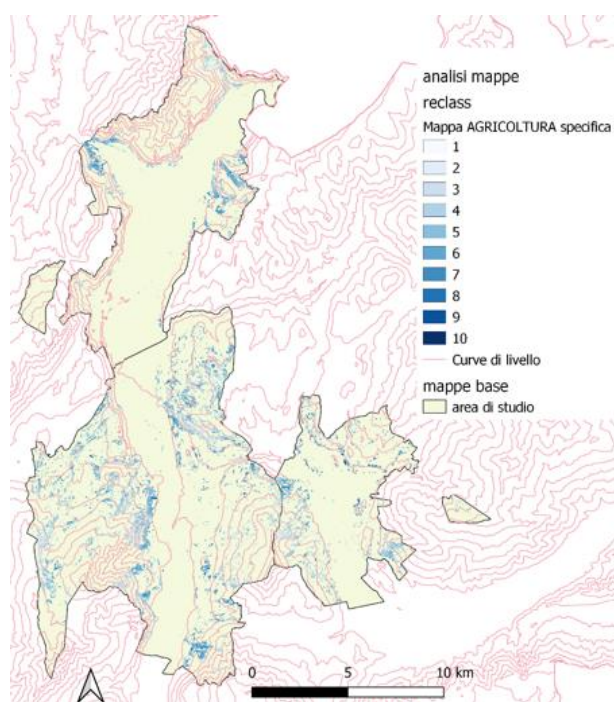


Figure 2. Multi-criteria analysis results for agricultural assessment.

From the second analysis, it can be determined how the two aspects interact with each other. The value, which can vary between 0 and 100, will be higher for those lands that have both a high agricultural value and a high ecological value. However, this analysis does not discriminate which of the two aspects prevails for the plot and may equal plots with opposite aspects. As in the previous analysis, the second one can also be used for a preliminary assessment. Furthermore, the map can be used to identify areas suitable for sustainable agricultural restoration (permaculture or organic), which does not affect the ecosystem

but rather benefits it. The areas most suitable for restoration are those with the highest ecological and agricultural value.

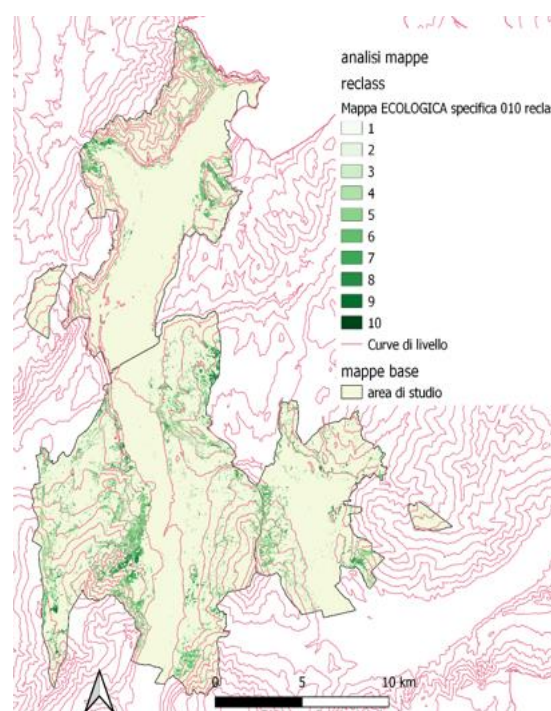


Figure 3. Multi-criteria analysis results for ecological assessment.

The script has been created to solve the problems arising from the first two analyses and to obtain a new method of comparing two multi-criteria analyses, that is running a multi-objective analysis for the spatial evaluation of two multi-criteria analyses simultaneously. Using the script, it is possible to determine both graphical and quantitative values of both unified analyses and their interaction. The obtained map shows an identification code for a certain agricultural/ecological class, as explained above in the code description.

The methodology, developed and tested in the SATURN project, can be applied in different assessment analysis of two or more projects to be implemented in the territory. Through the script, the values of both unified analyses and their interaction can be determined both graphically and quantitatively. As far as the limitations of the model and the mappings obtained are concerned, they can be divided into four broad categories: spatial resolution of the maps, map dating, assignment of weights, choice of the criteria. Concerning maps spatial resolution, the greatest limitation of the model is the use of maps with different spatial resolutions. The accuracy of the model varies depending on the resolution of the map and thus the number of pixels it has. However, this limitation is negligible if the observation is performed on a large scale, as was done in this thesis.

The map resulting from the multi-criteria analysis has a resolution of 5m. Another limitation of the model is related to the dating of maps, in fact the temporal evaluation is a crucial element in map analysis. If the map turns out to be too dated, the model may suffer and become less accurate. In this paper, mostly recent maps were used, but the most up-to-date ones were selected. The oldest map used dates back to 2015 and concerns the nectar value. The assignment of weights is another important element to be considered, in fact it is the element most affected by the subjectivity of the operator, as explained above. For this study, a stratagem was devised to mitigate as much as possible

the error produced by the individual operator, considering both the opinion of a general sample of the population and that of a selected group of people directly involved in the project. Finally, the last limitation of the method can be related to the choice of criteria. The type of analysis and the variables involved in the multi-criteria evaluation are chosen according to the quantity and quality of data available. The more useful data are available for the area, the higher the quality of the result. If new information is received or updated, an update of the model is envisaged.

6. CONCLUSION

Preserving the ecosystem of an area, or rather the ecosystems mosaic of an area, is of fundamental importance to succeed in creating an eco-sustainable environment. To achieve this, it is necessary to perform spatial planning taking into account the ecological criteria together with the other criteria to identify key elements and aspects.

The results obtained in this work showed how the classical approach, based on single criteria analysis, differs from the multi-objective approach for its potential to produce a more precise and clearer classification output of the elements considered, showing the two multi-criteria analyses and their dependence on a single final map.

The multicriteria approach, which initially provides for a separate analysis of the research layers and then integrates them into a single final output, may represent a starting point for future ecosystem evaluations and in general, improve the quality of environmental planning.

The model presented in this work can be replicated by changing the current research object, i.e. the agricultural assessment, and keeping the ecological assessment instead. An example would be a new methodology for risk assessment, identifying which of the three aspects between hazard, vulnerability and asset value predominates over a given area. With this methodology, a separate and more precise classification could be achieved.

Future development includes the transformation of the Python script into a plug-in for QGIS, guaranteeing greater functionality for those who wish to use it.

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APPENDIX

Data for different features, Topography, DTM, Land Use, Urban Planning, Cadastral Data, hydrography, in Shape file format can be downloaded at the following address: Provincia Autonoma di Trento - Urbanistica - Cartografia PUP, http://www.urbanistica.provincia.tn.it/pianificazione/piano_urbanistico_provinciale/cartografia/pagina161.html