

**INTEGRATION OF VEGETATIONAL AND MULTITEMPORAL  
ANALYSIS: A CASE STUDY IN THE ABANDONED MINE DISTRICT OF  
MONTEVECCHIO (SOUTH-WESTERN SARDINIA)**

GIANLUIGI BACCHETTA<sup>1</sup>, MAURO CASTI<sup>1</sup>, LAURA ZAVATTERO<sup>2</sup>

<sup>1</sup> *Centro Conservazione Biodiversità – Dipartimento di Scienze Botaniche –  
Università degli Studi di Cagliari. V.le Sant'Ignazio da Laconi, 13 – 09123  
Cagliari, Italy.*

*e-mail: bacchet@unica.it; maurocasti@hotmail.com*

<sup>2</sup> *Dipartimento di Scienze e Tecnologie per l'Ambiente e il Territorio –  
Università del Molise, Contrada Fonte Lappone - 86090 Pesche (IS), Italy.*

*e-mail: l.zavattero@tiscali.it*

**ABSTRACT** - In this paper the authors analyse the land cover transformation in the mine district of Montevecchio, through the integration of vegetational and multitemporal landscape analysis. For this purpose, three important dates (1955, 1977, 2000) of the district history have been considered and two different periods are analysed (1955-1977 and 1977-2000). Multitemporal analysis was carried out through the study of aerial photographs which resulted in the production of three 1:10.000 land cover maps. Vegetational data were obtained through the phytosociological study of the area. The results show the evolution of the natural vegetation as general trend in the territory. Particular analysis was carried out on the mining areas (mining dumps, surface mines and tailing dams) to understand how much and how have been re-colonized by the native vegetation. For the mining dumps the main transformations are towards the mediterranean maquis, the garrigue and the cork-oak woods. The surface mines was stable in the first period for 73.6% and the main changes are due to the diffusion of natural vegetation (e.g. to mediterranean maquis 14.7%). With regard to the tailing dams we observed an increase of stability (from 81.6% to 96.1%) together with a global increase of surface from 1955 to 2000. Therefore, the integration of the multitemporal and the vegetational analysis made possible to register a significant evolution of the vegetation cover on incoherent and polluted materials in relatively short times.

**KEY WORDS** - multitemporal analysis, vegetation, mining areas, Sardinia, Sulcis-Iglesiente, Montevecchio.

## INTRODUCTION

The mining district of Montevecchio was one of the most important lead-zinc district of Italy. Their metal-producing ores, also rich in copper, silver, tin and iron, have a total length of about 15 km and they were exploited industrially during the XIX and XX centuries (Stara *et al.*, 1996; Mezzolani & Simoncini, 2001).

The closing down of all the mining activities in the nineties was not followed by adequate measures for the reclamation of soil and for the reduction of environmental impacts. The landscape of Montevecchio, in particular the valley floor, abounds in vestiges of past activities such as mining dumps, surface mines and tailing dams (Di Gregorio & Mascia, 1992).

The problems produced by the heaps of such materials are not only connected with the visual impact, but they represent a serious source of risk for the environmental and human health as well. In fact, the oxidation of sulphides causes a strongly acidity of soils and produces a large amount of toxic metal in the fresh water (Caboi *et al.*, 1999; Fanfani, 1995, 1996; Fanfani *et al.*, 2000).

The analysis of temporal and spatial changes plays an important role in vegetational studies (Blasi *et al.*, 1996; Blasi *et al.*, 2003; Carranza *et al.*, 2003). The identification of historical and present processes, provides a holistic outlook of the territory and useful tools for a correct interpretation of landscape changes. The study of the relationship between human activities and natural resources enables to identify those formative factors which are responsible for the development of serial stages.

Aim of this paper is to evaluate through the integration of vegetational and multitemporal landscape analysis how much and how the mining areas (mining dumps, surface mines and tailing dams) have been re-colonized by the native vegetation.

For this purpose, three important dates of the district history (1955, 1977, 2000) have been analysed. In the aerial photos of 1955 we can observe the effects of the resumption of the mining activities after the Second World War. The high productions were due to the great demand of raw materials necessary to the country reconstruction. Since the beginning of the sixtieth, the signals of the crisis begin, but the levels of the production were still high and the mining companies made several attempts to relaunch the industry. The second considered period (1977-2000) is marked by the final crisis of the mining district due to the competition of other countries. The closing down of mining activity occurred in 1991.

## STUDY AREA

The mining district of Montevecchio (Fig. 1) extends for 2077 hectares and is located in the south-west of Sardinia (Sulcis-Iglesiente). The study area follows the line of the main mineral body (WNW-ESE) that occurs between the village of Guspini and the west coast of Sardinia. The country is mostly hilly; the medium height is about 420 meters a.s.l. The largest outcrops belong to the alloctonous Arburese Unit, belonging to the Palaeozoic basement, consisting of sandstone, metasandstones and metasiltsstones (Carmignani *et al.*, 2001).

With reference to the Rivas-Martínez' bioclimatic classification (Rivas-Martínez *et al.*, 1999, 2002) and basing on the termopluiometric data processed by Bacchetta

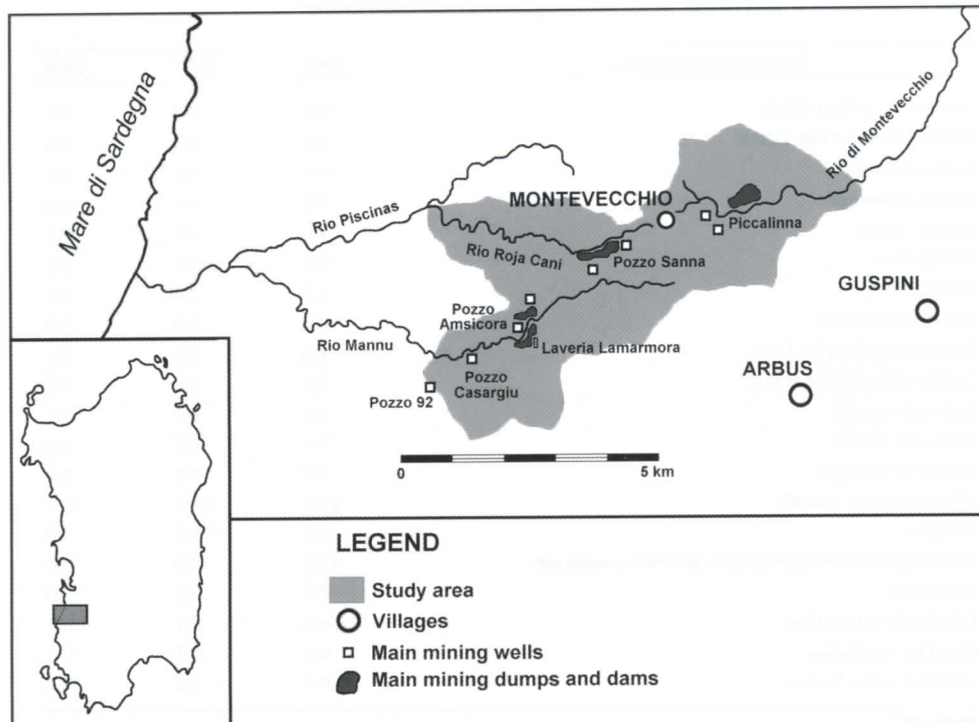


FIGURE 1 – Study area.

(2000), the whole study area is characterized by a Mediterranean pluviaseasonal bioclimate, with thermotypes ranging between the upper thermo- and the lower mesomediterranean and ombrotypes between the upper dry and the lower subhumid. The whole area belongs to the West Mediterranean Subregion and, more precisely, to the Italo-Tyrrhenian Superprovince, the Cyrno-Sardinian Province and the Sardinian Subprovince (Ladero Álvarez *et al.*, 1987; Bacchetta, *op. cit.*; Bacchetta & Pontecorvo, 2005).

#### MATERIAL AND METHODS

Multitemporal analysis was carried out through the study of aerial photographs which resulted in the production of three 1:10.000 land cover maps, referred to the years 1955, 1977 and 2000 (ArcView-GIS 3.2). Each land cover map followed the guide lines of CORINE Land-Cover protocol (CORINE, 1993). The legend shows a 4th level of detail for the artificial area and natural and semi natural surface. The percentage of land cover has been calculated for each typology in each of the 3 land cover maps (Table 1). Through transition matrixes it has been possible to know the principal land cover changes that took place during the studied periods (Fig. 2). In particular, in Figures 3, 4 e 5, for the mine categories (mining dumps, surface mines and tailing dams) the results of the transition matrixes analysis through “change-

TABLE 1 - Land cover percentage of all the categories in the three dates.

Land cover categories	1955	1977	2000
Continuous urban fabric	0.3	0.3	0.3
Discontinuous urban fabric	0.3	0.3	0.4
Road networks	0.3	0.3	0.3
Mining buildings	0.9	0.6	0.6
Surface mines	1.0	1.0	0.6
Tailing dams	0.6	1.0	1.0
Mining dumps	1.4	1.4	1.3
Construction sites	0.2	0.4	0.5
Non-irrigated arable land	1.6	0.6	0.6
Coniferous reforestations	0.5	2.6	3.2
Cork-oak woods	2.2	2.5	2.8
Holm-oak woods	3.1	6.3	3.6
Natural grasslands	3.0	2.3	2.4
Mediterranean maquis	67.5	69.0	72.1
Garigues	2.4	3.6	4.0
Therophytic/hemicryptophytic pioneer grasslands	13.7	6.9	5.6
Bare rocks	0.7	0.2	0.0
Helophytic vegetation	0.0	0.1	0.2
Riparian vegetation	0.1	0.4	0.3
Artificial water basins	0.2	0.2	0.2

stability” histograms are shown. Although a number of patch properties can be important to patch dynamics, we focused on class area (hectares), number of patches, mean patch size (hectares), and mean nearest neighbour distance (meters) (McGarrigal & Marks, 1995). Due to the aim of this paper, only the indexes related to the mine categories have been reported (Table 2).

Vegetational data were obtained from field-research carried out in spring and summer 2003-2005 and from recent publications (Bacchetta *et al.*, 2007a, 2007b). 120 phytosociological relevés were taken on the whole mining district and namely on substrata resulting from the mining activity such as mining dumps, surface mines and tailing dams.

## RESULTS

### *Multitemporal analysis*

The percentage of land cover for each land cover type on the maps has been compared in Table 1. The table shows that the land cover of Montevecchio district is mainly natural. The Mediterranean maquis represents the main category that increased its land cover during the considered period (from 67.5% in the 1955 map to 72.1% in the 2000 map). We note a continuous increase also for the cork-oak woods (2.2%, 2.5% and 2.8%) for the garigue (2.4%, 3.6% and 4.0%) and for coniferous reforestations (from 0.5% in the 1955 map to 3.2% in the 2000 map). The percentage of land cover of holm-oak woods increased in the first 20 years and decreased

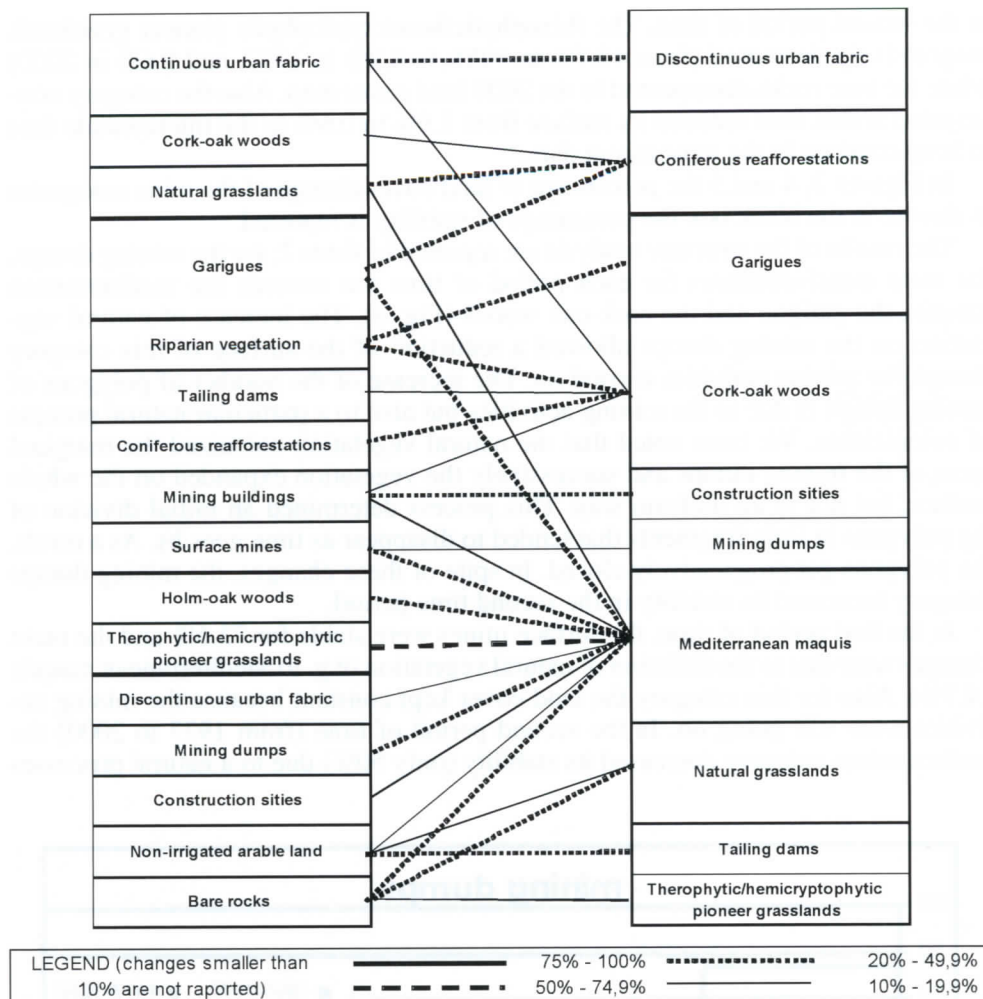


FIGURE 2 – Diagram of main land cover changes in the study area (1955-2000).

TABLE 2 - Indexes related to the three mines categories. CA = class area; NUMP = number of polygons; MPS = mean patch size; MNN = mean nearest neighbour distance.

Indexes	Mining dumps			Surface mines			Tailing dams		
	1955	1977	2000	1955	1977	2000	1955	1977	2000
CA	29,4	28,1	28,0	20,1	20,4	11,9	11,7	21,5	20,7
NUMP	25,0	39,0	42,0	7,0	15,0	13,0	1,0	1,0	1,0
MPS	1,2	0,7	0,7	2,9	1,4	0,9	11,7	21,5	20,7
MNN	118,6	61,9	55,7	254,8	57,9	65,8	0,0	0,0	0,0

in the second period of time. The therophytic/hemicryptophytic pioneer grasslands progressively decreased (from 13.7% in 1955, to 6.9% in 1977, and 5.6% in 2000) while the bare rocks disappeared in the 2000 land cover map. Also the category non-irrigated arable land reduced its surface from 1.6% to 0.6% in the intermediate date to keep constant in the most recent date.

In Figures 3, 4 and 5 the percentage of land cover change of the mine categories is shown, in the black box the percentage of stability is reported.

The results of the structure analysis are reported in Table 2; for the mining dumps, the main transformations for each period of time are towards the mediterranean maquis, the garigue and the cork-oak woods (Fig. 3). The increase of natural vegetation on the mining dumps allowed a reduction of the surface of this category though the mining activities carried on. The increase of the number of polygons of mining dumps is due to the mining activities but also to a particular natural process of colonization. We have noted that the natural vegetation colonized the marginal areas of the mining dumps and successively the vegetation expanded on the whole surface, but not in an uniform way. This process determined an initial division of the polygons in little fragments that tended to disappear as time goes by. As a result, the polygons get progressively closed. In spite of these changes, the mining dumps category increased its stability in the second time period.

In the first period of time, the surface mines were stable for 73.6% and the main changes were due to the diffusion of natural vegetation (e.g. to Mediterranean maquis 14.7%). Also for this category the land cover kept constant because the mining activities were still going on. In the second period of time (from 1977 to 2000) the surface mines category decreased its stability (only 50%) due to a natural processes

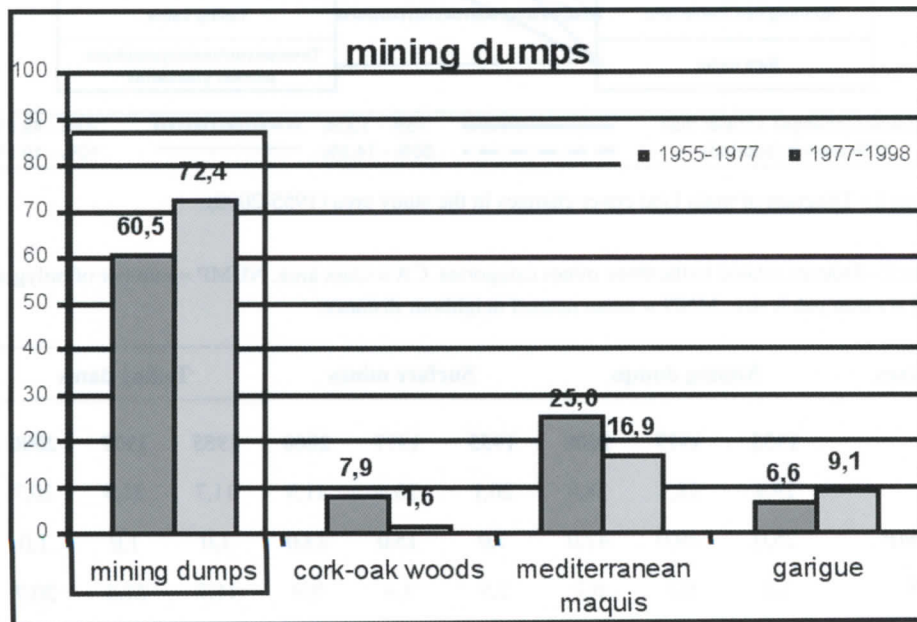


FIGURE 3 - Percentage of land cover stability (in the black box) and change of mining dumps.

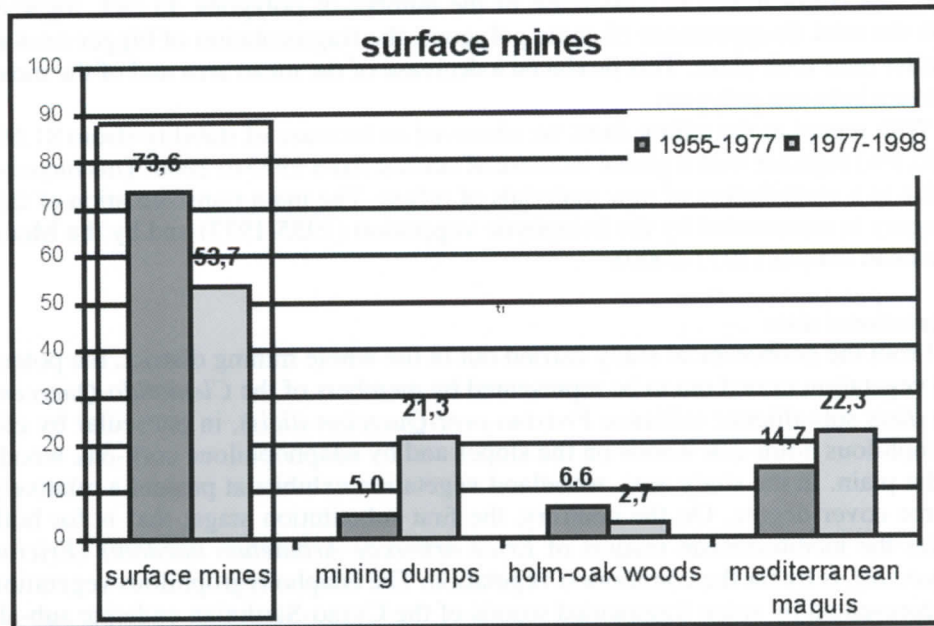


FIGURE 4 - Percentage of land cover stability (in the black box) and change of surface mines.

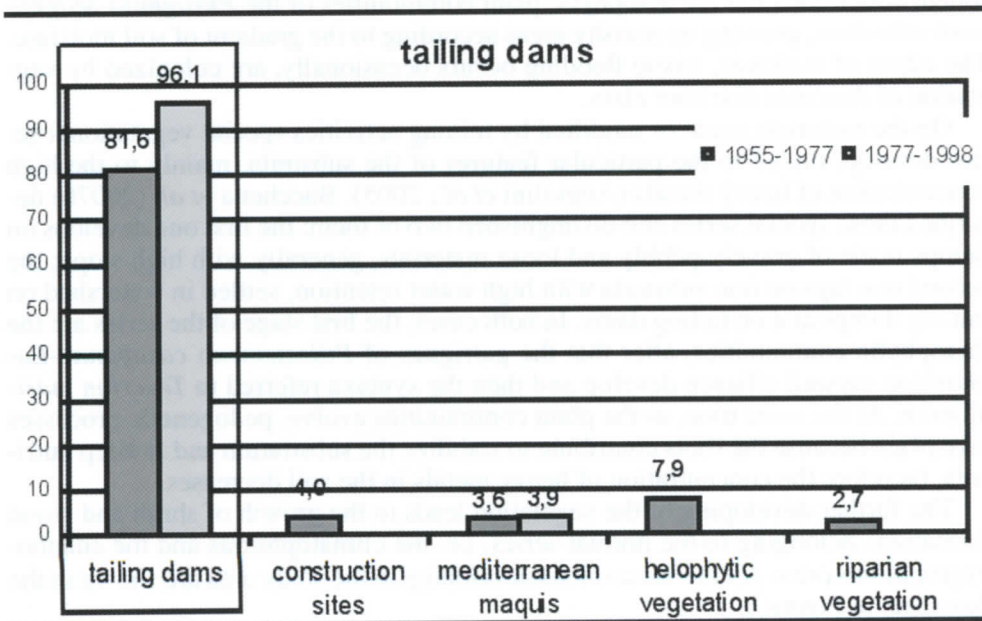


FIGURE 5 - Percentage of land cover stability (in the black box) and change of tailing dams.

of colonization together with the transformation operated by man (e.g. surface mines once closed were used as mining dumps). Like the mining dumps, the reduction of this class is not linked to a decrease of the number of polygons. In fact, together with the total disappearance of some polygons, the fragmentation of bigger ones in smaller ones took place. This produced a decrease of the mean area and of the mean distance between polygons.

With regard to the tailing dams we observed an increase of stability (from 81.6% to 96.1%) together with a global increase of surface from 1955 to 2000. This increase is due to a contribution of new materials of refuse. The main transformation of this category is represented by the helophytic vegetation (1955-1977) and by the Mediterranean maquis (1977-2000).

#### *Vegetational data*

From the geobotanical study carried out in the whole mining district, the potential vegetation turned out to be represented by members of the *Clematido-Quercion ilicis* sub-alliance (alliance *Fraxino orni-Quercion ilicis*), in particular by climatophilous holm-oak woods on the slopes and by edaphophilous cork-oak woods in the plain. In the study area, woodland vegetation exhibits at present a relatively scarce cover degree. On the contrary, the first substitution stage, that is for both series the mediterranean maquis of *Erico arboreae-Arbutetum unedonis* (*Ericion arboreae*), is by far the commonest vegetation. The edaphohygrophilous vegetation is represented by some fragmented woods of the Cyrno-Sardinian endemic sub-alliance *Hyperico hircini-Alnenion glutinosae* (*Osmundo-Alnion glutinosae*) (Bacchetta *et al.*, 2007c).

Along the streams, the edaphohygrophilous geosigmataxon of fresh water is found, which includes the helophytic plant communities of the *Phragmito-Magnocaricetea* class, growing on marshy areas according to the gradient of soil moisture. The edges of wetlands, where flooding occurs occasionally, are colonized by vegetation of *Juncetea maritimi* class.

On the materials made or modified by mining activities special vegetational series develop, linked to the particular features of the substrata, mainly to the high concentration of heavy metals (Angiolini *et al.*, 2005). Bacchetta *et al.* (2007b) described those special series and distinguished two of them: the first one develops on dumps made of gravely-pebbly and loose materials, generally with high slope; the second one lays on fine substrata with high water retention, settled in watershed on mining dumps and on tailing dams. In both cases, the first stage of the series are the therophytic communities, after that the garrigues of *Ptilostemono casabonae-Euphorbion cupanii* alliance develop and then the syntaxa referred to *Teucrion mari-alliance*. At the same time, as the plant communities evolve, pedogenetic processes take place because the roots contribute to stabilize the substratum and to keep nutrients, therefore the concentration of heavy metals in the soil decreases.

The further developing of the vegetation leads to the growth of shrub and wood formations belonging to the normal series, i.e. the climatophilous and the edaphohygrophilous ones. All the successions developing in the study area are shown in the flowsheet in Figure 6.



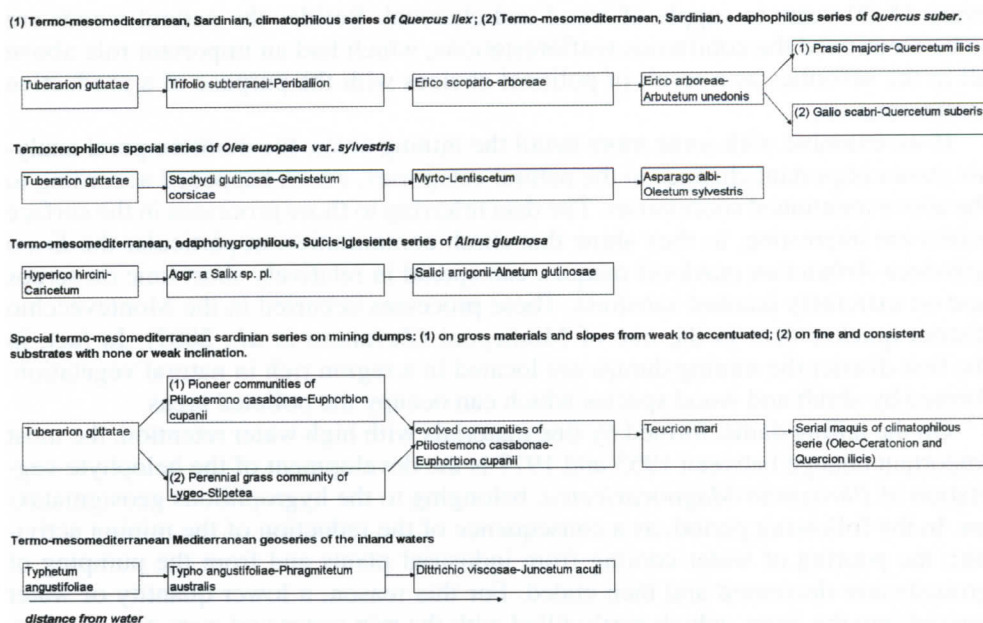


FIGURE 6 – Flowsheet representing vegetational series.

## DISCUSSION AND CONCLUSIONS

The results obtained from the multitemporal and the vegetational analysis, are strictly connected with the history of Montevecchio mines (which were until the eighties among the most productive of Italy) and with its steady decline until the complete closing down. As the mining activities rose in a territory lacking in economical resources, their closing down caused a strong emigration. The resident population of Montevecchio village decreased from 599 to 284 people between 1951 and 1991 (Castelli, 1994).

Among the transformations reported in Table 1, we can see first of all, as a main effect of the depopulation of this region, an evident reduction of the few agricultural fields, which were mostly cultivated with grain until the post-war period for the subsistence of families, but which were abandoned in the following years because of their low fertility.

The other main change in the territory was driven by the progressive evolution of the plant cover, which depended, in its turn, on the above mentioned reduction of the agropastoral activities in the hilly areas. As a general trend, in fact the grassland and grazing formations and rocky areas were replaced by the garrigues and the Mediterranean maquis, while the shrublands evolved in woods.

Regarding the forests, we can notice a constant increase of cork-oak woods, while the olm-oak woods, after having doubled their own cover in the first twenty years, reduced their extension in 2000 to the level of 1955. The change in maquis of these forests, which have an opposite trend if compared with the prevailing transformations, can be explained with the coppicing of the trees, which was traditionally made

every 15-20 years to supply of wood and charcoal. Besides the natural woods are to be mentioned the coniferous reafforestations, which had an important role above all in the seventies as a result of political choices with the purpose of a productive reafforestation.

If we examine with some more detail the mining areas, the multitemporal analysis shows important changes in the natural categories, which happened according to the above mentioned successions. The data referring to those processes in the surface mines are interesting, as they show that shrub communities, in particular the *Erico arboreae*-*Arbutetum unedonis* maquis, can spread in relatively short time on scraps and on extremely leached substrata. These processes occurred in the Montevecchio district quicker than in the one of Monteponi (Zavattero *et al.*, 2007). In fact, in the first district the mining dumps are located in a region rich in natural vegetation, formed by shrub and wood species which can occupy the polluted areas.

On the tailing dams, formed by fine materials with high water retention, the most important change between 1955 and 1977 is the development of the helophyte vegetation of *Phragmito-Magnocaricetea*, belonging to the hygrophilous geosigmataxon. In the following period, as a consequence of the reduction of the mining activities, the pouring of water coming from industrial plants and from the pumping of groundwater decreased and then ended. For this reason, a lower quantity of water arrived into the dams, which partly filled with the rain water and were colonized by Mediterranean maquis in their higher parts.

In conclusion, the multitemporal analysis results an important instrument to quantify the changes in land cover connected with the historical events of the territory. The integration of the multitemporal and the vegetational analysis made possible to register a significant evolution of the vegetation cover on incoherent and polluted materials in relatively short times. In particular, we observed that the gross materials with low metal concentration, like those of the mining dumps, appear to be more easily colonised if compared to the fine and more polluted materials of the tailing dams.

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