

NUMERICAL ASSESSMENT OF GEOLOGY AND GEOMORPHOLOGY IN LANDSCAPE ECOLOGICAL SURVEYS, SOME EXAMPLES¹

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ABSTRACT

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Landscape ecological surveys are used for mapping landscapes as carriers of natural and cultural ecosystems. Some examples from two regions are briefly discussed.

These are: 1) the Upper Arno basin (Tuscany, Italy), 2) a Prealpine Flysch area of Switzerland.

In the Upper Arno basin different landscapes were recognized on the basis of geological formations.

Calculations on the land characteristics of these landscapes resulted in the characterization of correlative complexes and differentiative complexes to characterize and differentiate the mapping units.

In the Prealpine landscape of Fribourg (Switzerland), calculations of the 'mutual information values, I_m ' made it possible to give a quantitative characterization of the land mapping units as correlative complexes. Good correlations were found between the biotic variables and the abiotic and land management variables.

Geological formations proved to be major independent variables in all cases where such differences occurred within a mapping area. One or more geomorphic variables also proved to be independent variables (differentiating characteristics).

INTRODUCTION

There is no doubt that the nature and development of any area of the earth's surface can only be understood if sufficient knowledge is gained of its geology and of its geomorphic phenomena and processes (ZONNEVELD, 1974; 1981). The use of geology and geomorphology in physiographic soil surveys has also been clearly demonstrated in many cases (see for example REMMELZWAAL, 1978). Only during the last decades more attention is being paid to landscape ecological mapping: depicting the landscapes as carriers of natural and cultural ecosystems. This involves the integrated study of relationships between the biotic and abiotic factors at or near the earth's surface and of the human influences on these (ZONNEVELD, 1979). One of the main concerns in these investigations is to bring the model of the landscape ecological system to manageable proportions (VINK, 1981).

During the last decade several research projects have been carried out for evolving efficient methods of landscape ecological mapping. Surveys by various teams and in various regions were carried out for this purpose (ASMAN & TJALLINGA, 1974; BAKKER ET AL., 1981). In some investigations guided by the present author the following regions were studied: 1) the Upper Arno basin in Tuscany, Italy (PEDROLI, 1980; VAN DEN BROEK, 1981; WESTERVELD & VINK, in prep., 2) a part of the Prealpine region of Switzerland (KWAKERNAAK, 1982). In both regions some special studies of a methodological nature were made and these will be briefly reported on in the following.

Due to lack of space no maps are produced in this paper.

THE INVESTIGATIONS IN THE UPPER ARNO BASIN

The intermontane basin of the Valdarno Superiore has its lowest parts along the Arno river at an elevation of 100 m to 180 m above sea level. Annual precipitation in the basin is

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approx. 900 mm/annum and the mean temperature approx. 14°C. It is a graben between the fourth ridge of the Northern Apennines, the Chianti Mountains (approx. 850 m a.s.l.), and the fifth ridge, the Pratomagno ridge at approx. 1500 m a.s.l.. Annual precipitation at the latter is approx. 1400 mm/annum and mean annual temperature 9°C.

The mountain ridges of the Upper Arno basin consist mostly of Macigno of the Serie Toscana, a Tertiary turbiditic Flysch of alternating sandstones and shales, which belongs to the 'Tuscan nappe' of OGNIBEN ET AL. (1975). The main dip in the areas described here is towards the northeast. The area is strongly influenced by active fault systems. Locally the surface rocks of the area consist of a tectonic breccia, the 'Argille scagliose' of 'Complesso Indifferenziato', consisting of poorly consolidated shales with stones and boulders. The Alberese limestone, a Lower Tertiary formation, occurs in some parts of the area.

The basin has been filled from Upper Pliocene to Upper Pleistocene times with a thick (some 500 m) succession of fluvio-lacustrine sediments, mainly sands, silts and clays and

some gravels. These have been, and still today are, strongly dissected by subsequent erosion. The top of the fluvio-lacustrine formation reaches to approx. 350 m a.s.l., where it rests against the footslopes of the Macigno.

For geomorphological and landscape ecological purposes the Tertiary 'Macigno' landscape and the Quarternary 'Valdarno' landscape are generally treated as two different entities, as their major geomorphic and lithological differences induce very different ecological processes and phenomena. Both landscapes have been strongly influenced by mass-wasting processes from early Pleistocene to Recent. Mass-movements are still rather common today, in particular in those parts of the Macigno where clayey shales abound and in the silty-clayey beds of the 'Valdarno' landscape. Similar phenomena have been described for Calabria by VAN ASCH (1980).

The land use in the Macigno landscape consists largely of woods and forests, some rather inaccessible grazing areas, abandoned farm lands and, in the not too steep valleyheads and valleys, terraced agricultural lands. The 'Valdarno' land-

Table I. Legend of the 'Valdarno' landscape in the Pian di Sco area (Tuscany, Italy) (Westerveld et al in press*)

Land unit	Differentiating characteristics						
	slope gradient	slope form	geology 1)	altitude	denudation ")	parent material	physiography
Valdarno landscape							
V1 pianalto	2-8°	straight flat	Vcg+Sb	250-350	0	colluvium alluvium	'highplain'
V2 slightly eroded pianalto	9-14°	(concave)	Vcg+Sb	250-350	(1)	(-----)	slopes
V3 very steep cliffs	> 24°	straight flat	Vs	200-250	3	slope dep. colluvium	slopes
V4 steep slopes associated	> 24°	straight flat	Vag	(200-250)	3	slope dep. colluvium	slopes
V5 upper colluvial slopes	--	complex	Vag	150-175	3	slope dep. colluvium	slopes
V6 lower colluvial slopes	(9-14°)	complex	Vag	150-175	(1)	colluvium alluvium	slopes
V7 fluvial terraces	2-8°	straight flat	Q+Qt	(-----)	0	colluvium alluvium	fluvial deposits
V8 tributary valley bottom	2-8°	valley bottom	Q+Qt	150-175	0	colluvium alluvium	valley bottom
V9 Arno valley bottom	0-1°	valley bottom	Q+Qt	100-150	0	colluvium alluvium	fluvial deposits

*) based on the modal classes of some variables. Variables are chosen according to the significantly differing class frequencies in at least 60% of the total number of possible combinations.

-- : two modal classes

1) all Quarternary formations:

Vag = lower Pleistocene silty clays

Vs = lower Pleistocene silts and sands

Vcg = middle Pleistocene sands and gravels

Sb = upper Pleistocene sands

Qt = upper Pleistocene terraces

scape is, over approx. 90% of its surface area, used for various kinds of agriculture, ranging from large-scale growing of wheat, vineyards and olives in large enterprises to a very small-scale mixed agriculture ('coltura mista' or 'coltura promiscua') with olives, grapevines, cereals and sown pastures in small-holdings.

Landscape ecological mapping in the areas discussed here was done on scale 1:50 000 using systematic airphoto interpretation, map interpretation (in particular of the relevant geological map sheets on scale 1:100 000) and field observations (approx. 4 to 10 observations per km²) with the soil auger (length 1.20 m), an inclinometer and other simple utensils. Observations were made on geology, geomorphology, soils, vegetation and land use. For a discussion of the mapping methods see VINK (1980; 1981; 1983).

The Pian di Sco area

In this area two landscapes were recognized, the (Tertiary) 'Macigno' landscape and the Quarternary 'Valdarno' land-

land use	soil texture	gravel content	sample size °)
arable land	sand	(slightly gravelly)	17
(arable land)	(sandy loam)	(gravelly)	9
wood + shrub	sandy loam	(slightly gravelly)	22
grazing land	(-----)	absent	23
--	(loam)	absent	19
arable land	(-----)	absent	19
(-----)	sand	(slightly gravelly)	7
arable land	sandy loam	(absent)	18
arable land	(silt)	absent	18

- () class is not significant for the land unit according to one-sample tests
 °) number of observations
 °) 0 = absence of the phenomenon
 °) 1 = weak occurrence of the phenomenon
 °) 3 = strong occurrence of the phenomenon

Table II:

Differentiating capacity (d) of the variables used in the landscape ecological survey of the Pian di Sco area, indicated by the ratio in % between (s) the number of times that a variable makes a significant (10% probability level) distinction between two land units, and (n) the total number of possible combinations of two lands units.*
 $d = \frac{s}{n} \times 100$

<i>M-landscape</i> (max. number of comb. n=10)		<i>V-landscape</i> (max. number of comb. n=36)	
variable	percentage	variable	percentage
altitude	90	slope gradient	81
land use	80	slope form	81
stability	80	geological formation	78
anthropogenic terraces	70	altitude	75
vegetation	70	denudation intensity	73
slope form	60	parent material	69
pH (acidity)	60	physiography	69
		land use	67
		texture of soil	67
		gravel content	61

* only values higher than 60 are given in the present publication.

scape, as described above. For each of these two landscapes, the randomized individual field observations were entered into a computerized data base. This was used to test the validity of the landscape ecological classification with regard to the differentiating ability of the data for the mapping units delineated on the map. The procedure resulted in the legend of the landscape ecological map with frequency percentages to indicate the classes of the various characteristics per map unit. A distinction was made between differentiating characteristics and other diagnostic characteristics, the latter being used for the additional characterization of the map units of the landscape ecological map which is published elsewhere (WESTERVELD ET AL. in press; WESTERVELD & VINK. in prep.). As a typical example, the map legend of the 'Valdarno' landscape and a list of variables and their differentiating capacities are given in Tables I and II.

The Talla-Capolona area

In this area situated some 15 km south (upstream along the Arno) of the Pian di Sco area, three landscapes were distinguished (PEDROLI 1980):

- M: Mountain landscape, consisting of dissected mainly east-dipping Miocene Macigno, comparable to the Macigno landscape of the Pian di Sco area, altitudes between 500 and 1450 m a.s.l.,

- H: Hill landscape, undulating hills, consisting of: 1) Macigno siltstone, 2) Argille scagliose, and 3) Alberese limestone at altitudes between 250 and 700 m a.s.l.,

- T: Terrace landscape, mainly formed in unconsolidated Pleistocene fluvio-lacustrine deposits, comparable to those of the 'Valdarno' landscape of the Pian di Sco area, altitudes between 200 and 300 m a.s.l. As a typical example, the differentiative part of the legend of the map produced by PEDROLI (1980) is given in Table III

Table III.
Legend of the landscape ecological map of the Terrace Landscape (T) in the Talla-Capolona area (Tuscany, Italy) (after Pedroli 1980)

physiography	slope gradient	map unit	area covered ha	Differentiative complex (relevant distinctive criteria)												N of obs.	
				slope profile convex	dissected plain	hydromorphic mottling	CaCO ₃ within 30 cm	sheetwash erosion	drainage class 4	drainage class 0 to 3	stoniness class 1 or 2	slope of 0-2°	land use: annual crops	drop impact erosion	slope profile straight		
Arno alluvial plain	0-3°	Ta1	281	—	—	—	++	—	++	—	++ ³	.	.	++ ³	— ³	18	
Fluvial terraces	0-3°	Tr1	171	.	.	.	.	.	+²	- ²	- ³	++ ²	++ ²	- ³	++ ³	8
Fluvio-lacustrine Terrace remnants	0-3°	T10	147	.	.	.	.	.	.	.	-³	.	.	- ³	++ ³	6
	3-6°	T11	613	730	++	++	++	—	++	—	+	-	.	.	++ ³	— ³	32
	6-12°	T12	117															4
12°	T13	144	.														
Total T-landscape			1473													73	

Key to the differentiative complex resulting from PCA

— = absent
 ++ = present, with factor loadings from .76-1.00
 —, + = idem, with factor loadings from .51-.75

-², -³ = absence indicated by 2nd, 3rd factor etc.
 . = relatively indifferent (factor loadings <.50 and/or factor scores <.60)

The boundaries drawn during the field survey were retained in the final map. In order to determine the actual meaning of these boundaries, correlation matrixes were established for the observation points within the different map units and a principal components analysis (PCA) was made (KIM, 1975). For each landscape a 'unit-defining differentiative complex' was determined and thus a reliability of the differences between map-units could be indicated (Table III). The use of the differentiative complex, which is indicative for a large number of associated landscape variables, provides an approach to the problem of the 'correlative complexes' already indicated by VISSER (1949). The calculated factor loadings are a measure for the preference for a certain value of a variable within a given map unit. A high positive loading indicates a high preference. High negative loadings indicate a preference for the absence of a certain value. A further check by means of a chi-square test for two independent variables (SIEGEL, 1956, cited by PEDROLI, 1980) proved that the obtained values were realistic. The differences between the landscapes are indicated by the essential differences between the differentiative complexes which were found to be meaningful.

The Subbiano area

This area, which adjoins the eastern part of the Talla-Capolona area across the river Arno, was divided into three

landscapes with altitude as the principal differentiating characteristic (VAN DEN BROEK, 1981):

- M: altitude above 650 m a.s.l. (Macigno),
- H: altitude between 300 and 650 m a.s.l. (Macigno, locally Argille scagliose and Alberese limestone),
- V: altitude between 100 and 300 m a.s.l. (Upper Pleistocene and Holocene fluvial terraces).

The M and H landscapes were subdivided according to surface lithology (Macigno, Argille scagliose, Alberese) and to slope gradient. The V landscape was subdivided according to geomorphic units (three fluvial terrace levels) and to slope gradient. In the calculations the three landscapes were treated together as a single 'population' of data. For all variables observed during the survey the frequencies per map unit and the chi-square values were calculated.

The latter, corrected according to their degrees of freedom, indicated the highest discriminating values between individual map units for the following variables: geological formation, slope gradient, landform and altitude (in descending order). The chi-square values have also been used to test the discriminating value of the variables for their ability to distinguish between the three landscapes. The results were satisfactory for the following variables: geological formation, slope aspect and effective soil depth.

Subsequently the association values of the variables were calculated. These are a relative measure for the degree to

which a variable is associated with the other variables of the system. The highest association values were found for soil depth, slope gradient, drainage class and geological formation (in descending order).

THE INVESTIGATIONS IN A PREALPINE AREA OF SWITZERLAND

Investigations were carried out in the La Berra-Schwarzsee area of the Pre-Alps of the Canton of Fribourg, Switzerland (KWAKERNAAK, 1982). Altitude is 850-1750 m, annual precipitation approx. 1600 mm, mean annual temperature 4.8 to 6.4°C. The differentiating characteristics used for the landscape ecological map of the area are given in Table IV.

The central criterion used in the classification and evaluation of the observations is the 'information value'. It is originally related to the presence of a plant species with regard to the probability of its occurrence (GUILLERM, 1971). The quantity of information regarding a site factor F is calculated from the observations on the presence or absence of a plant species P. It is expressed in the 'mutual information value, Im' of P with respect to F. This may be used for mutual informa-

tion between plant species and site-factors as well as between different site-factors.

The observed variables are divided into two groups:

- 'cause-variables', independent variables which are used as differentiating land characteristics during the survey;
- 'effect-variables', dependent variables used as accompanying land characteristics.

The former variables are considered to be indicative of the 'correlative complexes' of phenomena within the individual map units (VISSER, 1949; KWAKERNAAK, 1982). They are in this case: slope unit (denudational, transportational, accumulative slopes), slope gradient, altitude and slope aspect with regard to insolation (Table IV). The latter group of variables comprises all other abiotic variables (including soil variables) as well as land management variables (for pastures) and plant species; they are assumed to have cause-effect relationships with the cause-variables (CHORLEY & KENNEDY, 1971).

The relationships between the dependent variables and the independent variables have been computed with clustering techniques. For each ecological land unit these variables and their mutual information values (Im) with regard to that land unit, are given in the quantitative legend of the landscape ecological map (see KWAKERNAAK, 1982). The lists of plant

Table IV:
Example of the use of differentiating characteristics for the landscape ecological map, scale 1:25 000, of the La Berra-Schwarzsee area (Fribourg, Switzerland) (Kwakernaak, 1982).

Differentiating characteristics

MAP UNIT	SLOPE UNIT			SLOPE GRADIENT (degrees)				ALTITUDE (m)			SLOPE ASPECT (with regard to insolation)	
	accumulative slope	transportational slope	denudational slope	<14	14-20	20-27	>27	<1150	1150-1450	>1450	N	S
A1b	x			x					x		x	
A1B	x			x					x			x
A1c	x			x						x	x	
A1C	x			x						x		x
T1B		x		x					x			x
T1c		x		x						x	x	
T2b		x			x				x		x	
T2c		x			x					x	x	
T2C		x			x					x		x
D1b			x	x					x		x	
D1B			x	x					x			x
D1c			x	x						x	x	
D1C			x	x						x		x
D2bg			x		x				x		x	
D2Bg			x		x				x			x
D2bs			x			x			x		x	
D2Bs			x			x			x			x
D2cg			x		x					x	x	
D2Cg			x		x					x		x
D2cs			x			x				x	x	
D2Cs			x			x				x		x
D3a			x				x	x			x	
D3b			x				x		x		x	
D3c			x				x			x	x	
D3C			x				x			x		x

species of the ecological profiles with their I_m per land unit, although for convenience given separately in the publication, are an inherent part of this legend.

In the quantitative legend, the mutual information values (I_m) of the abiotic and land management (grazing land use-) variables are schematized into four classes, indicated in 'bits' the undefined basic unit of the numerical system used. These classes are:

- class a: I_m from 0.025 to 0.050 bits
- class b: I_m from 0.050 to 0.075 bits
- class c: I_m from 0.075 to 0.100 bits
- class d: I_m higher than 0.100 bits.

In this manner a reliable indication of the strength of correlation of each variable within each map unit has been given.

DISCUSSION AND CONCLUSIONS

To some extent the map scale for a survey determines the efficiency of variables as differentiating characteristics. In the cases discussed here, the landscape ecological maps were produced on scale 1:50000 (Tuscany), 1:25000 (Switzerland, main area) and 1:10000 (Switzerland, sample areas). It is possible that for very large scales (more than 1:10000) or for very small scales (less than 1:50000) the results would show some differences with regard to the most appropriate differentiating characteristics to be used in relation to the amount of detail indicated by each differentiating characteristic.

The nature of the area to be mapped certainly has an influence on the choice of differentiating characteristics as well as on their differentiating capacity. It is therefore useful to consider the position of the geological variables as differentiating characteristics in the various landscapes which have been described.

In the Italian Flysch landscapes, together with the associated geological formations of Argille scagliose and Alberese limestone, the following conclusions may be drawn:

1. In a landscape with Macigno as the predominant formation (Pian di Sco area, landscape M), no differences are made on the basis of geology. Some geomorphic variables (altitude, stability, slope form) have a good differentiating ability (Table II).

2. In a case where various geological formations are treated together (Subbiano area) 'geological formation' is found to have the highest differentiating capacity, followed by several geomorphic variables (slope gradient, landform, altitude). Geological formation in this case was also found to have a high association value with other land characteristics. Of the geomorphic variables, slope gradient was found to have by far the highest differentiating capacity as well as association value.

In the Swiss Flysch area the differences in geological formation have as much as possible been eliminated beforehand by

selecting an area with homogeneous lithology with regard to the predominant geological formation. This was done in order to facilitate a more precise investigation of the relevance of the geomorphic variables. With regard to these geomorphic variables in the slope areas the following conclusions may be drawn:

1. Four of the differentiating characteristics selected during the initial survey could be retained after mathematical treatment as independent variables; they relate to geomorphic phenomena and processes: slope unit, slope gradient, altitude and slope aspect (Table IV).

2. The dependent abiotic and land management variables show clear relationships, as indicated by the I_m values, with the (geomorphic) independent variables.

3. The plant species as biotic dependent variables show clear relationships (I_m values) with the correlative complexes of the abiotic and land management variables, which were distinguished by using the geomorphic independent variables.

In the Pleistocene fluvio-lacustrine landscape in the Upper Arno basin, differences between Lower Pleistocene (Vag), the Middle Pleistocene (Vs, Vcg, Sb) and the Upper Pleistocene to Holocene (Q, Qt) formations are good indicators of the landscape ecological differences. The geomorphic variables 'slope gradient' and 'slope form' score highest in differentiating capacity in the Pian di Sco area (Tables I and II). Slope profile has high factor loadings, indicating a considerable influence on the results, in the differentiative complex of the Talla-Capolona area (Table III).

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