Comparability of landscape diversity indicators in the European Union

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SUMMARY:

CORINE Land Cover allows landscape diversity indicators to be computed and comparisons among European regions to be established. We try to assess here to what extent the indicators are really homogeneous across different countries and which indicators are less dependent on the scale of the information. For this purpose, CORINE Land Cover indicators are compared with similar indicators from more detailed data on some test sites. The results suggest that landscape diversity comparisons among regions depend not only on the landscape itself, but also on the way the CORINE Land Cover methodology has been applied in each region. Comparing diversity in different regions can also give quite different results depending on the indicator selected. Calibrating diversity indicators would require detailed land cover data for a large sample in the EU, possibly from a ground survey with compatible specifications.

1 Introduction: Land cover maps and landscape indicators.

The concept of landscape has complex and subjective components, including esthetical, historical and cultural considerations. Some papers can be found in the literature, that analyse the link between subjective landscape quality and landscape diversity indicators (Kuiper, 1998). Here we consider a limited concept of landscape, that can be quantified in an objective way on the basis of a land cover map.

Landscape metrics is a topic that has been extensively discussed in numerous publications in recent years. Some texture measures that had been developed for pattern recognition in image analysis (Haralick, 1979, Haralick and Shapiro, chapter 9, 1992) have been applied to measuring the fragmentation, complexity or diversity of a landscape pattern. The fact that many indicators come from image analysis reminds us that we are measuring the structure of a representation of the landscape rather than the landscape itself.

The indicators considered in this paper exclude several aspects that can be quantified and may be integrated in the future, including:

- Topographic roughness indicators from Digital Terrain Models (Brabyn, 1997, Mc Nab, 1989)
- Indications on the open/closed landscape type.
- Impact of the human presence (for example sparse buildings in rural areas).

In the simplified case of a landscape with only two land cover types, the landscape can be characterised by (Patil et al, 1998):

- proportion of each land cover type
- aggregation into patches (shape),
- distribution of patch size
- spatial distribution of patches(clustered or dispersed)

We say that a landscape is complex if it is made up of a large number of small patches very mixed in the geographic space, so that there is no land cover type that is clearly dominant. The meaning of “land cover type” and “patch” strongly depend on the chosen nomenclature and observation scale, in particular the size of the Minimum Mapping Unit (MMU).

The terms "fragmentation", "complexity" or "diversity" correspond to similar ideas that are not easy to discriminate. Papers related with biodiversity or species dynamics use often the term "fragmentation" (Hargis et al, 1999, Delin and Anren, 1999, Banks, 1998, Tewksbury et al, 1998) or heterogeneity (Ziv, 1998, Turner and Gardner, 1991). Here we prefer the term "diversity", that is often used in a more general context of rural land patterns (Nagaike and Kamitani, 1999, Palang et al, 1998) or when looking at management aspects (Lin and Buongiorno, 1998).

2 Land cover information.

Having sufficient information on land cover for landscape analysis is a major problem, especially if the area of interest is large or the analysis is to be carried out at a detailed scale. Many researchers decide to simulate landscape patterns, that are expected to behave more or less like real ones, in the sense that real

and simulated landscapes have similar values for some landscape indicators. Landscape simulation models can be neutral, if they do not consider specific processes (Gardner et al, 1987, With and King, 1997) or explicit (Moloney et al., 1996). Geostatistical simulation techniques (Deutsch and Journel, 1992) can be considered as neutral models.

Remote sensing can provide valuable information on land cover. Landscape indicators can be computed on classified satellite images (Patil and Taillie, 1999). However the choice of the classification algorithm or the application of filters (Lillesand et Kiefer, 1999) can substantially modify the values of landscape indicators. Comparisons between diversity indicators can be considered objective when the area under study is small enough to fit in a single satellite image and the same automatic procedure is used for different areas or the same area in different dates (Chuvieco, 1999). Photo-interpretation of satellite images from different dates on the same area can provide valuable information on land use changes to analyse the impact of spatial policies (Smits and Annoni, 1999).

2.1 CORINE Land Cover.

CORINE Land Cover is described in Chapter 1 of this volume in some detail. Here we only remind that:

- There is no information in CORINE Land Cover about the size of the agricultural plot. For example an agricultural plain of 1000 ha divided into 5000 plots of 0.2 ha will be a single polygon for CORINE Land Cover, the same as if it were a single plot of 1000 ha.
- The Minimum Mapping Unit size is 25 ha. Under this threshold landscape units may be included in surrounding categories. For example a few plots of woodland in the middle of arable fields will be included in an arable land polygon if the woodland is a small proportion. If the proportion is large, the polygon will be labelled as “heterogeneous agriculture”.

For the current work we have grouped the 44 CORINE Land Cover classes into 23 and further into a simplified version with 9 land cover classes according to Table 4.1.

23 class legend	CORINE Code	Label	9 class legend
1	1	Artificial surfaces	1
2	211	Non irrigated arable land	2
3	212	Permanently irrigated land	2
4	213	Rice fields	2
5	221	Vineyards	3
6	222	Fruit trees and berry plantations	3
7	223	Olive growes	3
8	23	Pastures	4
9	241	Annual crops associated with permanent crops	5
10	242	Complex cultivation patterns	5
11	243	Land principally occupied by agriculture, with significant areas of natural vegetation	5
12	244	Agro-forestry areas	5
13	31	Forests	6
14	321	Natural grassland	7
15	322	Moors and heathland	7
16	323	Sclerophyllous vegetation	7
17	324	Transitional woodland-shrub	7
18	33	Open spaces with little or no vegetation	8
19	41	Inland wetlands	8
20	42	Coastal wetlands	8
21	511	Water courses	9
22	512	Water bodies	9
23	52	Marine waters	9

Table 4.1: CORINE Land Cover grouped nomenclature.

CORINE Land Cover provides rather coarse information, but it is the only data set that allows comparison of land cover indicators across most EU countries in a coherent way. Still a number of questions remain to be answered:

- The diversity indicators depend not only on the landscape but also on how meticulous is the work made by photo-interpreters?
- What is the impact of the scale of CORINE Land Cover on the comparisons?

- The comparisons remain stable if CORINE Land Cover classes are grouped into a simplified nomenclature?
- Some CORINE Land Cover classes are heterogeneous by definition. How to quantify their contribution to the global diversity?

In order to explore some of these questions, landscape diversity indicators computed on CORINE Land Cover (coarse scale) have been compared with indicators computed on ground data (fine scale) coming from the MARS Project. Comparisons have also been made with indicators computed on a more detailed land cover map produced by the Italian Statistical Institute (ISTAT) in a test site in Arezzo (Tuscany).

2.2 The MARS sites.

A sample of 60 sites of 40 km × 40 km (Map 4.1) has been used for rapid estimation of inter-annual crop area change in the European Union in the so called Activity B of the MARS Project (Meyer-Roux and Vossen, 1994). Some of the sites needed a within-site stratification. Most of them are not stratified. In any case a sample of approximately 16 segments of 196 ha (Figure 4.1) is surveyed by points using a systematic grid of 40 points per segment (Carfagna and Gallego, 1997). Altogether more than 38000 points have been surveyed on the ground.

Each point of this grid has been surveyed by ground visits with a nomenclature that is focused on agriculture, and hence quite detailed on crops (annual and permanent), but rather rough for non agricultural land. For the purposes of this study, the survey nomenclature has been recoded into 9 classes that correspond to the 9 classes of the grouped CORINE Land Cover nomenclature described above.

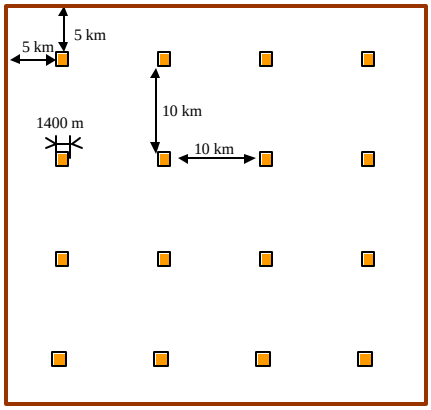


Figure 4.1: Sample of segments in a site.

2.3 Detailed land cover map in Arezzo

The Italian Institute of Statistics (ISTAT) is testing a methodology to produce a detailed land cover map. The data sources for this land cover map include aerial orthophotographs and commercial and industrial census as well as satellite images. The nomenclature is compatible with CORINE Land Cover and the minimum mapping unit is 1.5 ha (1 ha for urban areas). It is therefore much more detailed and in principle more accurate than CORINE Land Cover. Hence it can be used to calibrate diversity measurements computed from CORINE Land Cover, although there are some problems because the reference dates do not coincide. The methodology has been tested in a test area of about 2000 km^2, in the province of Arezzo. The resulting land cover map, currently under validation (Napolitano et al, 2000), has been kindly provided by ISTAT.

3 Diversity indices

We use here the next indicators (see chapter 1 for more detailed definitions):

- Shannon index. sometimes called diversity (O'Neill et al, 1988). It can be computed on small windows of classified satellite images (e.g. 3×3 pixels) and then averaged for a certain region (Chuvieco, 1999). Here it is computed on the MARS segments of 196 ha. For the Arezzo site it is computed on 1 km^2 cells.
- Average number of classes per reference unit.
- Edge density. This indicator does not depend on the size of the reference unit and can be computed directly for the administrative units to be compared.

In the case of CORINE Land Cover, the existence of heterogeneous classes suggests directly using their area percentage as an additional type of diversity index. Although quantitative calibration has not been performed, areas coded as "heterogeneous agriculture" have been visually identified as the most complex areas (high diversity). These labels also exist in the ISTAT land cover map for Arezzo, but they appear less frequently because the scale is more detailed.

4 Comparisons in the MARS sites

We have computed diversity indexes in three different ways:

- From CORINE Land Cover at the site level. We consider all the classes present in each 40km × 40km site.
- From CORINE Land Cover at the segment level. We only consider the classes present in each sample segment of 1400m × 1400m. The indexes at the segment level were averaged by site. However the meaning of the same index computed at the site level or computed at the segment level and later averaged by site is not the same.
- From the points surveyed in each segment, using the ground survey or the point photo-interpretation (not CORINE Land Cover). These indexes computed at the segment level were also averaged by site. For the computation of the Shannon index, the proportion of points in a certain class leads to an estimator of the area of the class, that is used in the usual formula.

In the following tables and maps diversity indexes are labelled:

- SH9 (SH23): Shannon index with the nomenclature of 9 classes (23 classes)
- NUMC9 (NUMC23): number of classes present in a pre-defined unit. This index has been computed only at the level of the segment.
- EDGE: Edge density.
- HETE: % of heterogeneous agriculture.

Additionally a plot size indicator is computed for each of the ground surveyed points. For the specific needs of MARS-Activity B, these points had been photo-interpreted on satellite images, including the delineation of a "homogeneous polygon" around the point. For agricultural points, this "homogeneous polygon" is in principle a parcel otherwise it can be a patch of forest or a town for example. For complex natural vegetation areas, the meaning of these polygons may be more subjective. For areas where the patch size is too small for individual identification at the resolution of the image, the photo-interpreter is asked to draw a very small polygon around the point of the order of magnitude of the pixel. The area of the polygon would have been a better indicator, but these data had not been kept in the MARS database.

4.1 Correlations between indicators.

Table 4.2 gives the linear correlations between diversity indices computed from CORINE and from points in the MARS segments. For this table the CORINE Land Cover indicators are computed at the level of the segment and then averaged by site. We can draw a few conclusions.

Table 4.2: correlation between diversity indexes from CORINE Land Cover and from point observations.

	From points (MARS)	Average distance to plot border	Shannon index (9 classes)	Number of classes (/9 classes)
From	Edge density	-0.20	0.69	0.63
CORINE	% heterogeneous agric.	-0.39	0.57	0.53
	Shannon index (23 classes)	-0.14	0.73	0.61
	Shannon index (9 classes)	-0.10	0.75	0.62
	Number of classes (/23)	-0.07	0.61	0.52
	Number of classes (/9)	-0.05	0.66	0.55

The correlations between *Average distance to plot border* (indicator of the size of parcels or landscape elements at detailed level) and all CORINE Land Cover indexes is quite low. The only noteworthy correlation appears with the *% of heterogeneous agriculture.* This means that Shannon's index or the number of CORINE Land Cover classes are not enough to give an indication of the parcel size, which is an important aspect of the landscape fragmentation . The *% of heterogeneous agriculture* gives only a partial information.

The plot in figure 4.2 suggests that a high % of heterogeneous agriculture generally corresponds to small plots, but a low % of heterogeneous agriculture does not give information on the size of plots.

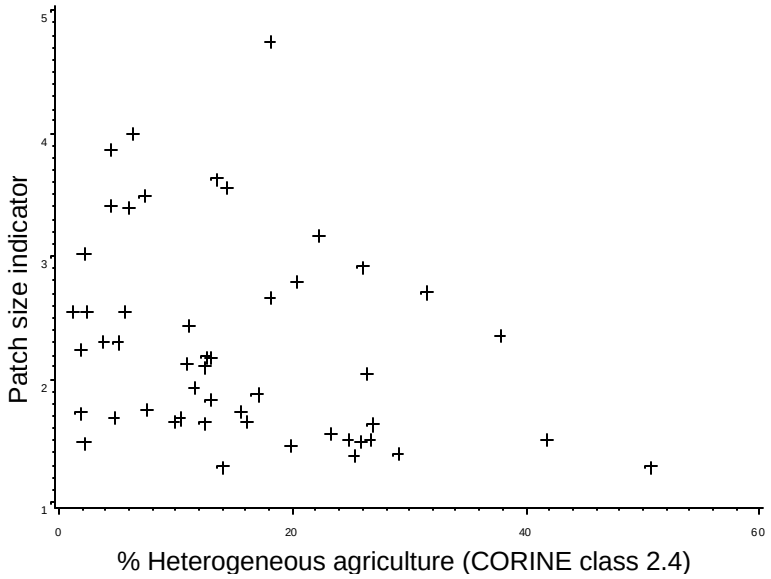


Figure 4.2: Plot of a parcel size index (from point photo-interpretation) and the % of heterogeneous agriculture from CORINE Land Cover

The other indices from CORINE Land Cover seem to correspond reasonably well to the diversity computed from the point observations, but seem to be redundant, at least concerning the information they give on these more detailed indicators. Shannon's indexes are better correlated than the "number of classes". These conclusions are confirmed by stepwise regressions of both point indexes with CORINE Land Cover indexes as regressors.

4.2 Shannon's Index and the number of CORINE Land Cover classes per segment.

Shannon's Index (on CORINE Land Cover) and the average number of CORINE Land Cover classes per segment basically correspond to the same type of diversity. Let us illustrate with an example the difference between both indexes.

We compare the segment no.15 of the Melun site with the segment 9 of the Padernborn site (Table 4.3). In one case we have 5 CORINE Land Cover classes, but one of them (arable land occupies 88% of the segment). Shannon's index takes into account the number of classes and the % of each class, while the number of classes does not make the difference between equally distributed 5 classes or one very dominant class and 4 classes with a marginal presence. The ground survey confirms that the diversity index is more reliable if it takes into account the proportion of each class.

Table 4.3: Number of classes and Shannon's index in two classes.

	Melun 15	Padernborn 9
% CORINE 1	0.5	0.0
% CORINE 211	87.9	30.8
% CORINE 242	9.2	38.0
% CORINE 243	0.5	31.3
% CORINE 31	1.9	0.0
Number of classes (CORINE)	5	3
Shannon's index (CORINE)	0.67	1.58
Number of classes (Ground)	3	5
Shannon's index (Ground)	1.03	1.96

The plot given in Figure 4.3, where each point corresponds to a segment, shows that there is a considerable range of different values of Shannon's index for the same number of classes in the segment. Disagreement is much smaller when both indexes are averaged on larger units (sites), as shown in Figure 4.4. This seems to imply that there is not much difference in practice between both indicators when they are computed on mid-size units (a few km^2) and averaged later on administrative units.

However the high correlation between the two indicators (r=0.953) does not mean that both indicators give the same information. We can measure the consistency in this way: since we have 50 sites, there are 1225 pairs that we can compare to conclude that site A has a higher diversity than site B or the opposite. In 106 cases the comparison changes sign if we take one or the other indicator. This is a moderate proportion, but not negligible, specially if we consider that the main target of quantifying diversity is not deciding that the Valence site has a higher diversity than the purely agricultural site of Bernburg; this will be obvious looking at the land cover map, without any quantification. There might be a higher interest on deciding whether the site of Vicenza has a higher or a lower diversity than the site of Bourges (both with a high percentage of agriculture and a middle degree of diversity). In this particular case the conclusion will depend on the indicator selected.

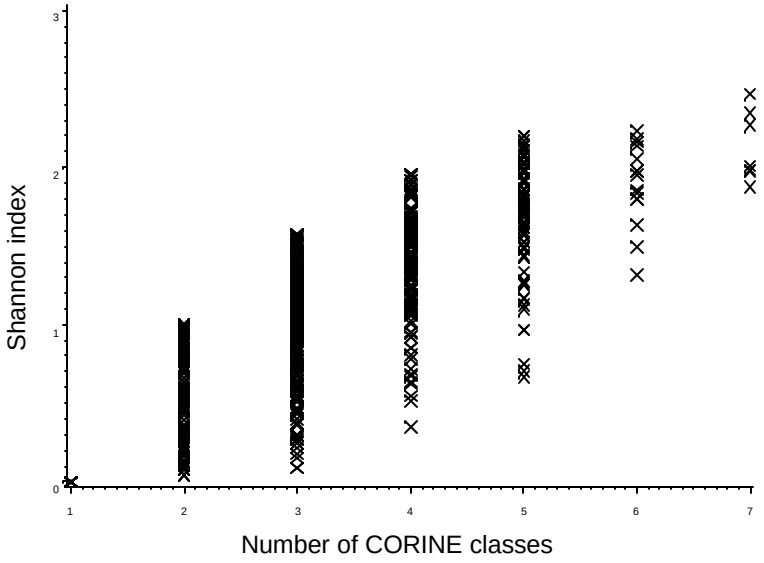


Figure 4.3: Number of classes per segment and Shannon's index computed on CORINE Land Cover for each segment.

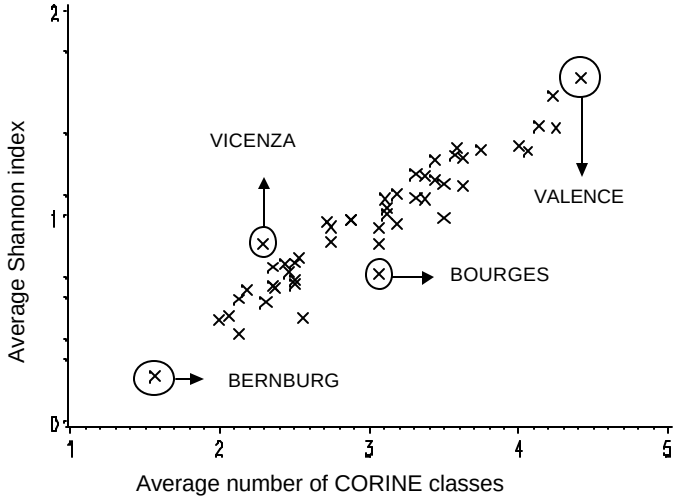


Figure 4.4: Number of classes per segment and Shannon's index computed on CORINE Land Cover for each segment and averaged per site.

5 Comparisons in the Arezzo site

We have cut into pieces both CORINE Land Cover and ISTAT land cover map with a square grid of 1 km^2 cells. We only kept cells that are at least 95% inside the study region.
For each cell we computed the next indicators:

- Number of classes
- Shannon index
- Edge density
- % of class "heterogeneous agriculture"

Table 4.4 reports correlations with the 23 classes nomenclature; Results are very similar with the reduced nomenclature of 9 classes.

Table 4.4: correlation between diversity indexes from CORINE Land Cover and from ISTAT Land Cover map.

	ISTAT land cover map	Edge density	Shannon index	Number of classes	% heterog. agriculture
CORINE	Edge density	0.61	0.55	0.42	0.21
	Shannon index	0.58	0.75	0.59	0.33
	Number of classes	0.48	0.66	0.57	0.29
	% heterogeneous agriculture	0.52	0.58	0.52	0.47

6 Are CORINE Land Cover indices really comparable?

Although CORINE Land Cover is the most homogeneous land cover map available covering nearly all European countries, some technical choices have been different from one country (or region) to another, for example resolution of the images (SPOT XS or Landsat TM), or photo-interpretation on hard copy or on screen. Even with the same technical choices, photo-interpreters in some regions might have been more meticulous than in others. The same landscape photo-interpreted by different operators may give different diversity indices. We try here to explore this hypothesis through the link between CORINE Land Cover indices and indices computed from more detailed and less subjective point data from ground surveys.
As stated before, a Shannon's index (9 classes) from ground survey is well correlated with several indices from CORINE Land Cover. A stepwise regression (without intercept) only selects 2 CORINE Land Cover indices to predict the ground survey index:

$$SH9GS = 1.20 \times SH9COR + 0.94 \times HETECOR + e$$

where SH9GS is a Shannon index computed on ground survey data recoded into 9 categories, SH9COR is the same indicator computed from CORINE Land Cover on segments of 1400 m × 1400 m and averaged per site, and HETECOR is the proportion of the CORINE Land Cover class 2.4 (heterogeneous agriculture).
When the residual e in the regression equation given above is positive for a site, this means that the forecasted Shannon index for the ground data is smaller than the index actually computed. This might mean that CORINE Land Cover tends to underestimate the diversity. On the contrary, in sites with a negative residual, CORINE Land Cover might tend to overestimate the diversity, compared to the diversity in other sites.
The *between-sites* variance can be compared with the *within-sites* variance through an F-test. The result for the residuals of the regression is F=3.4 and the hypothesis that the site has no influence is rejected ($p<0.001$). It could be thought that the site effect is due to spatial autocorrelation, but the correlogram shows very low values for the within-site distances (Figure 4.5).

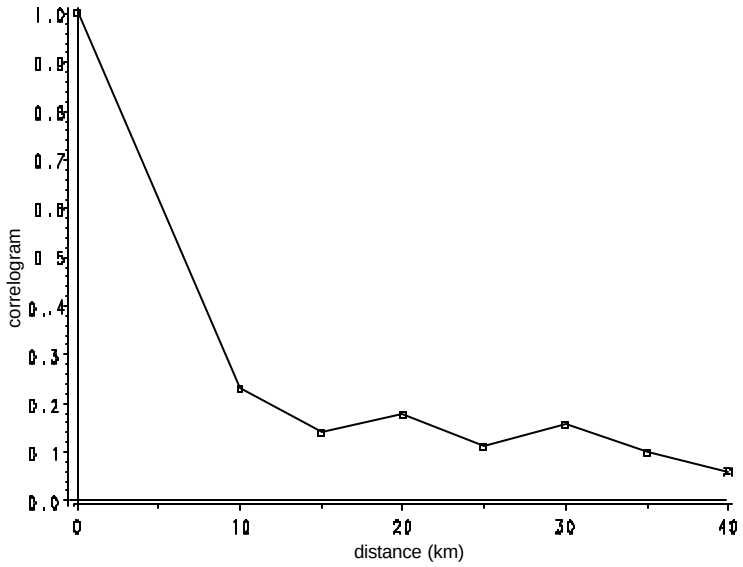
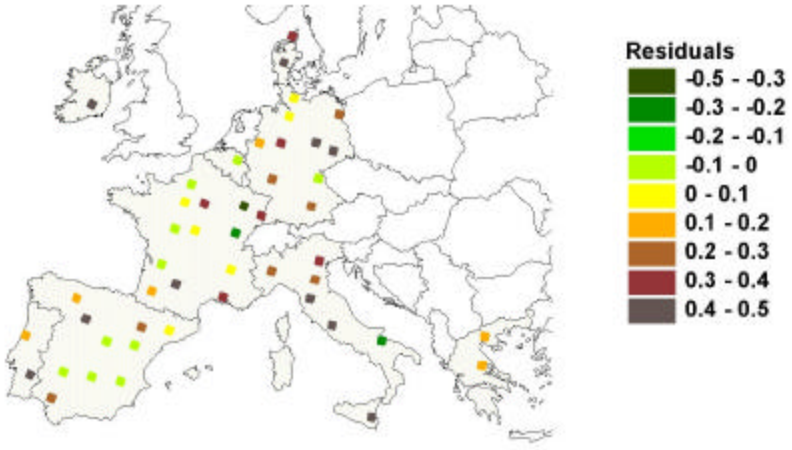


Figure 4.5: Within-site correlogram of regression residuals for the Shannon indicator.

It should be noticed that the coefficient of SH9COR is higher than 1. This is due to the tendency of the Shannon indicator to have lower values on CORINE Land Cover data than on more detailed data. The main reason for this tendency is the scale effect, acting on two ways: aggregating small patches into large polygons labelled "heterogeneous agriculture" while other small patches, that represent a low proportion in the surrounding area, are simply absorbed by the dominant class.



Map 4.1: Residuals of Shannon's Index (points) regressed with CORINE Land Cover indexes

The geographic layout of residuals (Map 4.1) suggests that CORINE Land Cover diversity indices might be overestimated in some areas, as the Centre-South of Spain and underestimated in other areas, including Portugal, most of Italy and Germany. This hypothesis should be studied on the basis of more scattered ground data.

7 Conclusions

The information given by the Shannon index and the number of classes per monitoring unit is often very different at the level of the single reference unit (segments of 196 ha or cells of 1 km^2), but become strongly correlated when they are averaged for larger units (sites of 1600 km^2). However the Shannon index computed on CORINE Land Cover is better correlated with both the Shannon index and the average number of lasses on ground data. Therefore the Shannon index should be preferred to the average number of classes.

Although the specifications of CORINE Land Cover are homogeneous, there are some indications that the different application in each country may give biased comparisons yielding higher diversity values where the photo-interpretation work has been more detailed. Testing this conjecture and mapping areas for which photo-interpretation seems to have been more detailed would be possible if a more dense ground survey were available with compatible specifications across Europe.

The parcel size, which is an important aspect of the landscape fragmentation is insufficiently indicated by CORINE Land Cover. The *% of heterogeneous agriculture* gives only a partial information: a high % of heterogeneous agriculture generally corresponds to small plots, but a low % of heterogeneous agriculture does not give information on the size of plots. Other indices from CORINE Land Cover do not seem to give any information on the parcel size.

Diversity indicators cannot be summarised into a single figure, but the % of heterogeneous agriculture in CORINE Land Cover can be combined with a standard diversity indicator to improve the correlation with ground data.

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