Evaluation of economic, social and sector impacts of agricultural land loss

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Abstract

Throughout Italy, soil sealing has had a significant impact on the landscape and on agricultural land. This issue needs to be analyzed in order to provide the policy maker with strategic information for rational land planning and environmental management. In this context, the purpose of this study is to widen our knowledge about the consumption of agricultural land in Italy, analyzing its dynamics, causes and impact. The analysis considers three specific aspects: design of a territorial model to study the extent of land consumption, qualitative-quantitative evaluation and classification of the ways in which sealing areas are extended, and analysis of impact and driving forces. The results have helped identify the extent of soil sealing on a geographical basis and, at the same time, to understand how artificialization morphotypologies are linked to the changes that take place and what impact these changes have in relation to territorial multifunctionality and hydrogeological risk.

Introduction

Throughout Italy, landscape and agricultural land are very important resources. Their conservation is an essential prerequisite for sustainable economic development (Bernetti, 2009).

Unfortunately, over the last decades, the loss of rural land caused by the expansion of production, residential and infrastructural areas has increased at twice the rate of demographic growth, with a long-term trend that is clearly not sustainable (Salvati *et al.*, 2011). Besides leading to serious hydrogeological risks, soil sealing involves a reduction in the quality of agricultural production, changes the environmental equilibrium in the agrosystem, and results in what is often an irreversible deterioration of the landscape (Munafò *et al.*, 2013).

The national and international debate on landscape planning, which started at the beginning of the 21st century with the signing of the European Landscape Convention, has highlighted the need to broaden the focus on environmentally relevant areas to embrace all quality landscapes, including those jeopardized by residential growth (Council of Europe, 2000). The problem of agricultural peri-urban areas was raised in a report by the European Economic and Social Committee on 16th September 2004. The following issues were identified as relevant for the continuity and the stability of the agricultural production activities in urban belts: urban pressure, the concept of *agriculture without farmers*, and the common agricultural policy reform itself. These problems appear to be more marked in these areas than in others with similar agro-climatic conditions, increasing the risk that agricultural activities will disappear (Tóth, 2012).

In 2006, the European Environment Agency (EEA, 2006) published a scientific report that focused on urban sprawl, providing strategic information for the development of specific policies. It is, therefore, crucial that specific action be developed for the management of a problem found in several European areas, in which the expansion of urban spaces generates a conflicting pressure with rural areas, resulting in chaotic changes in land use.

In Italy, the recent Draft Bill on the *valorization of agricultural lands and soil preservation* established the objective of promoting farming, landscape and environment for a balanced development of urbanized and rural areas. The Bill also set a limit on the use of agricultural land for construction purposes considering the following aspects: i) the size and the location of agricultural lands in relation to urbanized areas; ii) the size of land already used for construction; iii) the number of unused buildings; iv) the need to create new infrastructures. Regional landscape planning must respect these limits that govern the amount of agricultural land that can be used for construction.

Under this premise, the aim of this study is to widen our knowledge about the consumption of agricultural land in Italy, analyzing its dynamics, causes and impact. In detail, the analysis will focus on the following objectives: i) the design of a territorial model to study the extent of land consumption; ii) the qualitative-quantitative evaluation and classification of the ways in which sealing areas are extended; iii) the analysis of impact and driving forces.

On the one hand, the analyses carried out and the model used can not take into account all the possible changes in the macroeconomic context or in the legislative and policy frameworks. However, on the other hand, the methods used can provide extremely useful information to help the decision maker select the most appropriate response and, above all, to identify those areas at the greatest risk of land consumption.

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Materials and methods

Territorial information systems

In Italy, the Corine land cover (CLC) classification represents the only available information system on land use/cover (or at least the most up-to-date). The CLC project envisages the realization of land coverage cartography with a scale of 1:100,000 and using 44 items on three hierarchical levels. It refers to special units that are homogeneous or made of elementary zones belonging to the same significant (according to the scale) size class. So far, the CLC project has produced cartographies for three periods: 1990, 2000 and 2006. Because of its particular characteristics, CLC gives an approximate measure of changes in land use. In fact, the minimum survey unit is 25 ha, with a minimum linear dimension of 100 meters, and this means that only major changes are recorded. For example, a new settlement of 10 residential units might not be recorded. On the basis of existing literature (Prokop *et al.*, 2011), this can result in an underestimation of systematic land consumption of approximately 5%. Given the aims of this study, CLC 1990-2000-2006 were used together with the following geo-databases: i) Open Street Map street graph (available from: http//www.openstreetmap.it); ii) ISTAT, Territorial Indicators Systems (*Sistema Indicatori Territoriali*) (available from: http://sitis.istat.it/sitis/html/); iii) Database of National Ecological Network of vertebrates (Boitani *et al.*, 2002); iv) Map of Italian Lands Potential (Mancini and Ronchetti, 1968); v) Map of landslides and floods (number of events) and of census sites in every Municipality (Guzzetti *et al.,* 2002); vi) Map of Italian Landscapes (Ciancio *et al.*, 2004).

The territorial accounting model

The most efficient way to analyze the entity and the effects of trends in landscape change is to provide the territory with an environmental system that determines the extent and type of change (Feranec *et al.*, 2010). The methodology for the development of such a system consists in the use of a transition matrix. The matrix is based on the comparison of the changes that have occurred in a significant time interval through overlaying, with a cross tabulation procedure, two land use maps for the time points t_1 and t_2. Table 1 shows the transition map that was used in this study (Pontius *et al.*, 2004)·

In Table 1, $S_{i,j}$ represents the area that shifts from land use category i to land use category j and the values on the diagonal indicate the area that does not shift. The gross losses for each category are calculated as the difference between the totals at Time 1 (t_1) and the *persistence*, while the gross gain are calculated as the difference between totals at Time 2 (t_2) and the *persistence*. The last line of the matrix shows net and total changes. The matrix is useful to analyze what land use change categories are mostly responsible for landscape change in order to identify significant transitions on which to focus sustainability evaluations. Another advantage of using the matrix is that it can distinguish between a clearly systematic landscape transition and a seemingly random landscape transition (Pontius *et al.*, 2004) favoring impact analyses depending on temporal dynamics.

The classification of soil sealing morphotypologies

The results of recent research activities (Angel *et al.,* 2007; Herold *et al.,* 2003; Sudhira *et al.*, 2004) and other reports in literature on the analysis of the soil sealing phenomenon from a land planning point of view (EEA, 2006) led to the creation of the method for the analysis of the forms of urbanization as it is shown in the flow chart (Figure 1). The application of the method is based on the utilization of four thresholds to be identified experimentally according to the characteristics of local urban areas. The thresholds are described in Table 2. On the basis of the four thresholds, the proposed method classifies urban areas through focal analyses and binary operators in the following categories: i) main urban areas; ii) minor urban areas; iii) urban fringe areas; iv) urban sprawl areas. The details of the classification method are shown in the flowchart in Figure 1 and in Table 3. Even though it contains empirical elements, this method allows us to identify types of settlement and this is useful in order to create an initial framework assessment of critical environmental and landscape issues. However, it must be underlined that the parameters used are a suitable compromise to describe urban sprawl on a national level. In order to use such a methodology to identify territorial requalification policies, it would be appropriate to identify the geographical parameters on a smaller scale, *i.e.* nomenclature of territorial units for statistics (NUTS) 2 or 3.

Table 1. Land use change transition map.

Time 1			Time 2			Losses
	Land use 1	Land use 2	…	Land use n	Total time 1	
Land use 1	$S_{1,1}$	$S_{1,2}$	…	$S_{1,n}$	S_{1+}	$L_1=S_{1+}-S_{1,1}$
Land use 2	$S_{2,1}$	$S_{2,2}$	…	$S_{2,n}$	S_{2+}	$L_2=S_{2+}-S_{2,2}$
…	…	…	…	…	…	…
Land use n	$S_{n,1}$	$S_{n,2}$	…	$S_{n,n}$	S_{n+}	$L_n=S_{n+}-S_{n,n}$
Total time 2	S_{+1}	S_{+2}	…	S_{+n}	-	-
Gain	$G_1=S_{+1}-S_{1,1}$	$G_2=S_{+2}-S_{2,2}$	…	$G_3=S^{n+}-S_{n,n}$	-	-
Net change (gain–losses)	G_1-L_1	G_2-L_2	…	G_3-L_3	-	-
Total change (gain+losses)	$\lvert G_1\rvert+\lvert L_1\rvert$	$\lvert G_2\rvert+\lvert L_2\rvert$	…	$\lvert G_3\rvert+\lvert L_3\rvert$	-	-

Table 2. Geographical parameters for the classification of soil sealing morphotypologies.

Threshold	Unit of measurement	Description
Alpha	Pixels	Average filter kernel for the calculation of urban density
Beta	%	Percentage of urban density that identifies a compact urban area
Gamma	Square meters	Minimum surface to define an urban area as *main*
Delta	Meters	Maximum distance to define urbanisation as urban *fringe*

Land use changes drivers and impact evaluation

Land consumption is the consequence of many factors and identifying the most significant causes might be extremely difficult because of the different geographical, economic, social and political conditions in European countries, cities and regions. On the basis of the European Environmental Agency guidelines (EEA, 2006), it is possible to classify some of the main factors that drive change: i) macroeconomic: economic growth, globalization, European integration; ii) microeconomic: improvement in daily living conditions, land market; iii) local: efficiency industrial production specialization; iv) demographic: demographic growth, housing preferences; v) urban: air pollution, noise, social security, quality of life, house/apartment size; vi) transportation: availability of roads and facilities; v) regulatory: land planning guidelines, application of existing planning projects.

Specifically, according to reports in the literature (EEA, 2206; Salvati and Zitti, 2008) and national characteristics, the drivers analyzed are: distance from roads, building density, population density, and the North-South geographical gradient. The drivers can refer to a detailed geographical level or can be aggregated on the basis of administrative limits. This last distinction strongly influences the methods used to analyze driver effects on changes in land use. In the first case, geo-statistical analytical procedures can be used, while in the second case it is necessary to use econometric techniques.

Empirical geo-referred land use change models estimate the existing relationship between changes that have already taken place and physical, infrastructural or socioeconomic factors in the location where they occurred. Such techniques are used for two purposes: i) to improve the understanding of mechanisms and processes of change through an estimation of the statistical significance of tested predictors; and/or ii) to obtain an approximate prediction of possible locations of future changes in order to adopt appropriate land management initiatives. Since change in land use cannot be usually represented by a linear system, the logistical form (both binary and multinomial) could represent an appropriate explicative model (Millington *et al.,* 2007; Trexler and Travis 1993).

Generalized linear models are frequently used (Millington *et al.*, 2007; Venables and Ripley, 2002) given their ability to overcome the intrinsic limits of linear models (categorical variables, not distributed normally, etc.). The following is a possible formulation:

$$\pi(x)=\frac{e^{\phi+\omega_1 x_1+\omega_2 x_2+\ldots+\omega_i x_i}}{1+e^{\phi+\omega_1 x_1+\omega_2 x_2+\ldots+\omega_i x_i}} \qquad (1)$$

where:

$\pi(x)$ is the probability of change to occur, ϕ a is the equation constant and ω_i are the coefficients of predictive variables (drivers) x_i.

The mathematical formulation of the multinomial logit model is more complicated than the binomial model. We want to model the probability π_{ij} that observation *i* is in each j_{th} class of the m response classes *j*=1...m. The first response class *j*=1 is taken as the base class. Therefore, the base probability π_{i1} is computed as the residual probability after the other classes $\pi_{i2}...\pi_{im}$ have been modelled. Thus the model has k+1 coefficients for each of the *j*=m−1 classes (leaving the base class out): one intercept $_j$ and one *slope* for each predictor (continuous, or each class of a classified predictor) ω_{lj} , where *l*=1...k is a column in the model matrix. The fitted probabilities are then:

$$\pi_{i,j}=\frac{e^{\phi_j+\omega_{1j}x_{i1}+\ldots+\omega_{kj}x_{ik}}}{1+\sum_{l=2}^{m} e^{\phi_j+\omega_{11}x_{i1}+\ldots+\omega_{lj}x_{ik}}},\ j=2,\ldots,m$$

$$\pi_{i1}=1-\sum_{j=2}^{m}\pi_{ij} \qquad (2)$$

The success of a logistical model can be estimated with the receiver operating characteristic (ROC) curve (Liao and McGee, 2003; Rossiter and Loza, 2008). The ROC curve graphically shows the *sensitivity* of the model (in terms of correctly predicted proportions of change) in relation to the so-called *specificity* (incorrect positive predictions proportion) calculated parameterizing the probability level given by the estimated model. An efficient model, even at low levels of probability,

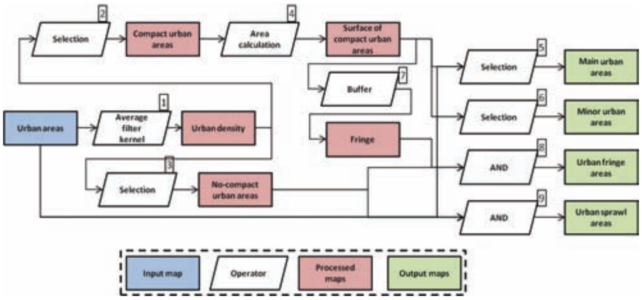

Figure 1. Flow chart for the classification of soil sealing morphotypologies.

Table 3. Operators for the classification of soil sealing morphotypologies.

Number	Operator	Parameter
1	Average filter kernel	Focal average; dimension of kernel=α
2	Selection	IF *Urban density*>β THEN 1 ELSE 0
3	Selection	IF *Urban density*$\leq\beta$ THEN 1 ELSE 0
4	Area calculation	Area calculation for *Compact urban areas*. Specific procedure depending on spatial analysis software
5	Selection	IF (*Surface of compact urban areas*>γ AND *Urban areas*=1) THEN 1 ELSE 0
6	Selection	IF (*Surface of compact urban areas*$\leq\gamma$ AND *Urban areas*=1) THEN 1 ELSE 0
7	Buffer	Buffer$_\delta$ (*Surface of compact urban areas*)
8	AND	*Fringe* AND *No-compact urban areas* AND *Urban areas*
9	AND	(NOT *Fringe*) AND *No-compact urban areas AND Urban areas*

should estimate a small percentage of incorrect positive evaluations so the slope of the ROC curve should increase rapidly. Overall, the quality of a model could be estimated by calculating the integral below the curve: in an ideal model with no incorrect predictions the area below the ROC curve is equal to 1 while in a completely random model the area is close or equal to 0.5.

The last step of the study was represented by an analysis of the potential impact of soil sealing in relation to four aspects linked to territorial multifunctionality and hydrogeological risk: i) landscape system soil sealing; ii) impact on the natural value of the ecological network of vertebrates; iii) impact on the agricultural potential of land according to its level of fertility; and iv) potential number of landslide or flood events. The landscape system classification is derived from the Map of Italian Landscapes (Ciancio *et al.,* 2004) realized through the combination of morphological, lithological and land use elements. The representative ecological network of Italian vertebrates (Boitani *et al.,* 2002) was obtained by overlaying 406 deterministic suitability models, one for each species, including 91 mammals, 194 birds, 43 reptiles, 25 amphibians and 53 fishes. In detail, it represents the distribution of the richness of species throughout the country. The potential productivity of land is classified in seven classes, from *nothing* to *high* (Mancini and Ronchetti, 1968) in relation to parameters such as the depth of soil profile, texture, draining conditions and chemical characteristics. Lastly, the number of landslide and flood events was represented cartographically in relation to the frequency distribution that was recorded by the local town councils since 1950 (Guzzetti *et al.,* 2002). The impact analysis was conducted for both the variation in soil sealing in recent decades and the potential variations for 2020. In the last case, the evaluation is made by the combination, through spatial overlay operations, of the four previously described components with the results of territorial accounting and the results of the multivariate multinomial logit model.

Results

The territorial accounting model

The results of the territorial accounting model for 1990-2000 and 2000-2006 transitions are shown in Figure 2. Table 4 focuses on transitions in the period 2000-2006.

The data show that, on a national level, the sealing rate of soil has been quite constant at over 8000 ha per year. While in the 1990-2000 period, sealing occurred at the expense of arable crops, areas with natural interest and complex particle systems, in the 2000-2006 period, urbanization has almost exclusively occupied specialized arable crop lands.

Similar studies carried out throughout Italy were based on other approaches and databases (CRCS, 2012; Pareglio, 2010). These also estimate a constant rate of soil sealing over the years with a growing trend, but their estimate of the size of the area concerned by this phenomenon is approximately half of that estimated with our approach using the CLC database. This may open up an interesting discussion about the appropriateness and effectiveness of using one database rather than another but, on the other hand, it does show how both approaches are able to clarify the phenomenon and to provide responses that are consistent with the assumptions that were made. In this context, it seems particularly interesting to highlight how different studies are able to identify and analyze the problem of soil consumption in Italy in a concordant way rather than focusing on the results, in absolute terms, produced by either study, as the results depend on the database that is used.

Classification of soil sealing morphotypologies

Figure 3 shows the national map of soil sealing morphotypologies classified according to the procedure shown in Figure 1 and Table 2. Urban sprawl is concentrated near major metropolitan areas (*i.e.* Milan, Turin, Rome and Naples), with no particular differences between northern and southern Italy. A detailed look at the Florence-Lucca-Pisa metropolitan area shows how the sprawl tends to seal major urban areas with linear strings, degrading large plains from an agronomical, landscape and environmental point of view.

Land use change drivers: the multivariate multinomial logit model

Estimation of the multivariate multinomial logit model was made in three steps: i) estimation of univariate logit models, to identify the most significant variables; ii) estimation of the soil sealing probability multivariate logit model; iii) estimation of the multivariate multinomial logit model with soil sealing morphotypologies as dependent variable.

Figure 2. Gains and losses.

Figure 3. Soil sealing morphotypologies.

Figures 4 and 5 show the results of the univariate logit models. The analysis demonstrates that all the observed territorial drivers are significant, with a high sensitivity and specificity and with areas below the ROC curve showing values much higher than 0.5. On the other hand, the observed geographical driver (the North-South geographical gradient) does not appear to be significant, confirming the hypothesis that there are no substantial probability differences between northern and southern Italy.

The combination of the different variables in the multivariate multinomial logit model (Figure 6) improves the overall quality of the estimation, with 0.83 specificity, 0.81 sensitivity and area below the ROC curve 0.892.

Figure 7 shows the map of probability of change in land use calculated on a national level.

Lastly, Table 5 shows the parameters of the multivariate multinomial model calculated using soil sealing morphotypologies as dependent categorical variable. Consistent with the hypotheses, the results highlight that the urban density driver (*dart*) especially influences the probability of expansion of compact urban areas, while the distance from roads (*distr*) is especially correlated with urban sprawling. The values of Wald statistics, all of them well over standard errors, validate the quality of the estimation.

Combining the results of the territorial accounting analysis with the models in Tables 5, it is possible to forecast changes in terms of soil sealing morphotypologies for the year 2020.

In theory, the future consumption of land depends on the market

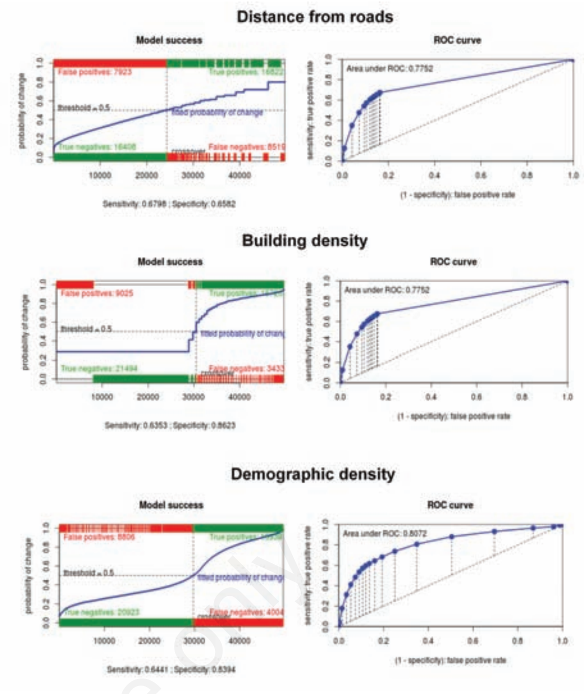

Figure 4. Probability of change in land use for territorial drivers.

Table 4. 2000-2006 transition matrix (ha).

2000	2006													
	Artificial surfaces	Arable land	Rice fields	Vineyards	Fruit trees and berry plantations	Olive groves	Pastures	Annual and permanent crops	Complex cultivation patterns	Agriculture with natural land	Agro-forestry areas	Natural surfaces	Water	Losses
Artificial surfaces	-	199	7	25	7	0	167	7	103	109	0	386	152	194
Arable land	31,077	-	1849	2501	1692	394	0	321	956	49	0	873	1153	6811
Rice fields	901	2135	-	0	0	0	0	0	0	0	0	0	5	507
Vineyards	547	731	0	-	0	0	0	11	37	0	0	0	0	221
Fruit trees and berry plantations	269	863	32	25	-	0	0	46	125	0	0	0	40	400
Olive groves	1688	116	0	11	46	-	0	202	230	177	0	14	0	414
Pastures	746	78	0	13	0	16	-	73	0	0	0	307	13	208
Annual and permanent crops	716	273	0	119	468	500	6	-	179	232	0	88	6	431
Complex cultivation patterns	7536	154	17	113	159	0	0	0	-	5	0	12	154	1358
Agriculture with natural land	1349	176	0	20	124	145	0	20	44	-	6	881	189	492
Agro-forestry areas	46	0	0	0	0	0	0	0	0	0	-	0	304	58
Natural surfaces	2880	1663	41	216	116	85	14	93	107	1436	16	-	1872	1423
Water	50	378	0	0	0	0	0	0	0	0	0	733	-	194
Gains (ha/year)	8134	1128	324	507	435	190	31	129	297	335	4	549	648	-

equilibrium between the demand and supply of land for residential and commercial building.

An individual model of residential land use demand *f* (Peng and Weaton, 1993) can be formulated, at a first stage, as a function of the annual price for the use of a residence *r* (the installment of a hypothetical mortgage or a rental fee), of income *I* and of the prices of the other goods in the consumer basket P_z; aggregate demand *F* will then depend on the increase in the number of families in the area *n*:

$$F = f \cdot n = f(r, I, P_z) \tag{3}$$

Considering *r* and P_z to be constant throughout Italy, (3) can be written as follows:

$$F = n \cdot f(I) \tag{4}$$

Similarly (Wheaton *et al.* 1990), the increase in the aggregate demand of land for industrial use *K* will result from the increase of employment *M*, the increase of the value of production *W* and from the cost of capital *c:*

$$K = f(M, W, c) \tag{5}$$

Considering *c* constant, we have:

$$K = f(M, W) \tag{6}$$

The supply of land, on the other side, given the requirements of Italian legislation, is determined by local (currently regional and provincial) urban planning policies.

Although the construction of macroeconomic scenarios of land con-

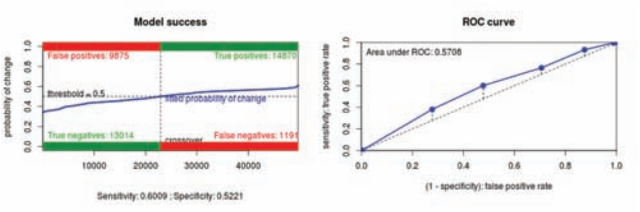

Figure 5. Probability of change in land use for the geographical driver.

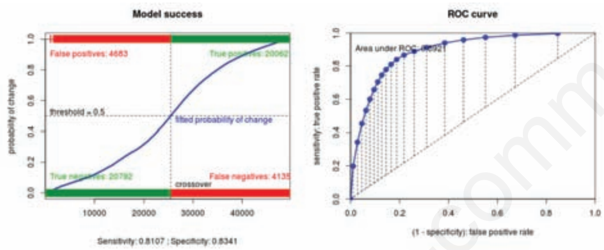

Figure 6. Multivariate logit model.

Table 5. Multivariate multinomial logit model.

	Intercept	log(dart+5)	log(distr+150)	log(pop+10)
Coefficients				
Centres	−15.080	3.5253	−0.3189	0.6623
Fringe	−7.1099	1.7916	−0.3066	0.6151
Sprawl	−0.5865	0.4593	−0.5652	0.6167
Std. errors				
Centres	0.4038	0.0734	0.0406	0.0243
Fringe	0.1788	0.0260	0.0213	0.0157
Sprawl	0.1029	0.0185	0.0129	0.0114
Value S/E	-	-	-	-
Wald statistics				
Centres	−37.343	48.049	−7.8631	27.149
Fringe	−39.775	68.842	−14.338	39.299
Sprawl	−5.5177	24.864	−43.883	53.942
Residual deviance	77,443	-	-	-
AIC	77,467	-	-	-

Std, standard deviation; AIC, Akaike Information Criterion.

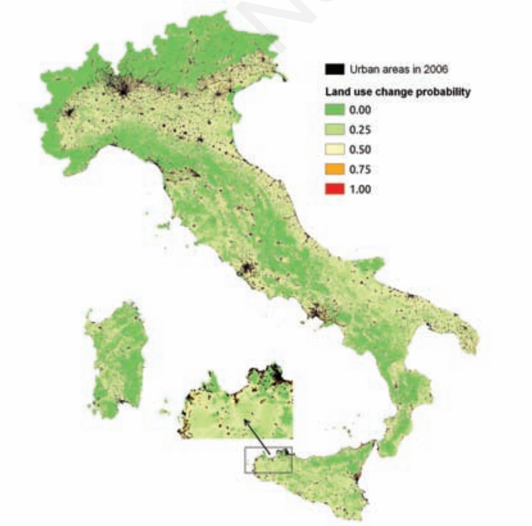

Figure 7. Change probability

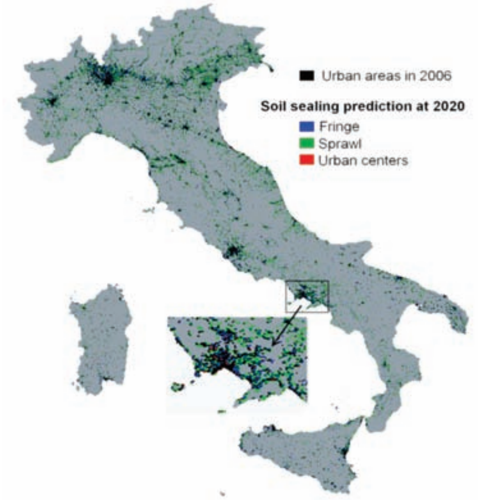

Figure 8. New soil sealing morphotypologies probability: results of the multinomial model.

sumption is beyond the aims of this study, as an example of the potential of the model, the map in Figure 8 shows a forecast, calculated on the basis of a national urbanization rate of 8000 ha per year (equal to the 2000-2006 rate). The simulation shows that the greatest expansion is linked to sprawl dynamics while densification of existing urban areas is almost non-existent.

Impact analysis

The last step of the study concerned the analysis of the possible environmental impact of changes that have already occurred and of the 2020 projections shown in the previous paragraph.

The different impacts were divided according to the different aspects of the multifunctionality of the territory and to hydrogeological risk.

The landscape systems considered in the study (Figure 9) represent 90% of soil sealing in the last decade. The first measured impact concerns the plain areas in which the greater consumption of soil takes place. This impact covers 61% of the overall change, caused by urban sprawl for 38% and by urban fringe for 18%. The soil sealing of the plains affects the open plains More than the half of soil sealing impacts on the open plains, while the remaining impact is concentrated in the costal plains and valleys. The other landscape systems in which soil sealing takes place regard the remaining 30% of the total area characterized by the phenomenon, corresponding mainly to hill systems which, in contrast to what it was seen for the plain areas, are linked to urban sprawl.

The projections for 2020 show that the area involved in the phenomenon should more than double, with a similar distribution in the landscape systems. However, a greater impact on the coastal plain areas, on the metropolitan areas and on the foothills is estimated compared to the period 2000-2006.

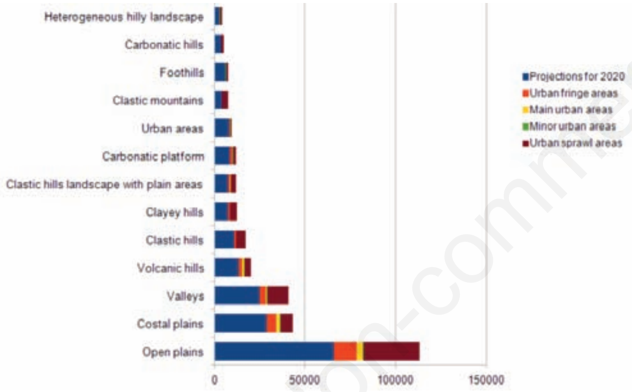

Figure 9. Artificialization for the landscape systems.

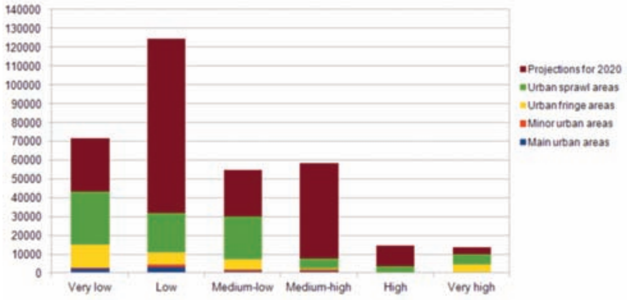

Figure 10. Impact on natural value of the ecological network of vertebrates (hectares of soil sealing morphotypologies per natural value class).

The impacts on the ecological network of vertebrates were classified in relation to the natural value of the areas (Figure 10). In this case, the major impacts on the territory linked with soil sealing phenomena mainly affect those territories characterized by a low natural value; only 26% involve those showing a high natural value. Also in this respect, these effects are related to the sprawl phenomena for 64% and to urban fringe areas for 27%.

Also in the case of natural value, the impact of soil sealing more than doubles, but it is not equally distributed with respect to the value of the territories, mainly affecting those characterized by low and medium-high value.

The impacts calculated in relation to the agricultural potential of the soils show that the greatest effects occur precisely in those areas characterized by a higher productivity (soils with a high to moderate productivity potential). This observation is in line with findings concerning landscape systems, especially with regard to how soil sealing affects in particular plain areas (Figure 11). The data analysis shows that 72% of the effects related to the sealing affect areas with high agricultural potentiality, 27% those with a moderate agricultural potentiality (soils with poor to very low productivity potential) and only 1% those with no productivity potential at all. Moreover, the impacts analyzed for morphotypologies of soil sealing show a variation for soils that have very limited agricultural potentiality, varying from 70% to 86%. This last figure highlights the fact that, regardless of the type of urbanization, the soils that are shown to be the most suitable for agricultural purposes are those that have always been used. In 2020, the area of territory affected by soil sealing should more than double, but on average its distribution in relation to the agricultural potentiality of the soils would remain the same as that of the previous period.

Lastly, we examined the number of landslides and floods, in terms of their frequency distribution related to soil sealing variation. Figure 12 shows the areas affected by landslides and flooding, classified by the number of events per year; sprawl concerns 58% of the area affected by landslides, and urban fringe 27%. In terms of frequency of the events, the highest frequency is seen in the class *more than 25 events* (35% of the area affected by the phenomenon); in urban sprawl areas, the high-

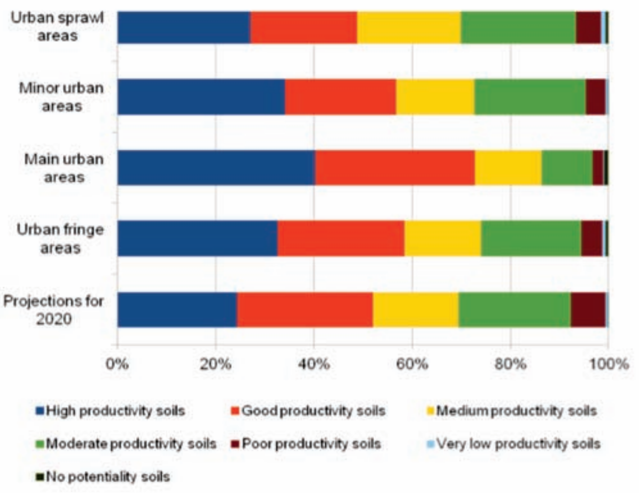

Figure 11. Impact on the agricultural potential of lands according to their fertility level.

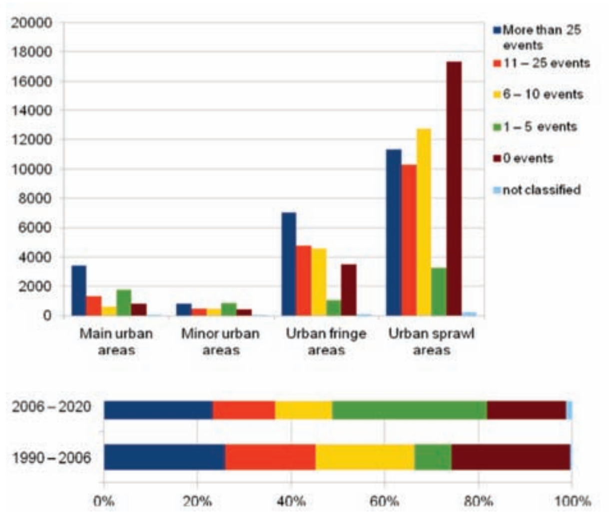

Figure 12. Number of landslides and floods.

est frequency is seen in the class *6-10 events*, while for fringe areas the frequency of events increases, and here the highest frequency is seen in the class *more than 25 events*. In this last case, the projections for 2020 show that the number of the areas involved should more than double and a distribution that shifts to a smaller number of events per year, but these are obviously characterized by a much greater intensity.

Conclusions

The widening of the cognitive framework concerning consumption of agricultural land throughout Italy has helped to identify and forecast its major causes and impacts. These results were achieved by the construction and implementation of a territorial model to study the extent of land consumption, the classification and qualitative-quantitative evaluation of soil sealing morphotypologies, and an analysis of the impact of driving forces.

The methodology used was based on the *transition matrix* that compares the changes that have occurred over a significant period of time by overlaying two land use maps relating to two different time points. The classification of soil sealing morphotypologies was used to support the matrix, with typologies representing different urbanization forms. This classification was realized through the use of four thresholds experimentally defined according to the characteristics of urban areas in the territory examined. Moreover, as land consumption is the result of a series of geographical, economic, social and political factors, many explicative drivers were identified for land use change. The drivers were identified on a detailed geographical level, so that a geostatistical analysis could be conducted to better understand the mechanisms and processes of change and/or to forecast the localization of future changes.

The results have helped identify soil sealing on a geographical basis and, at the same time, to understand how morphotypologies are linked to the changes and what is the impact of such changes in relation to territorial multifunctionality and hydrogeological risk. Moreover, it was possible to forecast the evolution of soil sealing in relation to its localization and to different land services.

Data analysis showed that plains and areas with high agricultural potential are the most sensitive. It is evident that this phenomenon, mainly caused by urban sprawl and fringe expansions, has an important impact on both landscape and production as it targets those territories with higher agricultural vocation. An important impact was also observed on the natural value of the ecological network of vertebrates and on the potential number of landslides and floods. Therefore, the research has also confirmed that the recent legislative initiatives (such as the Italian Government Draft Bill on the *valorization of agricultural lands and soil preservation*) are satisfactory in the light of the emergency situations illustrated by the analyzed data. Under the hypothesis of the persistence of the current trends, the impact observed in this study is destined to grow and average land consumption will exceed the 8000 ha per year recorded in the 2000-2006 period. This growth will particularly affect specialized arable crop areas and will mostly take the form of urban sprawl. Sprawl growth (both current and in the 2020 projection) mainly takes place in major metropolitan areas, progressively and linearly sealing the main cities seriously degrading the large plains in terms of agronomical, environmental and landscape damage.

The main limitation of this research is the database that was used. In fact, the CLC classification identifies changes in land use on areas over 5 ha. Although acceptable on a national scale, this is not suitable for detailed assessments on a regional or provincial level (NUTS 2 and NUTS 3). Moreover, it would be useful to integrate the methodology with an econometric land use model in order to identify scenarios that can help assess the effects of policies aimed at limiting land consumption.

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