Abandonment and Expansion of Arable Land in Europe

Erez Hatna[1]* and Martha M. Bakker[2]

[1]Department of Geography, Planning and Environment, Institute for Management Research, Radboud University, Nijmegen 6500 HK, The Netherlands; [2]Land Dynamics Group, Department of Environmental Science, Wageningen University, Wageningen 6700 AA, The Netherlands

ABSTRACT

Abandonment of arable land is often assumed to happen mostly in marginal areas where the conditions for arable cultivation are relatively unfavorable, whereas arable expansion is expected to occur mostly in areas with favorable conditions. This assumption, used in many land-use change forecasts, was never properly tested, mainly because the relatively short period of full-coverage land-use inventories did not allow a systematic analysis of the phenomena. With the recent release of CORINE 2006 this has changed. In this article, we explore the typical locations of abandonment and expansion of arable land in Europe during the period 1990–2006 by means of logistic regressions. More specifically, we test whether or not locations of abandonment and expansion can be inferred from the location characteristics of arable land in 1990. If the above assumption holds, this should be the case. We demonstrate that although arable expansion indeed happens in locations that resemble the bulk of arable land in 1990 (the presumably favorable locations), arable abandonment does not necessarily happen in locations that resemble the bulk of uncultivated land (that is, the presumably unfavorable locations). In other words, the assumption does not hold. Particularly, areas close to the road network were found to be associated with both high abandonment rates and high expansion rates, which suggest that abandonment is not limited to areas that are marginal in terms of agricultural production.

Key words: land-use change; Europe; agriculture; cropland; land abandonment.

INTRODUCTION

The past decades showed a gradual decline in agricultural area in Europe. This decline is usually attributed to modernization and intensification of agriculture, which boosted agricultural yields and allowed a decrease in area and labor devoted to agriculture (Ramankutty and Foley 1999). When a farmer stops farming, the land may be sold to other farmers or to property developers. When the

farmer cannot sell the land, cultivation will stop (although extensive use may be continued), and the land may eventually get repopulated by plants from the surrounding habitats (Sluiter and de Jong 2007). This latter process is often referred to as land abandonment, and is considered a problem from social and environmental points of view (Bakker and others 2005; García-Ruiz and Lana-Renault 2011).

Ecosystem functioning is strongly determined by agricultural land use. Knowing where agricultural practices will end and where they will start is crucial knowledge for the anticipation of ecosystem performance. European land-use studies have largely focussed on agricultural abandonment, as this happened more frequently than agricultural expansion.

Furthermore, concern about the impacts of abandonment on biodiversity and ecosystem functioning increased, as awareness of the importance of farming practices in certain agro-ecosystem grew. Several of these land-use studies suggested that agricultural abandonment is more likely to occur in marginal areas where biophysical conditions are relatively poor and economical activity is low (Lehouerou 1993; Tatoni and Roche 1994; MacDonald and others 2000; Lasanta and others 2006; Sluiter and de Jong 2007). Factors often associated with the location of land abandonment were topographic factors like elevation and slope (Mottet and others 2006), soil-related factors such as soil depth and erosion (Burgi and Turner 2002; Bakker and others 2005), climate conditions (Gisbert and others 2005), socio-economic factors such as the existence of alternative occupations for farmers (Kozak and others 2004; Rey Benayas and others 2007), and level of accessibility (Nagendra and others 2003). These studies are mostly based on small areas, biased towards marginal areas, and/or based on anecdotal or circumstantial evidence. Whether or not their findings can be extrapolated to wide-scale land-use change patterns is therefore unclear.

Although agricultural abandonment is considered a relatively complicated phenomenon with many driving factors, the prevailing perception is that it mostly occurs in areas that deviate from the bulk of agricultural land in a negative way, for example, by being more remote, having poorer soils, or exhibiting unfavorable topography. This assumption was often used in land-use modelling to identify areas that are likely to become abandoned in the coming years (Verburg and others 2006; Lesschen and others 2007; Verburg and Overmars 2009). The followed approach generally consisted of estimating the statistical likelihood for the occurrence of agricultural activity based on a set of factors such as soil type, slope, and population density. Agricultural areas with a relatively low statistical likelihood for agricultural activities were considered more sensitive to agricultural abandonment. The advantage of this assumption is that it requires only a single land-use map of the area of interest, rather than a panel or time series of land-use maps. The validity of inferring the location of abandonment from the location characteristics of agriculture, however, was never tested.

This article presents an empirical analysis of the actual arable abandonment and expansion occurring between 1990 and 2006 in Western, Eastern, and Southern Europe. With the release of the CORINE 2006 land cover maps, the amount and extent of arable abandonment and expansion occurrences allows, for the first time, a reliable empirical assessment of location properties of these land-use changes. Our first aim is to learn more about the location-determinants of agricultural abandonment and expansion; we achieve this by logistic regression analyses to describe the location characteristics of arable abandonment and expansion occurrences. The second aim is to explore the validity of inferring the location of abandonment and expansion from characteristics of arable land; to achieve this we perform a regression analysis that estimates the statistical likelihood of arable land (as opposed to uncultivated land) and test how well this regression describes occurrences of observed arable abandonment and expansion.

DATA

Land use was inferred from the CORINE1990 and CORINE2006 datasets (100-m resolution version) (EEA 2010). Because of limited extents of both datasets the following countries were not included in the analysis: Sweden, Finland, the UK, and Greece. The CORINE land-use/cover classes were aggregated into three categories: Arable land, uncultivated land, and other land use/cover (see Table 1 for more details). The uncultivated land category represents land-cover types that eventually appear after land abandonment (for example, natural grasslands, scrubland, and wetland). Hence, conversions from arable land in 1990 to uncultivated land in 2006 were taken to represent cases of arable abandonment, whereas conversions from uncultivated land in 1990 to arable land in 2006 were taken to represent cases of arable expansion. Conversions to and from other land uses (for example, cultivated pastures, agro-forestry land, artificial surfaces) were not taken into account.

Table 1. The Land-Use Classification Used in the Study

Newly derived Land use category	CORINE land-use/cover category
Arable land	Non-irrigated arable land, permanently irrigated land, rice fields
Uncultivated land	Scrub and/or herbaceous vegetation associations, open spaces with little or no vegetation, inland wetlands
Other land uses	Artificial surfaces, permanent crops, cultivated pastures, heterogeneous agricultural areas, forests, water bodies, all the rest

The abandonment that we therewith observe is long-term abandonment, as considerable time has to elapse before a new land cover develops. This also means that we observe only abandonment that must have occurred at least several years before 2006. As for the exact processes that preceded these land-cover changes, we cannot be entirely sure. We believe that in most cases the farmer stopped using the land and was unable to sell it. Yet, in countries with high land pressure (for example, The Netherlands), what we observe as land abandonment, may be cases where the land was sold to nature conservation organizations, or to private parties, for instance for the purpose of horse-keeping. This latter process is sometimes called horsification and is considered a special type of abandonment. Furthermore, we assume that changes from arable land in 1990 to forest in 2006 were mostly the result of planting production forest, and not the result of abandonment. By not including forests in uncultivated land we avoided mistaking conversions to production forest for abandonment.

The land-use maps were complemented with maps of ten spatial factors: slope, sun exposure, soil depth, soil water-holding capacity (WHC), stoniness, mean annual temperature, precipitation during growing season, cost distance to road network, distance to major cities, and regional population density (Table 2). The slope variable was derived from the SRTM digital elevation model (DEM) of the CGIAR Consortium for Spatial Information (http://srtm.csi.cgiar.org) using the slope function of the ESRI ArcGIS package. Sun exposure represents the relative amount of solar radiation a surface receives given its topography. It was calculated from the same DEM using ESRI ArcGIS Hillshade procedure given a 180° azimuth angle and a 45° altitude angle of the light source. Soil depth, water-holding capacity, and stoniness were taken from the European Soil Database. The soil depth variable represents soil depth to bedrock or impermeable layer in centimetres. Water-holding capacity represents the volumetric fraction of soil water available to plants. Stoniness represents the amount of stones in the soil based on the soil type. The temperature variable represents the mean annual temperature, averaged over the period 1960–1990 and was taken from the WORLDCLIM dataset. The precipitation variable contains the cumulative precipitation from March

Table 2. Factors Used in the Analysis

Factor	Description	Source
Slope (°)	Slope angle in degrees, derived from the original 70 m DEM	Derived from SRTM DEM
South exposure	A relative measure indicating the sun-exposure. Ranges from 0 to 255	Derived from SRTM DEM
Soil depth (cm)	Soil depth to bedrock or impermeable layer. Truncated at 1-m depth	Derived from European Soil Data Base by pedotransfer functions (Jones and others 2000)
WHC (mm/m)	Water-holding capacity. Volumetric fraction of soil water available to plants: the amount of water in mm held between field capacity (5 kPa) and permanent wilting point (1500 kPa) per cm soil depth, averaged for the entire soil depth	Derived from Jones and others (2000)
Stoniness (%)	The percentage of stones according to soil type	Derived from European soil data base by pedotransfer functions (Jones and others 2000)
Temperature (°C)	Mean annual temperature, averaged over the period 1960–1990	WORLDCLIM (Hijmans and others 2005)
Precipitation (mm)	Cumulative precipitation from march to august (generic growing season), averaged over the period 1960–1990	WORLDCLIM (Hijmans and others 2005)
Cost distance	Accessibility to the read network given a cost surface	Derived from GISCO roadmap (EuroStat) and SRTM DTM
Distance to major cities (m)	Euclidian distance to nearest major city	Derived from CORINE 1990 and www.city-population.de
Population density	Number of persons per square kilometer at NUTS2 units	EUROSTAT

to August (generic growing season), averaged over the period 1960–1990. The cost-distance variable represents the effort needed to reach the nearest road, and therewith represents accessibility. It was calculated using the cost-distance procedure of ArcGIS, whereby the ''cost'' on flat area was defined as one unit per meter. It was assumed that each degree of slope adds 0.2 units to the cost. The cost-distance is the accumulated cost for all cells between a location and the nearest road. The distance to major cities represents the Euclidean distance to the nearest large city. Regional population density represents the number of persons per square kilometer at NUTS2 level in 1990. To avoid problems of reversed causality between factors and land-use change, all factors represent the state before 1990. To reduce autocorrelation between adjacent points, the maps were systematically sampled every 900 m.

To avoid obscuring processes by studying areas that are structurally different within one regression analysis (described in the next section), Europe was divided into three regions: Western Europe, Eastern Europe, and Southern Europe. The division between east and west was made according to membership of EU15, whereas Southern Europe was distinguished according to climate characteristics as defined by Metzger and others (2005).

METHODOLOGY

General Trends and the Pattern of Observed Abandonment

The areas that underwent abandonment and expansion in the three regions were summed for each region to describe the general trends. A map of abandonment rates was created to obtain a general view of where abandonment occurred mostly between 1990 and 2006. Abandonment rates were presented at NUTS2 level as the percentage of the arable area in 1990.

Identifying the Spatial Factors Associated with Abandonment and Expansion

The associations between observed cases of abandonment and expansion (dependent variables) and the set of spatial factors (independent variables) were assessed using logistic regressions. We refer to these regressions as the *change regressions*, whereby we distinguish between the *abandonment regression* and the *expansion regression*. In the abandonment regression, cases of arable land in 1990 that changed into uncultivated land in 2006 were coded as ''1'' whereas cases of unchanged arable land were coded as ''0'' (Table 3). Accordingly, in the expansion regression, cases of uncultivated land in 1990 that changed into arable land in 2006 were coded as ''1'' whereas cases of unchanged uncultivated land were coded as ''0'' (Table 3).

The GLM procedure of the R software environment was used (R Development Core Team 2010). Rare event logistic regression (King and Zeng 2001) was used to account for the relatively small number of 1's compared to the much larger number of 0's. The regressions were calculated using the *Zelig* package (Imai and others 2006). The number of 0's sampled was such that each of the two datasets (one for abandonment and one for expansion) consisted of a total of 20,000 observations. As the regression analyses were based on samples of 0's, it was important to make sure that the regressions were robust to the sampling procedure. This was done as follows: for each regression, the sampling procedure was carried out 100 times and 100 regressions were calculated. We considered a regression coefficient meaningful for interpretation only in cases where two conditions were met: at least in 95 out of the 100 regressions the coefficient had the same sign (either positive or negative) and was significant according to the Wald statistic ($P < 0.05$). The goodness of fit of the regressions was estimated using McFadden's R^2 statistic (McFadden 1973). It is

Table 3. Description of Cases Marked as ''1'' and ''0'' in the Abandonment, Expansion and Arable/Uncultivated Logistic Regressions

	Regression	Cases marked as '' 1''	Cases marked as '' 0''
a	Abandonment	Locations that were arable in 1990 and uncultivated in 2006	A sample of locations that were arable in both 1990 and 2006
b	Expansion	Locations that were uncultivated in 1990 and arable in 2006	A sample of locations that were uncultivated in both 1990 and 2006
c	Arable/uncultivated	A sample of locations that were arable in 1990	A sample of locations that were uncultivated in 1990

calculated as the ratio of the likelihood of a regression model which contains the intercept and covariates (L_1) and the likelihood of a regression model which contains the intercept only (L_0): $R^2 = 1 - L_1/L_0$.

To visualize the regressions, we created maps of the statistical likelihood for abandonment and expansion using a GIS that contained the maps of all explanatory factors. We marked the locations with a relatively high probability (that is, probability above the 90th percentile) for abandonment or expansion in each of the three regions. Locations where these high probabilities coincided were also marked. The resulting map indicates the sensitive locations for abandonment and expansion, regardless of the rate of the processes.

Testing the Assumption that Abandonment and Expansion can be Inferred from Location Characteristics of Arable and Uncultivated Land

To test whether abandonment indeed happened in areas with low statistical likelihood for arable land, and whether expansion indeed happened in areas with high statistical likelihood of arable land, we performed regressions that infer the statistical likelihood of arable land in 1990 from the same set of spatial factors. As the 0's in this regression represent uncultivated cells, we refer to this regression as the *arable/uncultivated regression*. This regression expresses the statistical likelihood of finding arable or uncultivated land as a function of the spatial factors, just like the change regressions did for abandonment and expansion occurrences. We confined our sample of uncultivated land to cases where arable cultivation is feasible. This was done because in many natural areas agriculture is simply not feasible, and including such areas may bias the regression analysis. The areas where arable cultivation is feasible were defined as the set of uncultivated cases that are within the factor intervals of arable land occurrences in 1990. These intervals are presented in Table 4. Uncultivated areas with very steep slopes, very shallow soils, low water-holding capacity, low temperatures, low precipitation, or that were very remote, were hence excluded from the analysis.

Uncultivated observations were coded as ''0'' and arable observations were coded as ''1'' (Table 3). For all three zones, the regressions were based on a balanced sample of 20,000 records: 10,000 0's and 10,000 1's. Also here, the sampling procedure was repeated 100 times, and the goodness of fit of the regression was estimated using McFadden's R^2.

Table 4. The Factor Interval Where Arable Land Occurred in 1990

Factor	Interval
Slope (°)	[min,43)
Soil depth (mm)	(20,max]
Water-holding capacity (mm)	(0.61,max]
Temperature (°C)	(2,max]
Precipitation (mm)	(65,max]
Distance to main cities (km)	[min,1547)

The interval is the intersection of the six individual intervals.

To examine the degree to which abandoned areas had a low statistical likelihood for arable compared to unchanged arable land, we computed the descriptive power of the arable/uncultivated regressions for observed occurrences of land abandonment and unchanged arable land. Hereto, we considered the regression-derived probability for arable land P_{Arable} as the probability for unchanged arable land, and $1 - P_{Arable}$ as the probability for abandonment. For a balanced sample of abandonment and unchanged arable land observations, we computed the likelihood for each record as $(1 - P_{Arable})^y \cdot P_{Arable}^{1-y}$ where $y = 1$ for cases of arable abandonment and $y = 0$ for cases of unchanged arable land. The total likelihood (L_1) is the product of all individual likelihoods. The goodness of fit of the arable/uncultivated regressions for the sample of observed abandonment and unchanged arable land was calculated as the ratio of the total likelihood (L_1) and the likelihood of a regression model which contains the intercept only (L_0): $R^2 = 1 - L_1/L_0$. Note that, as we used a balanced sample (50% abandonment and 50% unchanged arable land), $L_0 = 0.5^n$, whereby n is the total number of sampled observations.

This procedure was repeated for a sample of expansion and unchanged uncultivated land observations, whereby the likelihood for each observation was computed as $P_{Arable}^y (1 - P_{Arable})^{1-y}$ where $y = 1$ for cases of arable expansion and $y = 0$ for cases of unchanged uncultivated land.

Regression Comparison

The individual regression coefficients were compared between the change regressions and the arable/uncultivated regressions and also between the abandonment and expansion regressions. The degree of colinearity between the spatial factors does not allow a detailed quantitative comparison, thus the comparison was limited to cases of obvious
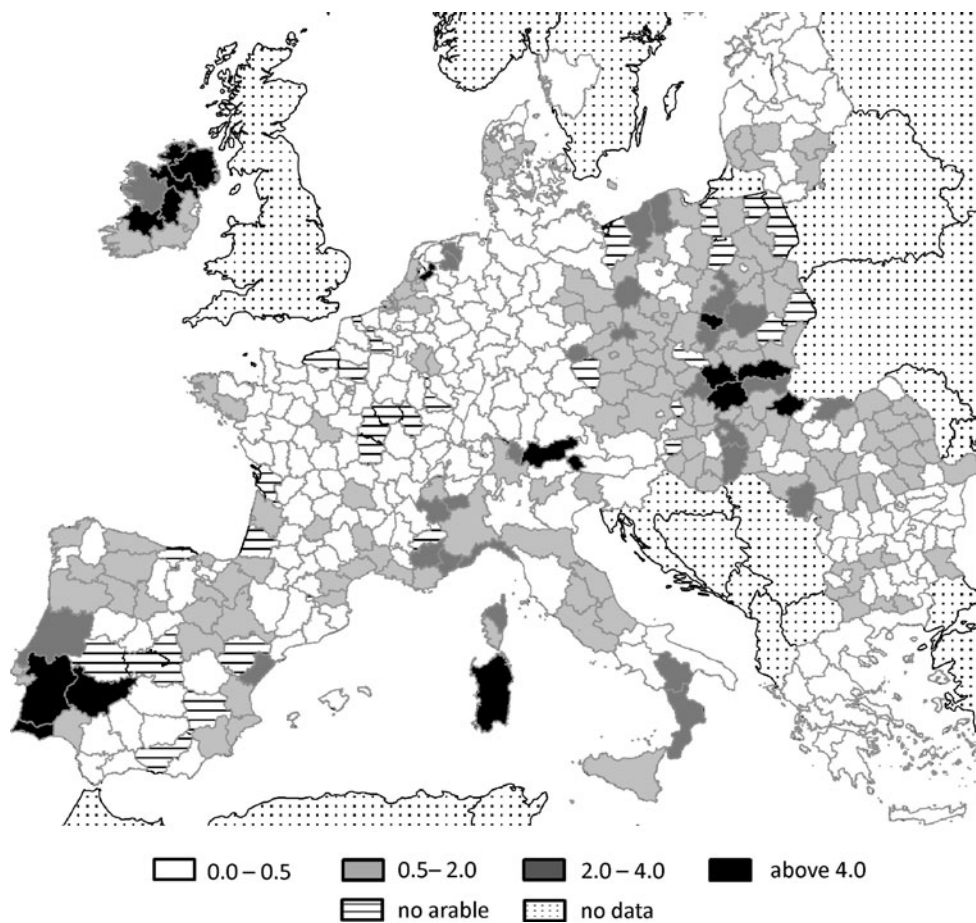
Figure 1. The rate of abandonment between 1990 and 2006 in percentages of the total arable area in NUTS2 units.

deviation, that is, when a coefficient for one factor had opposite signs in two regression equations.

RESULTS

General Trends and Patterns of Observed Abandonment

In Western Europe, a total area of about 54,920 ha was abandoned whereas arable land expansion comprised about 15,470 ha. In Eastern Europe, an area of about 67,960 ha was abandoned whereas expansion comprised an area of about 9,800 ha. The areas affected by the two processes in Southern Europe were larger and more balanced: about 118,020 ha underwent abandonment and about 114,780 ha underwent expansion. The map of abandonment relative to the area of arable land in 1990, at NUTS2 level, is presented in Figure 1. The spatial distribution suggests that abandonment is not limited to marginal areas, that is, areas where biophysical conditions are poor and economical activity is low. Contrarily, the supposed marginal areas in mountainous regions appear relatively stable. Because Figure 1 shows abandonment relative

to the initial arable area, a visual interpretation may overemphasize regions with little arable land. A more detailed spatial analysis is therefore described in the next paragraphs.

Spatial Factors Associated to Abandonment and Expansion

The coefficients and goodness of fit of the regressions that describe observed abandonment and expansion (the change regressions) are presented in Table 5 for the three zones, in the second and third columns. In general, observed abandonment and expansion is more strongly related to the spatial factors in Southern Europe than in the other two regions. For all three regions, observed expansion is more strongly related to the spatial factors than abandonment. This is particularly so for Western and Eastern Europe and to a lesser degree for Southern Europe.

Throughout Europe, abandonment happened mostly in warm regions with dense population and high accessibility (close to roads and/or cities). In Eastern and Southern Europe it also happened more on undulating terrain with shallow soils,

Table 5. The Coefficients and Goodness of Fit of the Abandonment, Expansion and Arable/Uncultivated Regressions for Western, Eastern and Southern Europe

Variable	Abandonment	Expansion	Arable/uncultivated
Western Europe			
Slope	*2.10E−02*	−1.59E−01	−2.76E−01
South exposure	*8.48E−03*	*2.57E−03*	−2.08E−05
Soil depth	*−4.42E−03*	2.65E−02	1.63E−02
WHC	−3.07E−01	6.44E−01	9.82E−01
Stoniness	−8.31E−01	*−1.79E−02*	*−1.78E−01*
Temperature	8.72E−02	3.60E−01	−9.79E−02
Precipitation	*4.23E−04*	−2.68E−03	−1.19E−02
Cost distance	−5.79E−05	−3.25E−05	−2.08E−05
Distance to cities	*−1.54E−06*	−7.09E−06	−1.87E−06
Region pop density	8.81E−04	1.25E−03	*−1.31E−04*
McFadden's R^2 (%)	5	29	36
Eastern Europe			
Slope	1.14E−01	−2.28E−01	−3.44E−01
South exposure	*2.84E−03*	*−8.31E−03*	2.07E−02
Soil depth	−1.15E−02	2.99E−02	2.02E−02
WHC	−1.26E+00	*1.74E−01*	8.62E−01
Stoniness	−9.61E−01	−9.86E−01	*1.73E−02*
Temperature	9.08E−02	4.16E−01	3.21E−01
Precipitation	*1.37E−04*	1.28E−02	5.41E−03
Cost distance	−9.69E−06	*−1.21E−05*	−2.59E−05
Distance to cities	1.51E−06	−5.28E−06	−2.70E−06
Region pop density	2.76E−04	*3.47E−04*	*3.24E−04*
McFadden's R^2 (%)	4	22	27
Southern Europe			
Slope	6.15E−02	−1.34E−01	−2.56E−01
South exposure	*4.68E−03*	*1.91E−03*	1.21E−02
Soil depth	−1.05E−02	1.35E−02	2.19E−02
WHC	−9.80E−01	*5.76E−02*	1.11E + 00
Stoniness	−1.80E−01	−4.80E−01	*−1.05E−01*
Temperature	1.30E−01	1.22E−01	1.20E−01
Precipitation	−5.89E−03	−3.66E−03	*−9.89E−04*
Cost distance	−1.25E−05	−2.21E−05	−3.37E−05
Distance to cities	−1.01E−06	1.58E−06	−9.29E−07
Region pop density	1.56E−03	*3.20E−04*	*2.66E−04*
McFadden's R^2 (%)	31	40	47

Goodness of fit is expressed as McFadden's R^2. Insignificant coefficients are in italics.

having a low water-holding capacity and few stones. In Western Europe, abandonment did not happen particularly on sloping land or shallow soils. In Southern Europe, abandonment also happened more in dry regions.

In the three regions, expansion happened mostly in warm areas, on deep soils and flat terrain. In Western Europe, expansion is also located in accessible, densely populated areas, close to cities, and on soils with high water-holding capacity. In Eastern Europe, expansion happens mostly in rainy areas and near cities whereas in Southern Europe, it happens mostly in dry areas that are close to roads, but far from cities.

Figure 2 shows areas that are most prone to abandonment or expansion. About 14% of the abandonment-prone locations coincided with expansion-prone locations, indicating areas with an increased likelihood of both processes. (Note that because these maps were computed from the factor maps, we could also include the countries for which no land-use data existed). Should the selection criteria for land-use decision-making stay the same within the near future, it can be seen that abandonment risks are high in Belgium, the south of the Netherlands, north and central Romania, Mediterranean coastal zones, Slovakia, and the southeast of the UK. Arable expansion, if any, is
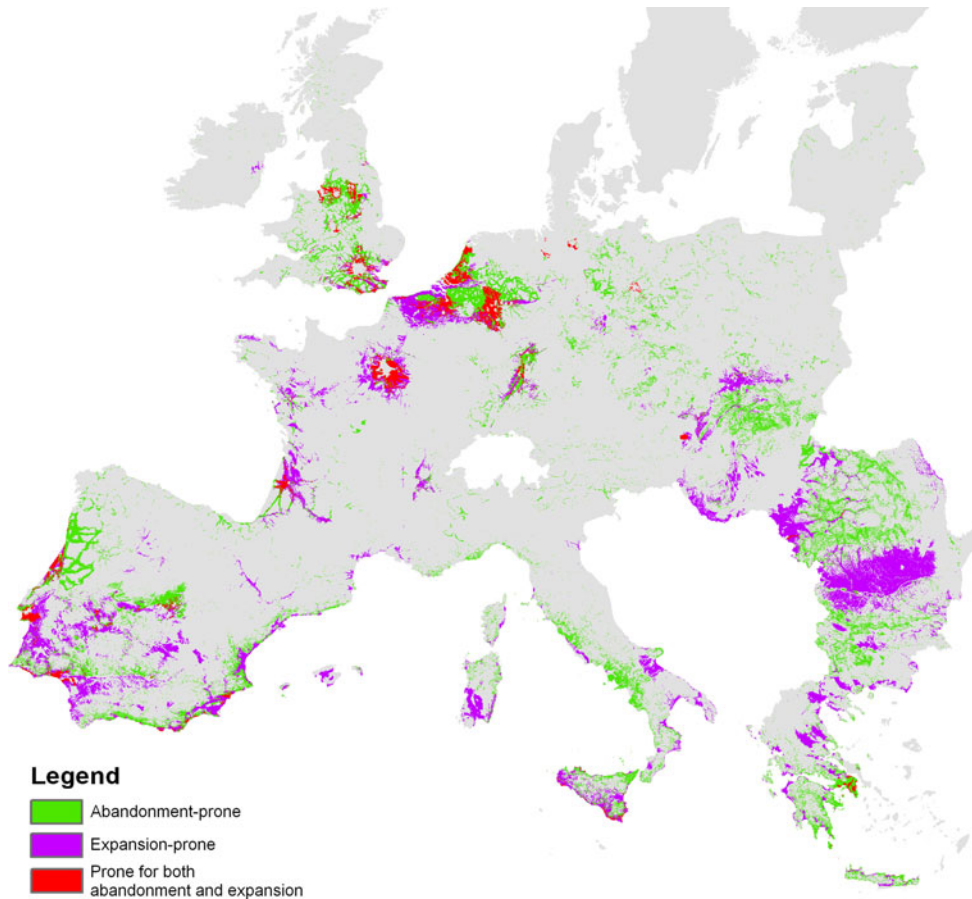
Figure 2. Areas with high probability (above the 90th percentile in each of the three regions) for expansion and abandonment according to the change regressions. Areas with high probability for both abandonment and expansion are also marked. The probabilities for Sweden, Finland, the UK, and Greece were extrapolated.

likely to happen in the south and west of Romania, the north of Bulgaria, Flanders, and the south of the Iberian Peninsula. Areas where both abandonment and expansion of arable land can be expected are areas with a high economic activity such as the Ruhr area (western Germany), the Randstad (western Netherlands), and areas around London, Paris and Lisbon.

Testing the Assumption that Abandonment and Expansion can be Inferred from Location Characteristics of Arable and Uncultivated Land

The coefficients and goodness of fit of the arable/uncultivated regressions are presented in Table 5 for the three zones, in the fourth column. According to the arable/uncultivated regressions, statistical likelihood for arable land is highest in flat, accessible areas near main cities, on deep soils with a high water-holding capacity. Some regional differences also exist: in Western Europe arable land occurs frequently in dry and sunny areas whereas in Eastern Europe arable land is situated more frequently in cloudy and wet areas. In Southern Europe, precipitation was found to be

insignificant, probably because the advantage of solar radiation was offset by the disadvantage of drought. Also mean annual temperature affects likelihood for arable land differently in the three zones: in Western Europe arable land is located more often in cold areas whereas the opposite tendency was found in Eastern and Southern Europe. This may be related to the marine climate with its mild winters, in combination with the abundance of crops that require winter dormancy such as wheat and barley in Western Europe. The goodness of fit of the regressions (McFadden's R^2) is highest for Southern Europe (47%), followed by Western (36%) and Eastern Europe (27%).

The descriptive power of the arable/uncultivated regressions for observed cases of expansion and abandonment is presented in Table 6 for the three regions. The McFadden's R^2 values for expansion are relatively high (27% for Western Europe, 26% for Eastern Europe and 18% for Southern Europe), whereas the McFadden's R^2 values for abandonment are negative for all zones. A negative value indicates that a random guess based on a 0.5 probability for each observation gives better results than the arable/uncultivated regression. Thus, we may conclude that the statistical likelihood for

Table 6. Descriptive Power (McFadden's R^2) of the Arable/Uncultivated Regressions in Relation to Land Expansion and Abandonment

	Western Europe (%)	Eastern Europe (%)	Southern Europe (%)
Expansion	27	26	18
Abandonment	−38	−19	−43

arable land estimated by the arable/uncultivated regression can describe cases of expansion, but not cases of abandonment.

Regression Comparison

Qualitative comparison of the signs of the coefficients indicates that the contribution of some factors to the statistical likelihood of abandonment and expansion (as given by the change regressions) are consistent with the coefficients in the arable/uncultivated regressions although others are not. With consistent we mean that the coefficient of a factor has the same sign in the expansion regression and the arable/uncultivated regression, and an opposite sign in the abandonment regression. The inconsistencies suggest that abandonment occurs in areas with a high statistical likelihood for arable land, and that arable expansion occurs in areas with a low statistical likelihood for arable land.

As for abandonment, in Eastern and Southern Europe this is associated with steep slopes and shallow soils with low water-holding capacity, which are indeed factors that affect the statistical likelihood on arable land in a negative way. Inconsistencies are found for temperature and cost-distance: abandonment was observed on locations that had a high statistical likelihood on arable land with respect to these variables. In Western Europe, observed abandonment is associated with low water-holding capacity and high temperatures, which are indeed factors that affect the statistical likelihood on arable land in a negative way. Inconsistency is found for cost distance: abandonment was observed on locations that were relatively accessible. Stoniness and population density were found to be insignificant in the arable/uncultivated regression in the three regions and thus cannot be compared.

The expansion regressions also contain both consistent and inconsistent coefficients in relation to the arable/uncultivated regressions: relationships between observed expansion and slope, soil depth, and cost distance are consistent with the arable/uncultivated regression in the three zones

(in cases where the coefficients are significant). The relationship with mean annual temperature is consistent for Eastern and Southern Europe but not for Western Europe. Apparently, in Western Europe expansion happens in warm areas, even though the bulk of existing arable land is located in relatively cold areas.

It follows from the inconsistencies that the abandonment and expansion regressions have quite some coefficients with similar signs, indicating that abandonment and expansion happen in similar areas. In Southern Europe, accessible, dry, sunny areas with non-stony soils show higher rates of both abandonment and expansion. In Western Europe, accessible, dry, sunny areas with high population density show high rates of both abandonment and expansion. In Eastern Europe, sunny areas with non-stony soils show high rates of both processes. From the marked areas in Figure 2 it can be seen that factors such as population density and cost-distance to roads are increasing the likelihood of both processes.

DISCUSSION

Our findings indicate that abandonment of arable land is not confined to marginal mountainous areas, as was often suggested in literature. In general, abandonment does not happen more frequently in areas that have a low statistical likelihood for arable land. On the contrary, abandonment was found to happen more in accessible and populated areas. A comparison between abandonment and expansion regressions reveals that some factors contribute to the likelihood of both processes in an opposite way whereas others do not. The opposite contributions are generally easy to explain. For example, arable expansion tends to occur in flat areas and on deep soils whereas abandonment occurs more in steep areas and on shallow soils. The similar relationships are more difficult to explain. The fact that some variables contribute positively to both abandonment and expansion suggests that some areas have high statistical likelihood for both processes, such as dry

areas, warm areas, and accessible areas. This probably results from multiple types of farms within one region. In Spain, for instance, large modernized farms choose to expand in dry and sunny locations with high potential productivity because they have the means to irrigate. In the same area, smallholders do not have the means to irrigate and are forced to de-intensify or quit farming as they cannot compete with the large farms (Bakker and others 2011, forthcoming). The large farms may buy the smallholders' land when conveniently located, but otherwise it is left abandoned. If this situation is exemplary for the rest of Europe, as the data suggest it is, it implies that at finer scales the assumption that abandonment happens on relatively unsuitable land may still hold, but that at broader scales it does not.

Furthermore, Figure 2 suggests that areas with a high economic activity show high likelihood of both abandonment and expansion. Again, this is probably related to multiple types of farms within one region: in areas with good accessibility to markets and labor force, large farms expand whereas at the same time the presence of economically attractive job alternatives leads to the ending of smaller family farms, as foreseen successors choose another occupation. An alternative explanation could be that abandonment near cities happens because arable land is bought by property developers in anticipation of a change in zoning plan or other permissions to build. Such a phenomenon should strictly not be considered land abandonment. However, we think our observations include relatively few such cases: most property developers would temporarily lease the land to farmers to avoid the spontaneous development of nature on their land, as that would complicate permissions for building on the land. Moreover, similar results were found in a study of land abandonment in the Swiss mountains (Gellrich and others 2007) where abandonment occurred more frequently in areas close to roads than in areas remote from roads, as well as in areas with higher proportions of part-time farms. Also, in this case, abandonment was positively related to economic opportunities.

Our analysis also suggests that abandonment is in general less related to spatial factors, compared to expansion. This was particularly so in Eastern and Western Europe and to a lesser extent in Southern Europe. The low goodness-of-fit of abandonment might be related to the actual factors selected which may be more related to expansion than to abandonment. It is, however, also likely that the differences in goodness of fit between abandonment and expansion are related to the scale of the two processes: Abandonment mostly happens when farmers decide to take part of their land out of cultivation, whereby they probably choose the part of the farm that is least productive; When farmers decide to expand, they probably choose the most suitable area from the entire pool of available land. As the area to select from in case of abandonment (that is, their property) is much smaller than the area to choose from in case of expansion (all available land in the vicinity), this can reduce the goodness of fit of the abandonment model at wide extents considerably. Accordingly, it may well be that information on the economic and demographic prospects of individual farms are more important for modelling spatial patterns of abandonment (Rey Benayas and others 2007). Modern GIS datasets make it possible to incorporate this kind of information in the analysis of abandonment (Mottet and others 2006) but the incorporation of this information in European-scale studies might be problematic due to limited availability of data.

The analysis reveals that the statistical likelihood of arable and uncultivated land, inferred from their location characteristics in 1990, can be used to mark areas prone to arable expansion, but cannot be used to detect areas prone to land abandonment. According to the assumption that abandonment should happen in locations with a low statistical likelihood for arable cultivation, areas that are farther from the road network are more likely to be abandoned. However, according to the observed abandonment regressions, areas that are closer to the network are more prone to abandonment. In contrast, it seems that the arable/uncultivated regressions may be used to predict arable expansion: areas favorable for arable cultivation are also likely to be chosen for arable expansion. Thus, the statistical likelihood for arable land should not be used for modelling arable abandonment without careful validation. Our study was conducted at the European scale and it remains to be studied whether or not the statistical likelihood for arable land can be used for cases of abandonment at subnational scales. In cases where statistical likelihood for arable land does not represent the likelihood for abandonment well, it may be better to predict future abandonment from the location properties of recent occurrences of abandonment, that is, to infer statistical likelihood of land-use change from change regressions, rather than from pattern-based regressions. However, this approach is more data demanding as it requires at least two sequential land-use maps and a sufficient number of change events.

Conclusions

Our findings suggest that abandonment does not necessarily occur in marginal areas, but more in areas where competition between smallholders and large enterprises is strong. These appear to be areas with high economic activity and high potential productivity. We demonstrated that abandonment and expansion cannot be regarded as mirrored processes with respect to spatial characteristics.

We found that abandonment is more difficult to explain at wider scales, probably because the process of taking land out of cultivation is often a local selection procedure whereby the relative quality of land within the farm is more important than its absolute quality. In addition, our study indicates that statistical likelihood for arable cultivation can, to some extent, be used to predict areas that are likely to be taken into cultivation, but not to predict areas likely to be abandoned.

ACKNOWLEDGMENTS

OPEN ACCESS

REFERENCES

Bakker MM, Govers G, Kosmas C, Vanacker V, Van Oost K, Rounsevell MDA. 2005. Soil erosion as a driver of land-use change. Agric Ecosyst Environ 105:467–81.

Bakker MM, Hatna E, Mucher S, Kuhlman T. 2011. Changing environmental characteristics of European cropland. Agric Syst (forthcoming).

Burgi M, Turner MG. 2002. Factors and processes shaping land cover and land cover changes along the Wisconsin River. Ecosystems 5(2):184–201.

EEA (2010). Corine land cover. 2006. Copenhagen.

García-Ruiz JM, Lana-Renault N. 2011. Hydrological and erosive consequences of farmland abandonment in Europe, with special reference to the Mediterranean region—a review. Agric Ecosyst Environ 140(3–4):317–18.

Gellrich M, Baur P, Koch B, Zimmermann NE. 2007. Agricultural land abandonment and natural forest re-growth in the Swiss mountains: a spatially explicit economic analysis. Agric Ecosyst Environ 118(1–4):93–108.

Gisbert JM, Ibanez S, Perez MA. 2005. Terrace Abandonment in the Ceta Valley, Alicante Province, Spain. Adv Geoecol 36: 329–37.

Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A. 2005. Very high resolution interpolated climate surfaces for global land areas. Int J Climatol 25:1965–78.

Imai K, King G, Lau O. 2006. Zelig: Everyone's Statistical Software. http://GKing.Harvard.Edu/zelig.

Jones RJA, Zdruli P, Montanarella L. 2000. The estimation of drought risk in Europe from soil and climatic data. In: Vogt JV, Somma F, Eds. Drought and Drought Mitigation in Europe. Dordrecht: Kluwer Academic Publishers. p 133–46.

King G, Zeng L. 2001. Logistic regression in rare events data. Polit Anal 9(2):137–63.

Kozak J, Ostapowicz K, Szablowska-Midor A, Widacki W. 2004. Land abandonment in the Western Beskidy Mts and its environmental background. Ekol Bratisl 23(1):116–26.

Lasanta T, Gonzalez-Hidalgo JC, Vicente-Serrano SM, Sferi E. 2006. Using landscape ecology to evaluate an alternative management scenario in abandoned Mediterranean mountain areas. Landsc Urban Plan 78(1–2):101–14.

Lehouerou HN. 1993. Land degradation in Mediterranean Europe—can Agroforestry be a part of the solution—a prospective review. Agrofor Syst 21(1):43–61.

Lesschen JP, Kok K, Verburg PH, Cammeraat LH. 2007. Identification of vulnerable areas for gully erosion under different scenarios of land abandonment in Southeast Spain. Catena 71(1):110–21.

MacDonald D, Crabtree JR, Wiesinger G, Dax T, Stamou N, Fleury P, Lazpita JG, Gibon A. 2000. Agricultural abandonment in mountain areas of Europe: environmental consequences and policy response. J Environ Manag 59(1):47–69.

McFadden D. 1973. Conditional logit analysis of qualitative choice behaviour. In: Zarembka P, Ed. Frontiers in Econometrics. New York: Academic Press. p 105–42.

Metzger MJ, Bunce RGH, Jongman RHG, Mucher CA, Watkins JW. 2005. A climatic stratification of the environment of Europe. Glob Ecol Biogeogr 14(6):549–63.

Mottet A, Ladet S, Coque N, Gibon A. 2006. Agricultural land-use change and its drivers in mountain landscapes: A case study in the Pyrenees. Agric Ecosyst Environ 114(2–4):296–310.

Nagendra H, Southworth J, Tucker C. 2003. Accessibility as a determinant of landscape transformation in western Honduras: linking pattern and process. Landscape Ecol 18(2):141–58.

R Development Core Team. 2010. R: A Language and Environment for Statistical Computing. http://www.R-project.org. Vienna, Austria.

Ramankutty N, Foley JA. 1992. 1999. Estimating historical changes in global land cover: Croplands from 1700 to 1992. Global Biogeochem Cycles 13(4):997–1027.

Rey Benayas JM, Martins A, Nicolau JM, Schulz JJ. 2007. Abandonment of agricultural land: an overview of drivers and consequences. CAB Rev Persp Agric, Vet Sci Nutr Nat Resour 2(057).

Sluiter R, de Jong SM. 2007. Spatial patterns of Mediterranean land abandonment and related land cover transitions. Landscape Ecol 22(4):559–76.

Tatoni T, Roche P. 1994. Comparison of Old-field and forest revegetation dynamics in provence. J Veg Sci 5:295–302.

Verburg PH, Overmars KP. 2009. Combining top-down and bottom-up dynamics in land use modeling: exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model. Landscape Ecol 24(9):1167–81.

Verburg PH, Schulp CJE, Witte N, Veldkamp A. 2006. Downscaling of land use change scenarios to assess the dynamics of European landscapes. Agric Ecosyst Environ 114(1):39–56.