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Linking land use and landscape process modelling: a case study for the Álora region (south Spain)

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Abstract

Changing land use is increasingly known to affect on-site landscape properties, nevertheless off-site effects are often neglected. A single process landscape evolution model (LandscApe ProcesS modelling at mUlti dimensions and scaleS (LAPSUS)) is used to explore the impacts of land use changes on landscape and soil properties. Examples are shown for both on-site as well as off-site effects of land use change and the influence of different pathways of change. A case study area near Álora, in the province of Málaga, south Spain is selected. In this area the main land use consists of citrus, olive/almond, wheat, semi-natural vegetation and a rest group (bare, river beds, urban). For a period of 10 years LAPSUS calculates soil redistribution (erosion and sedimentation) for different scenarios of input parameters. These inputs are a digital elevation model (e.g. slope lengths and angles), precipitation, soil erodibility, and land use related infiltration. For each scenario, different assumptions are made on direction and rate of land use change. As an example, effects of abandonment of olive orchards are demonstrated, simulating both a fast and gradual change for a period of 10 years. Each scenario produces different spatial and temporal patterns of total amounts of erosion and sedimentation throughout the landscape. As a result, potential land use related parameters like soil depth, infiltration and flooding risk change significantly too. The scenario of an abrupt change produces the highest erosion rates compared to the gradual change scenario and the baseline scenario. However, because of the multi-dimensional characteristics of the landscape, not only the area suffering from land use changes is affected. Increasing erosion and run-off rates from upstream-located olive orchards have an impact on down slope local run-on, erosion and sedimentation rates. In this case, the citrus orchards situated in the valley bottom locally suffer damages from re-sedimentation events but benefit from the increase in run-on water and nutrients. Concluding, off-site effects from an exogenous driven change in land use (EC subsidies) can trigger endogenous land use changes in adjacent areas.

Keywords: Land use change; Soil erosion; Re-sedimentation; Run-off; Southern Spain

1. Introduction

It is well known that changing land use affects on-site landscape properties, for example soil degradation and increased erosion after deforestation. Processes causing these effects operate in all types of landscape, although they are not always that evident and show lower rates when there is a continuous vegetation cover. Landscapes are considered multi-dimensional with vertical (on-site) and horizontal (off-site) properties and processes. The most dynamic interactions between agro-ecosystems and landscapes involve water-related processes. Water as precipitation is partly intercepted, evaporated and taken up by vegetation

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after which the remaining water is released into the landscape by infiltration or run-off. This migrating water has the potential to change a landscape by weathering (infiltrated water), erosion (run-off) and sedimentation (run-on). These landscape changing processes are thus directly influenced by the existing agro-ecosystems by water uptake or by slowing down the surface water, therefore stimulating infiltration. Land use has thus an effect on landscape processes, which, in turn, determine soil properties. If we consider a temporal scale from 1 year to 1 century we can focus our attention on erosion and sedimentation since weathering processes can safely be ignored.

Land use change can affect soil properties in the landscape context, either in a positive or negative way. Deforestation, for example, will almost always negatively affect soil properties. In most cases this leads to short-term soil productivity loss (Veldkamp et al., 2001). The conversion of forest to grasslands and permanent crops such as plantations usually leads to less degradation after several years because these systems allow the soil to recover to some extent. Conversion from forest or grassland to arable lands is the worst scenario in terms of soil productivity and quality (e.g. Dick, 1992; Caravaca et al., 1999).

However, we have to keep in mind that these changes take place in a landscape context where landscape processes on-site often cause unintended off-site effects in sloping areas. For example a decrease of the infiltration for one land use can lead to on-site increased erosion and run-off rates. Consequently for other land uses in areas down slope this can cause an increased sediment delivery, an increase in water availability or even more erosion because of the increased run-off (Bathurst et al., 1996).

Threshold effects are other typical aspects of landscape processes. Since the non-linear landscape processes tend to self-organise into stable domains, they do not immediately respond to a shift in one or a few of its many controlling factors. When many controlling factors are changing or if their magnitude of change is very large, the whole system will reorganise itself into a new stable domain (Milne, 1991). Such reorganisations often happen suddenly and are viewed as catastrophic events. An apparent small change in one of its controlling variables, like a precipitation event, may trigger such a catastrophic event. It is as if the system is pushed over a threshold (Holling, 1992). It can take years of small events and changes in the landscape to bring it to the brink of such a reorganisation. Examples of such catastrophic events are abrupt land use changes like abandonment, landslides, mudflows, large erosion and deposition events, but also fire, pests and diseases represent natural effects of ecosystem reorganisation. For example forest fires in the Mediterranean, apart from changing the vegetation, can alter soil properties like clay content, aggregate stability and water retention capacity (Boix Fayos, 1997). Again within the landscape context this will not only affect on-site but will also have off-site impacts.

Apart from the intense deforestation since roman times, land use has changed significantly in the Mediterranean region in the last decades (e.g. Le Houerou, 2000). Imeson et al. (1998) mention several key processes such as on the one hand population growth and development of industry, tourism and modern irrigated agriculture and on the other hand land abandonment in marginal areas because of economic and environmental factors. Since the founding of the European Community a third factor can be added namely the influence of European Community directed policies. Their main influence consists of subsidies and price controls. For example for olive orchards the current OCM (community organisation of the olive oil market) implements intervention mechanisms to guarantee income levels, to modernise the production process and to stabilise prices and production. In recent years changes in these policies, market demands and available technology have triggered important transformations in olive tree cropping in southern Spain (Rallo Romero, 1998; de Graaff and Eppink, 1999). The objective of this case study is to reveal the effects of two different land use change scenarios upon the spatial and temporal distribution of landscape shaping processes. A single process surface erosion model is used to simulate changing erosion and sedimentation patterns within the landscape represented by a digital elevation model (DEM). The main land use related parameters incorporated in this study are infiltration, soil depth and erodibility. Both on-site and off-site effects for two scenarios of abandonment of olive orchards are exemplified and demonstrated.

2. Materials and methods

2.1. Geo-referenced baseline information

Our case study area (Fig. 1) is situated in the south of Spain near the village of Álora in the province of Málaga (Andalusia). In this region the general climatological conditions are summer dry Mediterranean (Csa) with decreasing precipitation from west to east. The area around Álora shows a mean annual temperature of 17.5°C and receives a mean yearly rainfall of 534 mm, mainly from October to April.

A DEM with a spatial resolution of 25 m is the starting point for our grid based case study (Servicio Geografico del Ejercito, 1997). For this uni-scale experiment we have chosen a detailed section just north of Álora of 17.12 km^2 (Fig. 1). With a resolution of 25 m on an area extent of $5.35 \times 3.2\,km^2$ we obtain a grid of 128 rows × 214 columns (total 27 392 grids). The relief for the study area shows altitudes ranging from 100 to 625 m above sea level.

Fieldwork, aerial photographs, satellite images and expert knowledge provide the basis for building the baseline maps for the study area. The main land use can be divided into five major classes (Fig. 2), namely 11% annuals (wheat *Triticum aestivum*, chickpea *Cicer europea*), 26% citrus (orange *Citrus sinensis*, lemon *Citrus limon*), 39% olive (*Olea europea*) with some almond (*Prunus dulcis*), 19% semi-natural vegetation (matoral and forest) and 5% rest group (urban, bare, riverbed).

Soil types and properties of the area are described by Ruiz et al. (1993) and comprise typical catenas for semiarid to sub-humid areas. Parent material and tillage practices have resulted in stony soils especially under olive and almonds. These soils are tilled several times a year, depending on the rainfall, in order to control weeds and improve infiltration (e.g. Poesen et al., 1997; Quine et al., 1999). Extensive fieldwork (soil description, sampling and depth measurements) provided the resulting soil depth map (Fig. 1), which represents clearly the underlying geology, slope gradients and topographical position (de Bruin and Stein, 1998).

2.2. Landscape process modelling

For the calculation of the landscape dynamics, the LandscApe ProcesS modelling at mUlti dimensions

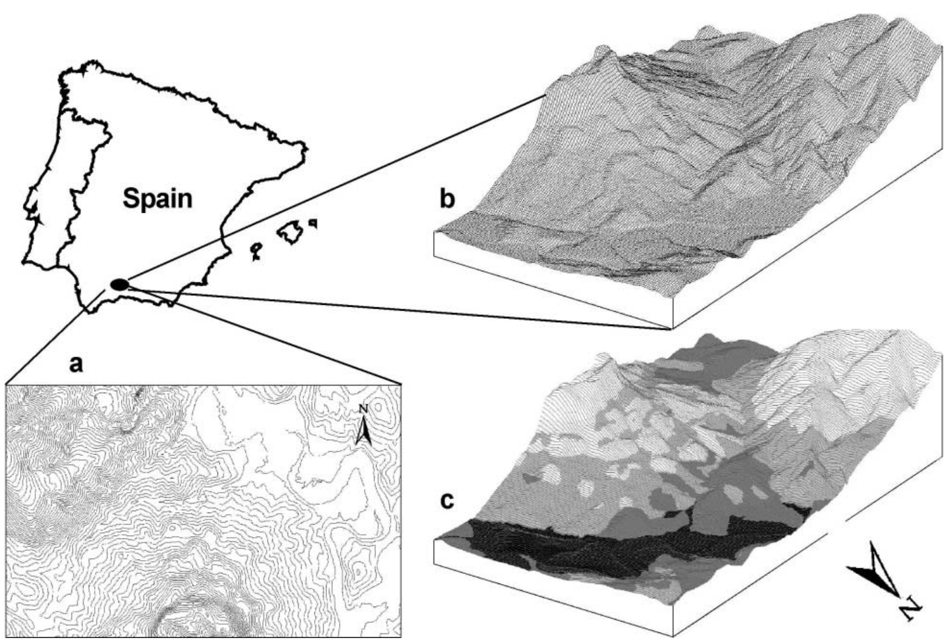

Fig. 1. Location of the study area in southern Spain including (a) the 20 m contour line map, (b) the DEM and (c) the soil depth from deeper than 1.50 m (shaded black) to less than 0.30 m (shaded white).

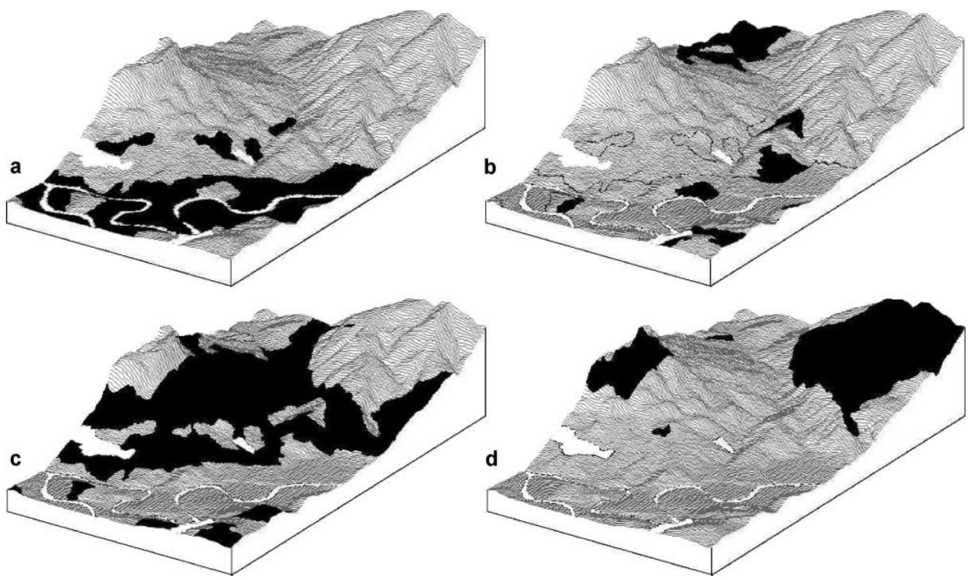

Fig. 2. Main land use in the case study area shaded black for (a) citrus, (b) annuals, (c) olive and (d) semi-natural vegetation with the rest group in white.

and scaleS (LAPSUS) model is used (Schoorl et al., 2000). LAPSUS is a basic surface erosion model based on the continuity equation for sediment movement (Kirkby, 1971, 1978, 1986; Foster and Meyer, 1972, 1975). After integration and under the assumption that the transport capacity C and the detachment capacity D or settlement capacity T remain constant within one finite element, the sediment transport rate is evaluated as follows:

$$S = C + (S_0 - C)\mathrm{e}^{-\mathrm{d}x/h} \quad (1)$$

where the sediment transport rate S (m^3/s) along dx (m) length of a finite element is calculated as a function of transport capacity C (m^3/s) compared with the amount of sediment already in transport S_0 (m^3/s). Term h (m) refers to the transport capacity divided by the detachment capacity (C/D) with D (m^2/s) or to the transport capacity in proportion to the settlement capacity (C/T) with T ($-1\ \mathrm{m}^2$/s).

This model evaluates the rates of sediment transport by calculating the transport capacity of water flowing down slope from one grid cell to another as a function of the discharge and the gradient of the slope. Surplus of capacity is filled by the detachment of sediment, which depends on the erodibility K_{es} (m^{-1}) of the surface. This detachment of sediment provokes lowering of the surface or erosion. However, when the rate of sediment in transport exceeds the local capacity, for example because of lower gradients, the surplus of sediment in transport will be deposited by a settlement function causing a higher surface or sedimentation. The routing of the overland flow and the resulting model calculations are done with a multiple flow algorithm to allow for a better representation of divergent properties of the convex topography (e.g. Freeman, 1991; Quinn et al., 1991; Holmgren, 1994). Our modelling framework was tested elaborately for the effects of changing flow algorithms, spatial resolution and temporal resolution (Schoorl et al., 2000). LAPSUS was only validated for its base scenario by field observations, it displays erosion and sedimentation patterns which match closely with real world erosion and sedimentation patterns at the same spatial resolution ($25 \times 25\ \mathrm{m}^2$).

2.3. Case study scenarios

Main input parameters for the grid-based LAPSUS model are the topographical potentials (slope gradients) from our DEM and the evaluation of the rainfall

Table 1
Scenario input parameters depending on parent material and land use: surface erodibility (K_{es}), water retention capacity (AWC), surface erodibility factor (EF) and infiltration factor (IF)[a]

	Parent material			Land use	
	K_{es} (m^{-1})[b]	AWC ($m^3\,m^{-3}$)[c]		EF (–)[b]	IF (–)[b]
Colluvium	7.4×10^{-6}	0.161	Citrus	0.5	1.0
Marls	11.1×10^{-6}	0.105	Annuals	1.3	1.2
Sand/gravel	7.4×10^{-6}	0.151	Olive A	0.75	1.5
Schist	6.7×10^{-6}	0.135	Olive B	1.5	0.75
Gneiss	5.2×10^{-6}	0.066	Olive C	1.5/0.75	0.75/1.5
Conglomerate	3.7×10^{-6}	0.055	Semi-natural	1.2	0.75
Serpentinite	2.2×10^{-6}	0.044	Rest	0.01	0

[a] Olive A, B and C indicate the different scenarios.
[b] Literature/model calibration.
[c] Reference profiles.

surplus that will generate the overland flow. Within each grid cell of $25 \times 25\,m^2$ we assume uniform conditions for all parameters involved. The model will evaluate all considered parameters on an annual basis for a total run time of 10 years. For the scenarios given, annual rainfall of 534 mm is considered to be constant over time and uniform over space, thus neglecting for example regional topographical effects.

The current situation is reflected in base scenario A (Table 1), which assumes that infiltration and erodibility depend on land use and underlying soil properties (e.g. Bonachela et al., 1999; Cerda, 1999). Indicative values given in Table 1 are compiled from fieldwork, literature and model calibration (e.g. Nicolau et al., 1996; Kosmas et al., 1997; Oostwoud-Wijdenes et al., 1997; Vanderlinden et al., 1998). As a result the infiltration (I) for each grid cell is calculated as follows:

$$I = \mathrm{IF} \times \mathrm{AWC} \times d_s \qquad (2)$$

where I is a function of soil depth (m) (d_s), water retention capacity ($m^3\,m^{-3}$) (AWC) and management practices (IF). Detachment of surface particles D (m^2/s) depends on

$$D = K_{es} \times \mathrm{EF} \times Q \times \Lambda \qquad (3)$$

where K_{es} is the erodibility of the parent material (m^{-1}), EF a surface management factor, Q the discharge (m^3/s) and Λ the height difference or slope.

Scenarios B and C are two simple examples of the links between the different components of the system by implying an abandonment of olive orchards in this area. This could happen for example as a result of changing EC policies and subsidising systems (e.g. Rallo Romero, 1998; de Graaff and Eppink, 1999). The assumption is that for the 5–10 years simulation period infiltration decreases, while the erodibility and run-off increase upon abandonment because of crusting and compaction of the soil (e.g. Boix Fayos et al., 1998; Renschler et al., 1999; Lasanta et al., 2000), poor regeneration of vegetation (e.g. Ruecker et al., 1998; Lasanta et al., 2000) and the lack of tillage practices (Gomez et al., 1999). In this case the scenario B uses an abrupt change of abandoning of all orchards within 1 year (see olive B parameters in Table 1), while scenario C implies a gradual annual change over 10 years of taking the olive orchards out of production. In this case the highest and steepest fields first, after 10 years the same values as for scenario B are reached.

2.4. Flooding risk

In order to evaluate the effects of changing land use we will use a simple indicator of flooding risk. For this case study the yearly flooding risk for each grid cell is calculated as a function of the distance to a channel, the discharge within that channel and the height difference with the channel bed.

3. Results

While presenting and discussing the outcomes of the simulated scenarios we have to take into account the different temporal and spatial levels used in this

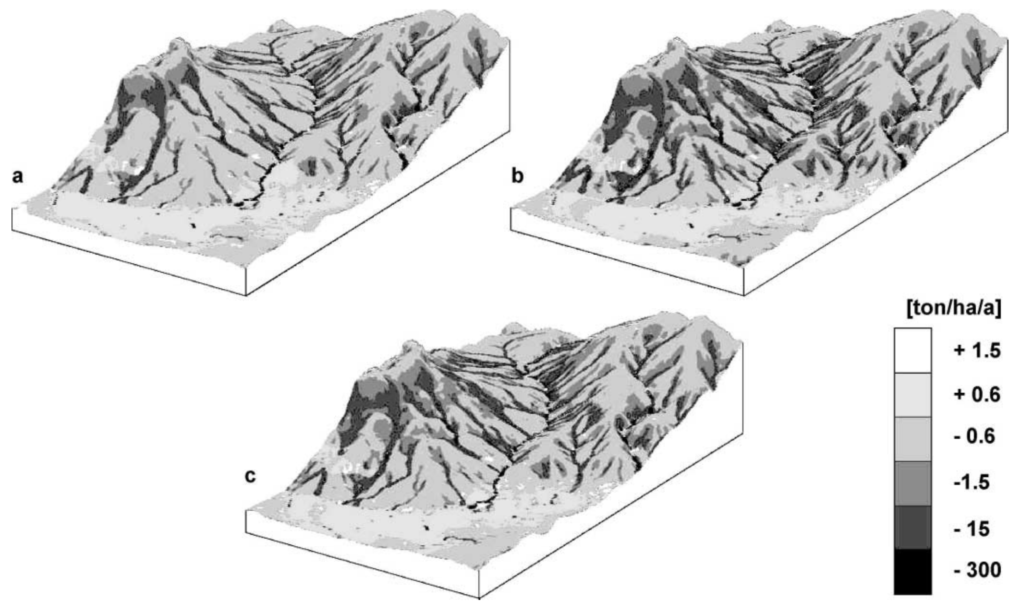

Fig. 3. Spatial distribution for the 10 years simulation period of total erosion (negative values) and sedimentation (positive values) for (a) scenario A, (b) scenario B and (c) scenario C.

section and in Figs. 3–6. These temporal levels vary from cumulative 10 year means (Figs. 3 and 5) to yearly rates (Figs. 4 and 6) and spatially from grid level (amounts in Figs. 3 and 6) to land use units (Figs. 4 and 5) to total area (patterns of Figs. 3 and 6, and graphs of Figs. 4a and 5a).

Local erosion and sedimentation rates for each grid cell and their spatial distribution are presented in Fig. 3 for each scenario. Local erosion rates throughout the area for the 10 year period varied from 0 to more than 300 $\mathrm{t\,ha^{-1}}$ per annum, with means of 1.3, 2.2 and 1.7 $\mathrm{t\,ha^{-1}}$ per annum for scenario A, B and C, respectively. In general erosion rates are clearly higher in down slope areas, on the steeper slopes and in areas where the run-off is concentrated in channels. Sedimentation is mainly concentrated within specific points in the main channels and on the transition from the steep slopes to the more flat areas in the central valley. Sedimentation rates varied from 0 to more than 1.5 $\mathrm{t\,ha^{-1}}$ per annum.

The calculated annual amounts of erosion for the three scenarios in metric tons per hectare are given for the area as a whole in Fig. 4a and for the main land use types in Fig. 4b–f. Note the different scaling of the *y*-axis for Fig. 4a and b while comparing the amounts. Under baseline conditions (scenario A), areas under semi-natural vegetation show the highest erosion rates followed by annuals and olive just above the mean rates for the whole area. Citrus and the rest group show much lower erosion rates. In general for scenario B all erosion rates are higher except for semi-natural vegetation and the rest group. The highest erosion rates are found in the olive area, which also cause a major increase in the mean total amounts. Also the annuals and citrus show an increase in erosion rates resulting in even higher erosion rates for the annuals than semi-natural vegetation. Finally the general trend for scenario C is a gradual non-linear increase of erosion rates during simulation. For the area under olive this increase is slightly exponential, while for annuals the increase in erosion rates is less halfway the simulation. Exceptions are again semi-natural vegetation and the rest group, which hardly show any changes.

Total cumulative amounts of sedimentation in metric tons per hectare are given for the whole area in Fig. 5a and per land use in Fig. 5b–f for the 10-year simulation period. Note the different scaling of the amounts for the rest group showing almost four times higher amounts of sedimentation than the other land uses. All land uses show an increase

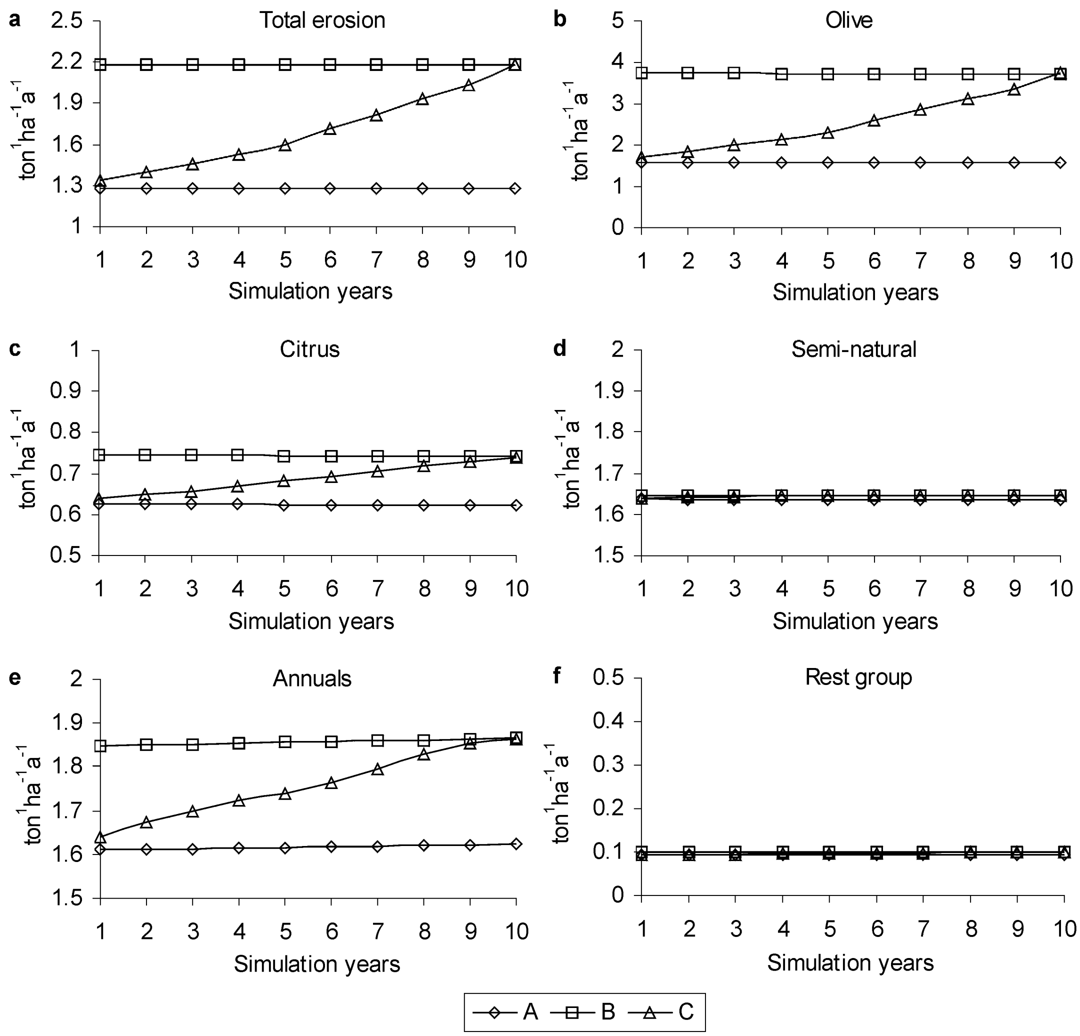

Fig. 4. Simulation of annual erosion for the scenarios A, B and C for (a) whole case study area, (b) olive, (c) citrus, (d) semi-natural vegetation, (e) annuals and (f) rest group. Note the different scaling of the *y*-axis for (a) and (b).

in re-sedimentation, except for the areas under semi-natural vegetation, giving a total increase going from scenario A to B of 71.9% and from A to C of 7.3%. As a rule the smallest amounts of re-sedimentation are found in the areas under annuals and semi-natural vegetation. Citrus and olive show larger amounts of re-sedimentation. While semi-natural vegetation does not show any effect of changing scenarios, olive shows the strongest increase of re-sedimentation quantities for scenario B and C of 159.6% and 9.9% respectively, followed by citrus (53.1 and 8.1%) and annuals (16.8 and 4.9%).

4. Discussion

In this case study only a limited number of parameters have been used, which makes the model relatively sensitive to these inputs. Also not taken into account is the temporal variation of these parameters with the changing soil depths or vegetation regeneration. However, changing soil depths do affect the run-off during the simulation, which is one of the major variables in calculating the transport capacity and detachment capacity (Q in Eq. (3)). The influence of vegetation regeneration is considered minimal for the 5–10 years

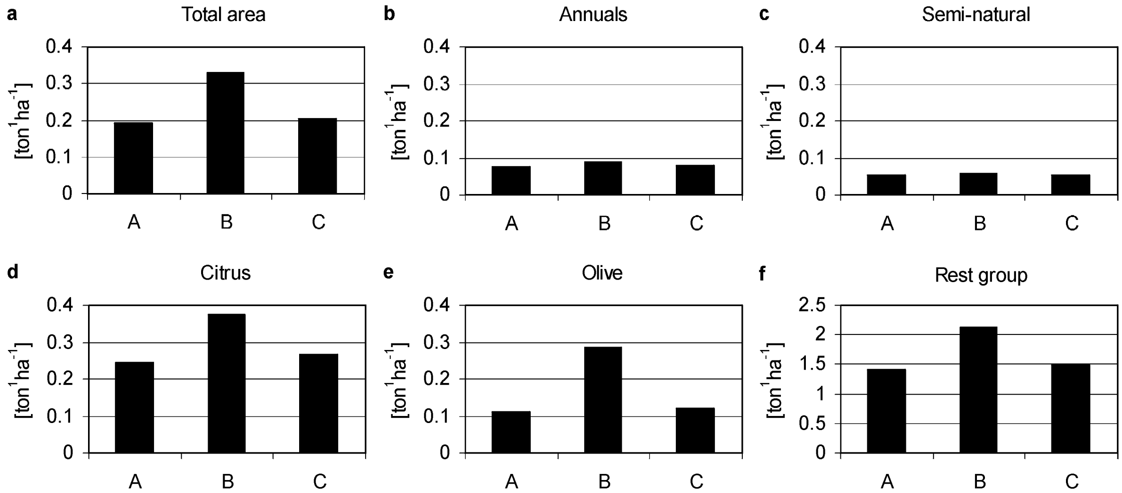

Fig. 5. Cumulative sedimentation for the simulated period and scenarios in metric tons per hectare for (a) whole case study area, (b) annuals, (c) semi-natural vegetation, (d) citrus, (e) olive and (f) rest group. Note the different scaling of the *y*-axis for the rest group.

simulation period (Ruecker et al., 1998; Lasanta et al., 2000) and the effect of no tillage will dominate the infiltration characteristics (Gomez et al., 1999). Nevertheless together with the temporal resolution of 1–10 years, this provides a simple and realistic example of an easy to adapt scenario driven comparison at the landscape level. For example the K_{es} factors (Table 1), in our case study, aggregates a lot of surface characteristics (including tillage and crusting) at a large spatial resolution. Although our K_{es} factor is not comparable by definition, the variability in these type of factors is high even under standardised

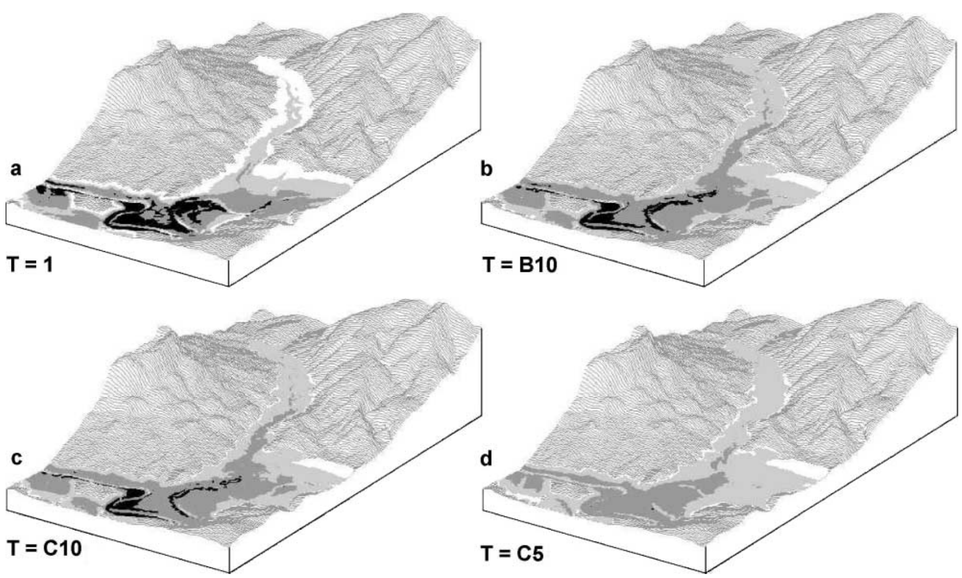

Fig. 6. Flooding maps for (a) the first time step $T = 1$ (valid for both A and C scenario), (b) increase for the last time step $T = 10$ of scenario B, (c) increase for the last time step $T = 10$ of scenario C and (d) increase for the fifth timestep $T = 5$ of scenario C. White (low) to black (high) grey scale indicates increasing flooding.

conditions as is clear from numerous *K*-factors found in USLE related studies (e.g. Torri et al., 1997).

4.1. Case study area general impression

Although at first sight, the overall impression of the erosion and sedimentation rates in Fig. 3 seems not to differ very much between scenarios, when concerning the patterns within the landscape we can see the different influence of the scenarios within the land use units. Not the unit as a whole but certain confined areas react more than other areas do (Puigdefabregas et al., 1998). These main patterns are determined by the underlying topography and the resulting drainage network, while the actual rates and impact of the erosion and sedimentation are determined by the parent material and land use (e.g. Cerda, 1998, 1999). Comparing the spatial distribution for the three scenarios shows the impact of the olive abandonment especially in the mid-slope areas where the largest changes in the erosion and sedimentation patterns can be found. However, also without any land use change (scenario A), the landscape will still be altered by the natural processes of landscape evolution.

4.2. On-site land use effects

In spite of the general trends during the simulation for scenarios A and B and increasing erosion rates for scenario C, the actual rates for each land use differ considerably (Figs. 4 and 5). They range from almost 3.7 t ha^{-1} per annum for olive in scenario B to less than 0.62 t^{1} ha^{-1} per annum for citrus under baseline conditions. The same holds true for the re-sedimentation as mentioned in the previous paragraph although there the citrus shows the highest and the annuals show the lowest rates.

Erosion rates for olive in this case study are moderately high compared to rates given by Poesen and Hooke (1997). However their data was compiled from different land uses, slope gradients and parent materials on small scale plot studies without major channels and gullies. Romero Diaz et al. (1999) give some differences in erosional response between olive and abandoned fields in the Mediterranean but their abandoned fields do not originate from olive orchards. Also erosion studies mentioned by Kosmas et al. (1997) show almost no erosion for olive in Greece because of management practices (no tillage, dense undergrowth). The question remains whether this example from Greece would be a possible scenario for the degraded environment of south Spain (Ruecker et al., 1998; Gomez et al., 1999; Lasanta et al., 2000). On the other hand our erosion rates seem low compared to rates found at the field level for olive orchards by Laguna and Giraldez (1990), indicating the potentials of many years of tillage erosion. Their results could indicate a slight underestimation of tillage erosion in our initial K_{es} factor for the scenarios, although important parameters at the landscape level as slope gradient, slope length, parent material and stoniness are different for the Álora region.

Since the topographical potentials move the water and sediments down slope, only areas down slope of olive areas will be affected. As a consequence the citrus area, located in the valley floor, reveals the largest impact followed by the annuals. Semi-natural vegetation however is hardly affected by the scenarios because most of the semi-natural vegetation classified areas are located in the landscape upslope of the olive fields. An exception to the general erosion and re-sedimentation rates is the rest group because of the fact that for urban areas and the riverbed the erodibility K_{es} was set to 0.

4.3. Off-site effects: flooding risk

Comparing scenarios A with B and C it was to be expected that olive would reveal an increased erosion since the scenario directly alters the input parameters for infiltration and especially erodibility. Of course this increase is not uniform and visualisation of the patterns in the three-dimensional landscape show the important relationship with the main parameters as slope length, slope angle and discharge. Nevertheless, the input parameters for the other land uses did not change, so the encountered differences (see Figs. 4 and 5) are a direct off-site result of changes in our dynamic landscape. In this case the increased erosion, the decreasing soil depth and decreasing infiltration of the areas under olive provoke an increasing run-off and sediment in transport into the other areas.

An example of this off-site effect is given in Fig. 6 where a simple evaluation is given for the risk of flooding. First of all the areas in Fig. 6a which are most prone to flooding are also the most affected ones by the off-site effects of the scenarios in Fig. 6b and c. The mid-slope on-site changes in the olive orchards trigger increased flooding in the whole valley area where no olive orchards can be found. Increasing amounts of run-off from the slopes are diverged into the channels, which continue to collect all extra run-off until the river is reached and the water leaves the case study area. Especially vulnerable areas are the sharp river bends, inner terraces and the alluvial fan area where the catchment drains into the central river valley. In our case study all these areas are used for citrus, which consequently have suffered flood damages in the past.

4.4. Pathway of change

As shown in the previous sections, when considering the pathway of change, the total impact of scenario B is much higher than scenario C. This holds true for erosion rates, re-sedimentation and flooding. However, the different responses comparing B and C are not linear. Accumulating the effects over the 10-year period suggests that gradual change of scenario C causes 53% less erosion and even 90% less re-sedimentation. Apparently the threshold effect of a sudden land use change in scenario B triggers slightly more erosion and much more re-sedimentation than the gradual change of scenario C.

However, the increased flooding risk map of Fig. 6b for scenario B is relatively stable for every single simulation year, since the most important flooding factor is the discharge. This is in strong contrast with scenario C where the flooding maps of Fig. 6c and d change considerably (after 10 and 5 years of simulation, respectively) since every year there are less olive orchards left and more run-off and erosion is generated. As a result the final flooding map of scenario C in our last simulation year in Fig. 6c resembles to and shows a similar impact as Fig. 6b. Even in the case of a gradual change scenario C if we do not alter the consequences of the simulated land use change by conservation measures or stimulating vegetation regeneration (e.g. de Graaff and Eppink, 1999; Lasanta et al., 2000), the final result, as far as annual erosion rates and increased run-off are concerned, is similar for both scenarios.

5. Conclusions

In this case study we demonstrated that in the landscape system, the on-site consequences of land use change can result in major off-site effects. Of major importance for the impact of changes in land use is the position of a certain land use within the landscape. Concerning the simulated landscape processes, the most important changing rates as a consequence of a land use change are run-off, run-on, infiltration, erosion and re-sedimentation. These changes occur both on-site as off-site of the land use under change. Changes in upland areas will influence both mid-slope and down slope areas. On the other hand upland areas receive initially less water than mid-slope areas and the impact will be less intensive. Also the effects will not be limited to the case study area alone. For example the increased run-off and sediment transport will eventually enter and possibly alter the down stream part of the whole river drainage system.

In our scenario examples we have simulated the impact of changes in landscape processes originated from changes in olive orchards. These orchards are mainly situated on mid-slope positions and as a result the on-site changes show off-site consequences for areas located down slope and in the valley floor. Future European policies on olive oil production can proof the significance of scenarios on olive field abandonment as an example of the impact of one land use change upon the landscape and other land uses. Implications of these types of changes in policies for subsidising crops can have serious influences on the biophysical landscape and the agro-ecological system as a whole.

These scenarios have also clearly demonstrated the dynamic interactions between land use and erosion/sedimentation. Especially the off-site effect might trigger unintended side effects. The significant increase of sedimentation on the valley bottom might hamper the citrus growth or destroy citrus plantations. Thus the decision to change the olive land use might indirectly drive a change in the citrus. This is a clear example of the feedback mechanisms of land use change. An exogenous driven change in land use (EC olive subsidies) might trigger endogenous land use changes in the citrus due to the off-site effects of the olive abandonment.

The model presented in this paper can be used as a tool to explore possible effects of certain land use changes within a dynamic landscape context. All type of changes affecting the infiltration and erodibility can be evaluated within the model, including management practices. Also the other way around, the effect of changes in landscape dynamics upon land use can be evaluated, for example variations in precipitation. The current model is far from complete since it only calculates effects of water erosion and re-sedimentation. Other relevant regional processes like land sliding, slumping and related mass movements are not included. But despite these limitations, the model is able to catch overall landscape system dynamics quite well.

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