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A SEMI-EMPIRICAL MODEL FOR THE NEAR FUTURE EVOLUTION OF THE LAKE KORONIA LANDSCAPE

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Abstract. Modelling tools are often used to simulate and predict land use changes. Especially for areas of a great environmental importance, and apart from the necessary soft and hard technical perfection, modelling tools must additionally exhibit strong analytical power to elaborate the causes and the consequences of land use changes. Recently the hydrological deterioration of the protected Koronia lake, northern Greece, is followed by landscape degradation. The research presents the simulation, in a short term base, of the land use/cover changes of the landscape of the Kolchicos river that discharges into the Koronia lake. Simulations were performed with the use of CLUE-S semi-empirical model. The modelling effort included a land use/cover change scenario (1993-2013), by linearly extrapolating past changes (1945-1993) of land use/cover. Simulation showed that all major land use/cover types would be increased from 1993 to 2013, especially in the expense of grasslands that are tending to extinction. Developmental planning and policy making must take seriously under consideration the predictions of grassland elimination and the decrease of the area of open shrublands in the future landscape, given that the ecosystems they support are important for sustaining the ecological integrity and the social reference of the landscape.

Keywords: landscape driving factors, CLUE-S, extensified husbandry, conversion elasticity, ROC.

AIMS AND BACKGROUND

There are a number of reasons for studying and constructing models for landscape evolution. Models serve as tools for analysing the drivers for land use changes and their consequences on the evolutionary behaviour of the landscape. In addition, they are used for the deep understanding of the operational features of the landscape and for the development and implementation of land policy measures[1]. Model predictions for landscape evolution, based on the development of land-use scenarios, may serve as early warning tools for possible negative consequences of some intended land management plans[2,3]. According to Lambin[4] modern land use/

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cover evolutionary models should be able to respond to some critical issues such as: (i) who are the biophysical and socioeconomic drivers that shape the evolution of land use/cover units? (ii) who are the most sensitive-to-change locations?, and (iii) what is the rate and intensity of changes observed in land use/cover types?

These issues are attempted to be challenged by the CLUE-S (Ref. 5) (the Conversion of Land Use and its Effects at Small regional extent) modelling framework that deals with landscape evolution by using the facilities of Geographical Information Systems. The framework was originally presented in 1996 by 'The CLUE GROUP' of the Department of Environmental Sciences of Wageningen University (Netherlands) as a dynamic, multi-scale land-use and land-cover change model. The CLUE-S has found a lot of applications in projects developed in many countries around the globe (e.g. Philippines, Vietnam, central America, etc.)[6].

The review of relevant bibliographic studies for the Mediterranean region and specifically for Greece has revealed gaps in the research about predicting landscape evolution[7]. The need to fill these gaps is more imperative since the application of socioeconomic (or/and biophysical) scenarios is a common ground in predicting landscape responses to a designed land use policy[8]. In the case of landscapes supported by ecologically sensitive areas prone to degradation, it is necessary to survey their temporal and spatial evolution in conjunction with projections of the current socioeconomic conditions.

The lake Koronia in northern Greece supports a very rich ecosystem and plays an important role both on local and national level. It belongs to the 'Special Protected Areas' (directive 79/409/EC), to the Greek 'Sites of Community Interest' (directive 92/43/EC), and it is a 'Med SPA' according to the Barcelona Convention. Also, the wetlands of the lake Koronia and of the adjusted lake of Volvi are protected by the Ramsar Convention. Despite the diverse legally-binded framework for protection, the lake Koronia is the most degraded lake of Greece in terms of water quality[9], while it additionally faces serious water quantity problems[10]. Also, the landscape that surrounds the lake is gradually degraded since signs of structural homogenization have been already recorded[11]. Consequently, it is important to quantify these trends and to predict their outcome, at least in considering the consequences of a 'business as usual' scenario in a short-term temporal base. The knowledge of landscape evolution may serve as a tool not only for restoring and retaining landscape diversity purposes, but also as a potential sided measure that may contribute to restore the water level of the lake. The aims of the present research were to figure out the near future pattern of the landscape supported by the lake Koronia, by defining its structural and functional characteristics.

EXPERIMENTAL

The landscape northern of the lake Koronia (20 km northeast of Thessaloniki) is characterised by the physiographic dominance of the Kolchicos torrent that spills out in the northern banks of the lake. The watershed of the torrent has an area of 24 558 ha, and it belongs to the administrative unit of the Lagadas county.

Landscape evolution was modelled by the use of the CLUE-S framework. The model consists of two explicit components[5] (Fig. 1); a non-spatial (demand component) that determines arithmetically and for a given time series the evolution of land use/cover units, and a spatial one (including a decision rule system) that converts/translates the determined arithmetic output into land use/cover types by using a system of geographical oriented rasters. Land-use management rules are set up for the area, and adequate time-lag for future land use/cover changes are inserted in the model through the decision rule system. The changes in the structure and the arrangement of the land use/cover types are forced by the Landscape Driving Factors (LDFs) (physiographic, geographic and socioeconomic); the latter being the independent variables in the statistical analysis that takes place into the spatial component[5,12]. Accordingly, the relationship (spatial logistic regression) between land use/ cover types and the LDFs is evaluated in the spatial component.

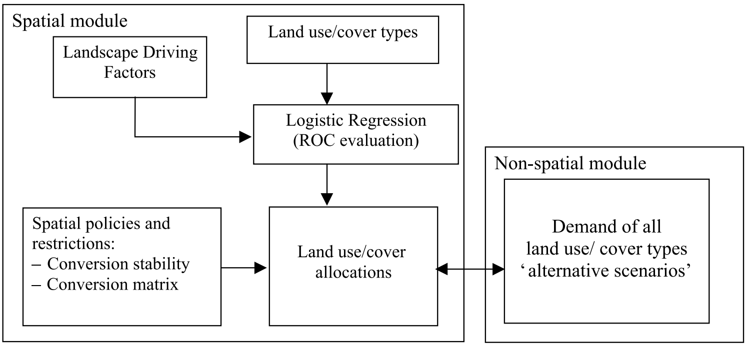

Fig. 1. Flow chart of the information used to run the CLUE-S

The spatial component uses empirical methods to determine the probability of occurrence a changing landscape due to the LDF variables. For these purposes, it is necessary to built the logistic regression model[5,12]:

$$\lg (P_i/(1 - P_i)) = b_0 + b_1X_{1,i} + b_2X_{2,i} + \ldots\ldots\ldots + b_nX_{n,i} \quad (1)$$

where P_i is the probability of occurrence of a specific land use/cover type, X_i – the LDF variables that determine landscape evolution, and b_i – regression coefficients with i – each pixel of the raster. The CLUE-S considers the Forward:Conditional – stepwise technique as more suitable for regression analysis[5]. The test for the goodness of fit of the regression model is made by using the Relative Operating

Characteristic (ROC) index, which is additionally considered as one of the best indices to validate predictive models for landscape evolution[13]. The ROC index is a result of the evaluation of the predicted probabilities by comparing them with the observed values over the whole domain of predicted probabilities. The values of the ROC index range between 0.5 (the model is completely randomly adjusted) and 1.0 (the model is perfectly adjusted) – values over 0.75 imply that the model appears good fit to the data[14].

The logistic regression analysis is followed by the inclusion in the spatial component of the CLUE-S a number of area restrictions, e.g. restrictions dictated by specific policies or tenure status. Area restrictions are considered in the model by combining both the coefficients of conversion elasticity and the change matrix for each land use/cover type[12,14].

After insertion of spatial and non-spatial data the CLUE-S starts to redistribute and simulate future land use/cover types. Model output includes a series of digital thematic maps and data bases for landscape evolution.

In the case of the landscape of the lake Koronia, the physiographic LDF included five variables (elevation, slope, parent rock material, soil depth, potential erosion), the geographical (or accessibility) LDF included five variables (distance from: road network, water courses, center of settlements, center of forest units, animal sheds), and the socioeconomic (or demographic) LDF included four variables (population density, working force density of the primary sector, number of sheep/cows per unit of grazing area, number of goats per unit of grazing area)[7]. Especially for parent rock material, soil depth, and potential erosion several classes were defined. Two types of data were used, numerical and categorical. A total of 25 variables from the three LDFs were included in the logistic model. Variables with a statistical significant effect (for significance level p=0.02) were retained in the model, and regression coefficients were calculated. The value of a coefficient illustrates an arithmetic measure of the significant impact exerted from the associated variable to the probability of occurrence of the land use/cover type under consideration.

Six land use/cover types were selected as dependent variables in the logistic model, i.e. grasslands, agricultural land, open shrublands (10-40% cover), close shrublands (> 40%), open forests (10-40%), and close forest (>40%), while remaining land (urban areas, bare land) was not included in the analysis since it was considered rather unchanged through the years. The land use/ cover types were spatially defined after the digital processing and photo-interpretation of the aerial photographs of 1993 (Refs 7 and 11). All variables were entered in the logistic model as ASCII files. Statistical analysis was further supported by the SPSS (ver. 11.0) software.

Present research deals with one baseline scenario, i.e. the linear extrapolation of the spatial data of the six land use/cover types obtained from the photo-interpretation and digital processing of aerial photographs of 1945, 1960, and 1993 and ortho-photomaps of 1983. Digital processing and photo-interpretation were facilitated by the ArcGIS software (ver. 9.0)[15]. Generally, a baseline ('if nothing' or 'business as usual') scenario is the one that has the higher probability to occur in short term projections. Linear extrapolation implies that the all LDFs have linearly affected a land use/ cover type during the scenario reference period (1945-1993), and it is assumed that this impact will still hold through the scenario prediction period (1993-2013).

Landscape structural and functional characteristics were further discussed after calculating two landscape indices (shape and diversity metrics) the Mean Patch Fractal Dimension (MPFD) and the evenness of the Shannon's diversity index (SEI)[16]. Both indices were calculated by using the Patch Analyst software (ver. 3.1)[17] and produce valuable information regarding the ecological and functional status of landscapes.

RESULTS AND DISCUSSION

The ROC values for the six main land use/cover types ranged from 0.758 to 0.925, so indicating that the logistic regression model (1) appears significant goodness of fit to the LDF data. Indicatively, the logistic equation for grasslands (ROC = 0.758) is of the following form: $\lg (P_i/(1 - P_i))_{\text{grassland}} = - 1.885 + 0.067 \times$ 'slopes' $- 1.729 \times$ 'alluvial deposits' $+ 1.098 \times$ 'schist' $- 1.381 \times$ 'gneiss' $- 0.633 \times$ 'deep soil' $- 0.650 \times$ 'intermediate soil depth' $+ 0.214 \times$ 'shallow soil' $- 0.0006 \times$ 'distance from road network' $+ 0.004 \times$ 'distance from water courses' $- 0.0002 \times$ 'distance from the center of settlements' $- 0.0005 \times$ 'distance from the center of forest' $+ 0.0004 \times$ 'distance from the shed' $- 9.672 \times$ 'working force density of the primary sector' $- 0.306 \times$ 'number of sheep/cows per unit of grazing area' $+ 0.341 \times$ 'number of goats per unit of grazing area'

There are 15 (out of 25) variables that exhibit any type of statistical effect (positive or negative) in the occurrence of grasslands in the landscape of Lagadas. The occurrence of grasslands in the landscape is positively determined from the increase of inclination, shallowness of the soils, and distance from water courses. Consequently, grasslands are mostly located in areas where human activities, except livestock grazing, are restricted (e.g. inclined and/or shallow soils) and are not located in wet areas (e.g. land stripes along torrents), where ecological conditions potentially favour other vegetation types, like shrublands and forest. On the opposite, agricultural land (20 out of 25 variables are having a significant effect) is positively associated with soils of intermediate (deep to shallow (56475.3) and shallow to deep (25272.9)) and high (2.621) depth, and alluvial deposits (313.5). Surprisingly, the probability of occurrence of agricultural land is quite high in shallow soils (4538.2), where rather grasslands are expected to occur, so expressing the social pressure for agricultural land. The probability of occurrence of agricultural land is also dependent from infrastructures, as the increase of the distances from road network and settlements decrease the probability of occurrence (–198.8 for roads, –62.76 for settlements). Open shrublands (12 out of 25 variables with a significant effect) and close shrublands (19 out of 25 variables) are mostly limited from elevation (–5.401 for open and –25.30 for close shrublands), alluvial deposits (–252.1 and –12,607.2, respectively), deep soils (–4,240 and –6.426, respectively), and goat density (–1.438 and –1.364, respectively), while both shrublands are favoured from deep soils of high rockiness (776.0 for open and 14 178.3 for close shrublands) and the distance from the forest (4.087 and 8.331, respectively). On the contrary, open shrublands are limited from inclination (–1.686), while close shrublands are not (1.818), the distance from the road network (–13.22), while close shrublands are not (347.0), and the distance from settlements (–5.904), while close shrublands are not (347.0); open shrublands are favoured from the distance from water courses (3.103), while close shrublands are not (–8.031). As it was expected, open forest (13 out of 25 variables with a significant effect) and close forest (13 out of 25 variables) are mostly limited from the distance of the center of their formation (–0.000 for open and –2261.7 for close forest), while both forest are favoured from granite (10.29 for open and 4.808 for close forest) and gneiss (6.473 and 2.775, respectively), elevation (8.664 and 7.312, respectively), and distance from road network (6.125 and 2.756, respectively). On the contrary, open forest are limited from the deep soil (–2.293), while close forest are not (1.770); open forest are favoured from the distance from water courses (4.693), while close forest are not (–20.12), and from the density of sheep/cow (1.280), while close forest are not (–1.195).

The coefficients of conversion elasticity entered in the CLUE-S are presented in Table 1. Grasslands of Lagadas were assigned with a zero value because they are considered as transitional communities prone to convert to other land use/ cover type[11]. The rest types were assigned with intermediate values, with the two forest types, close shrublands and agricultural land to be considered more stable (values approaching 1) and open shrublands to be considered less stable[7].

Table 1. Values of conversion elasticity entered in the CLUE-S for the case of Lagadas landscape

Land use/cover type	Conversion elasticity
Grasslands	0
Agricultural land	0.8
Open shrublands	0.4
Close shrublands	0.7
Open forest	0.7
Close forest	0.9

The linear projections of the impact of the LDFs on land use/cover types during the baseline scenario reference period (1945-1993) for the prediction period (1993-2013), indicatively for grasslands and close forest are presented in Fig. 2. It is expected that grasslands in 2013 will almost disappeared from the landscape of Koronia, if the impact of LDFs still remains the same during the period 1993-2013. On the opposite, forest area is expected to increase almost in a twofold rate (from 2400 ha in 1945 up to 4900 ha in 2013 approximately).

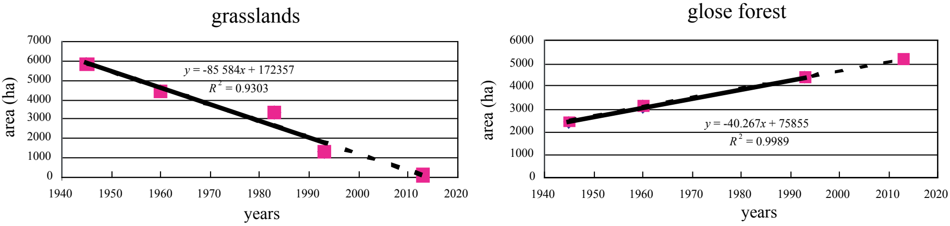

Fig. 2. Linear projection of grassland and forest area (reference period 1945-1993, prediction period 1993-2013) according to the baseline scenario

Predictive spatial information, produced from the CLUE-S, for future land use/ cover types is illustrated in Fig. 3. It is expected that grasslands will limited in sporadic spots in northeastern and northwestern of the landscape, and they will totally be disappeared from the central and the southern parts of the landscape. Also, the area of open shrublands, located in the peripheral zone of close shrublands in the central and western part of the landscape, will be reduced so mostly favouring the area of close shrublands.

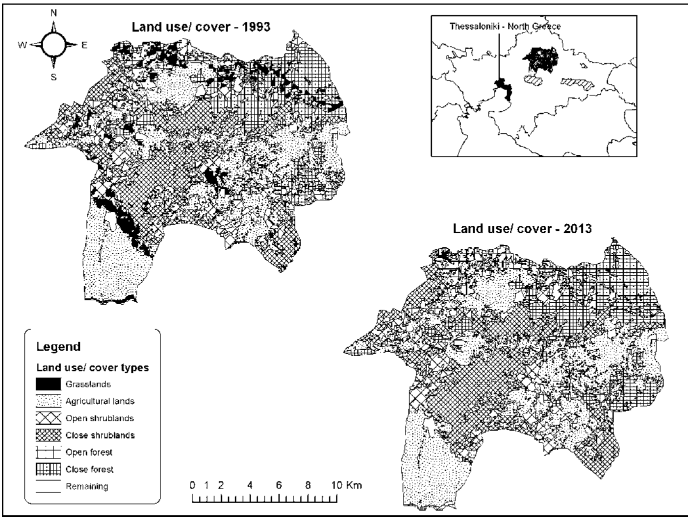

Fig. 3. Predictive spatial changes of the landscape of Kolchicos for 2013 in respect to 1993 according to the baseline scenario

Comparison of spatial data of the main land use/cover types revealed that the area of grasslands is expected to be dramatically reduced to 55 ha in 2013 from 1275 ha in 1993 (-95.69%) (Table 2). Similarly, but in a lower rate (-9.22%), the area of open shrublands is expected to be reduced from 2939 ha in 1993 to 2668 ha in 2013. The rest land use/cover types are expected to be increased, with close forest having the highest rate of increase (+11.98%), following from close shrublands (+11.95%) and, in a lower rate, from open forest (+4.05%) and agricultural land (+2.75%).

Table 2. Spatial changes in area terms of the main land use/cover types for the landscape of Kolchicos between 1993 and 2013 according to the baseline scenario

Land use/cover type	Area in 1993 (ha)	Area in 2013 (ha)	Change (%)
Grasslands	1275	55	-95.69
Agricultural land	8323	8552	+2.75
Open shrublands	2939	2668	-9.22
Close shrublands	5622	6294	+11.95
Open forest	1730	1800	+4.05
Close forest	4342	4862	+11.98
Remaining	327	327	0
Total	24558	24558	0

Insights in the landscape structural and functional characteristics revealed that both indices of MPFD and SEI are expected to be reduced between 1993 and 2013; the MPFD from 1.313 (1993) to 1.297 (2013), and the SEI from 0.915 in 1993 to 0.850 in 2013. According to these results landscape patches are expected to present increased uniformity. Consequently, the future landscape of Koronia will transform over the years to a less heterogenic and diverse landscape, so presenting decreases in significant ecological attributes like the homeostasis and its ability to withstand and recover after perturbations[7]. Also, the aesthetic and recreational attributes of the landscape will be degraded.

It is evident that if the baseline scenario remains into practice the grasslands of Koronia's landscape will extinct and the open shrublands will shrink in area terms. Previous research has shown that implemented socioeconomic practices and demographic changes and pressures have gradually resulted in the Koronia's landscape homogeneity[7,11]. These practices included the gradual ageing of population, the abandonment of firewood cutting, and mostly the passing from the extensified to the intensified type of livestock husbandry. The latter resulted in the significant reduction of goat number in the area, i.e. the restriction of the most important biotic factor that effectively controls shrublands' expansion. The recorded reduction of grasslands and open shrubland area and the unfavourable future perspectives may be taken under serious consideration in land use planning. For example, the national and EU subsidies that operates as a lever for agricultural land expansion maybe re-evaluated at least in rural areas of significant environmental importance. The increase of the density together with the encroachment of woody vegetation in the landscape of Koronia lake may also play a detrimental role in the reduction of biodiversity and the quantity of water that is available to feed the aquifers of the lake. Vrahnakis et al.[18] have shown that floristic diversity of the landscape of the lake decreases with the increase of shrubland density, and Myrovalis[19] stressed the need to control the expansion of woody vegetation in the area if the safeguarding of adequate water volume draining in the lake is in priority. In addition, the control of woody vegetation helps towards the decrease of fire risk[20]. Unambiguously, policies for development and land planning in the area must place emphasis in the direction of enforcing and supporting the extensified type of livestock husbandry, especially goat raising, as to obtain and exploit a biotic tool for the control of woody vegetation. This way, the benefits from the Koronia's environment will have the necessary sustainable character.

CONCLUSIONS

The short term predictions (1993-2013) of the CLUE-S modelling framework have shown that the landscape of the Koronia lake in northern Greece is going under rapid deterioration. This deterioration is mostly due to the almost total disappearance of the area of grassland, and the respect shrinkage of the open shrublands (cover 10-40%). On the other hand, the area of agricultural land, close shrublands and forest is expected to increase, so resulting in lower landscape diversity. Given that these landscape changes are associated with significant environmental issues, policies for land use planning must support the traditional extensified type of livestock husbandry, and especially goat raising, while they must reconsider the current socioeconomic factors that support this deterioration, and lead to the weakness of environmental sustainability.

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