Developing a nested-scale landscape modelling framework for ecosystem services assessment

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Abstract: Assessing landscape systems in relation to ecosystem services requires the ability to work at scales consistent with the service being evaluated. To support such assessments, a nested-scale framework of land use scenarios is proposed. Using scenarios, coherent assumptions on potential land use changes are specifically constructed to deduce landscape consequences. The approach uses a single modelling tool, LandSFACTS, to create potential land use patterns corresponding to the proposed scenario conditions. The model considers simple spatio-temporal constraints on land uses or cropping systems and its inputs are adaptable to multiple scales and scenario needs. The landscapes incorporating the simulated land use patterns can then be assessed for ecosystem services such as habitat networks and crop production at the required scale. The common approach across scales supports the analysis of benefits at multiple levels, and thus will facilitate a coherent assessment of ecosystem services across scales. Scenarios and their evaluation are iteratively refined through comparison between scale specific conclusions. The framework is currently being applied to the North-East of Scotland region, the Dee catchment and Tarland sub-catchment. Preliminary conclusions of the project are reported.

Keywords: landscape modelling; nested-scales; cropping systems scenarios; land uses scenarios; forestry

Introduction

Modelling the interactions between natural and human drivers influencing landscapes requires the integration of a wide range of research activities including environmental, agricultural, and socio-economic sciences (Groot et al., 2007; Matthews, 2006; Rounsevell, 1999). While such integration is essential to further understand the dynamics of the landscape systems, modelling all of the complex processes occurring within a landscape is not relevant or even possible for every research question or policy issue. For example, to explore the potential biodiversity gains through alteration of current cropping patterns, inputs can be restricted to the current system of crop succession and the spatial allocation of the crops (Joannon A. et al., 2009). In this case a simplified approach with few variables directly controlling the landscape elements spatially and temporally is relevant. Such approaches may fit within a scenario framework, where sets of coherent assumptions on land use changes are specifically crafted to test specific landscape-scale hypotheses. This approach recognises that a particular land use pattern is just one outcome that might result from a process of interactions of different factors. Two complementary points should be noted: (i) one or a few factors may be key in influencing the current outcome, and (ii) different sets of factors might combine to produce the same observed land use pattern.

A multi-scale framework is particularly useful for assessing landscape systems in relation to ecosystem services as these services also operate at different scales (Costanza, 2008). For example, climate regulation or cultural benefits are potentially global, whereas pollination or habitat cover are more spatially limited, and soil formation or soil erosion regulation are local. Conventional methods (e.g. Rounsevell et al, (2006)) have projected the impacts of local land use changes using statistical downscaling of regional simulations (i.e. top down approach). In this paper, an alternative approach linking nested scales of studies is presented. The general framework and the modelling tool are detailed first, then an example of nested-scale land use scenarios designed for future assessment of ecosystem services is provided.

1. Framework for nested-scale assessments

1.1. General framework

Land use scenarios should be considered a key feature for a holistic assessment of ecosystem services. Land use change is often characterised as being more abrupt in time than climate change due to factors such as fluctuations in commodity prices and markets. However, responses to climate change (mitigation or adaptation) by influencing land use patterns can also impact upon ecosystem services, and these indirect effects also need to be included in assessment of options.

In the general framework (1), scenarios of land use changes are developed on current land use systems, biophysical constraints of the landscape and real or prospective land use trends. Depending upon the scale and the ecosystem service to be studied, the representation of the current land use system may be approximated. Land cover may be used as a surrogate to land use for large scale modelling, whereas at small scales, agricultural statistics or even detailed farmer's surveys may be linked to individual land parcels. Small scale studies could thus focus on land decision units, whereas large scale studies would be more remote from individual land owner decisions. Multiple data sources may need to be combined to reach the desired degree of information, e.g. to model the interactions between agricultural systems and ecosystems, it might be relevant to integrate land cover classification for general habitat classification and agricultural statistics for refining the cropping systems. Land use trends, such as expansion of agricultural land, of a specific crop or land use conversions, are being integrated to direct the scenarios. The trends can be derived from policy targets, i.e. woodland cover is proposed to increase from 17% up to 25% in Scotland by 2050. Socio-economics factors can also be included to temper those trends, for example land owners might react differently to policies depending upon their activities and social networks. Biophysical constraints of the landscape, such as land capability or available water access, can be explicitly integrated through spatial restriction on land use changes. The potential alteration of land capability due to climate change, i.e. improvement or restriction of land uses, can also be integrated, as relevant, for future projections.

The above constraints have been combined through the LandSFACTS modelling tool, whose inputs can be easily adapted to the available datasets, their level of details and their extent (cf. section 1.2*.)*. The obtained land use patterns are then ready to be assessed for their respective impacts upon ecosystem services and can be assessed by both experts and stakeholders. Their feedback helps to refine the initial constraints or assumptions and thus improve the degree of reality (according to the participating experts and stakeholders) of the scenarios. The scenarios are thus designed to be refined iteratively in a participative process. This methodology is thus different from more traditional land use pattern predictions done with GIS models. This scenario building process can be considered as a learning tool to help identify important factors on plausible land use changes, and potential climate change responses relevant to the characteristics of the local landscape.

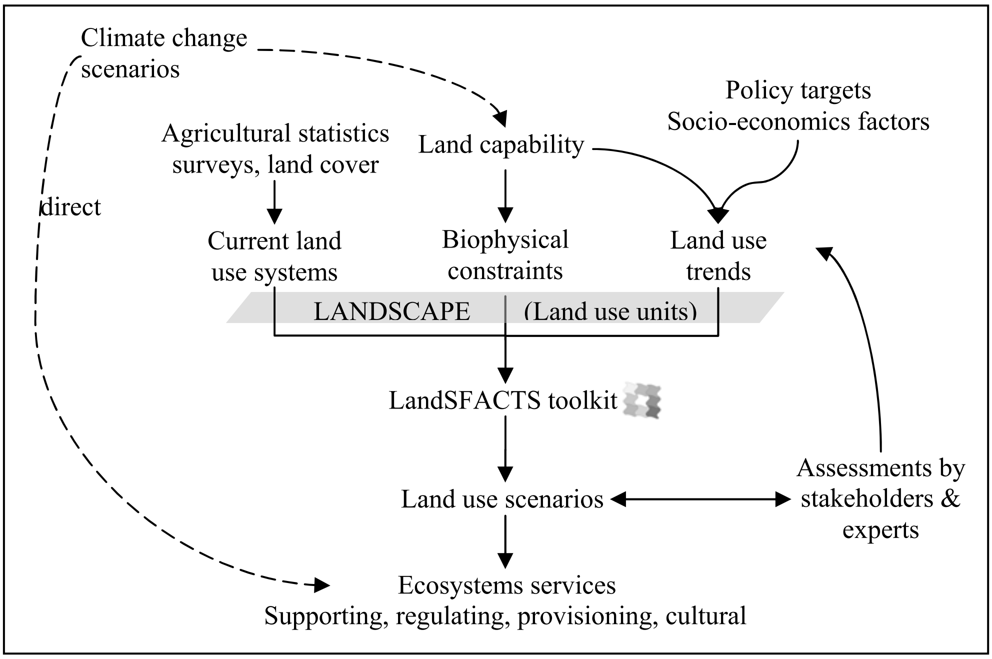

Figure 1: General framework

1.2. LandSFACTS toolkit

LandSFACTS requires the translation by the user of real world conditions (e.g. agricultural and socio-economic factors) into simple spatial and temporal constraints on land use. The model provides spatial allocation into land use parcels (polygons) while meeting all the specified global constraints (Castellazzi et al., in press) by using stochastic (probabilities of land use changes as Markov chains and simulated annealing) and rule-based processes (Figure 2).

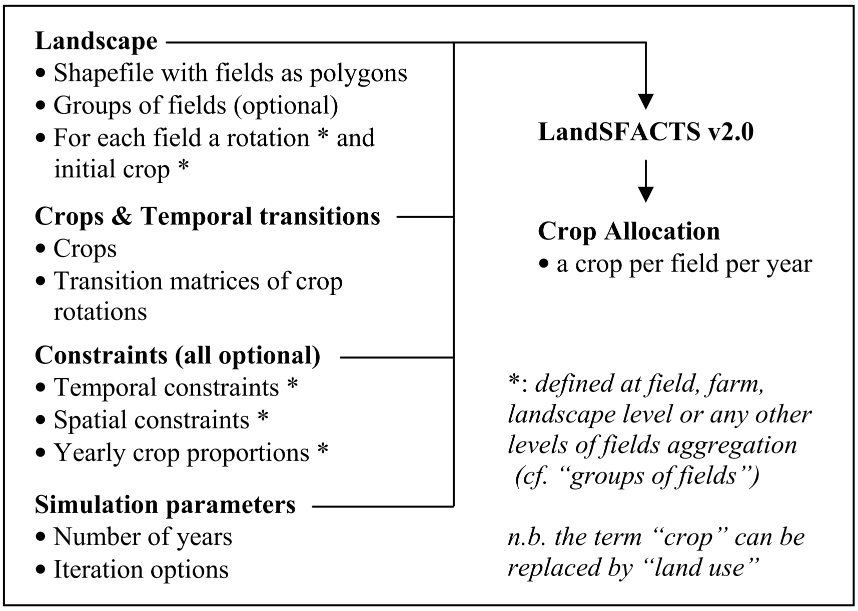

Figure 2: Inputs and outputs of LandSFACTS v2.0 model

Due to the stochasticity of the model, the allocation provided by each run of the model is one potential allocation among many others, therefore running the model multiple times is required for statistical analyses of the range of potential allocations. The model was originally developed to simulate cropping systems under potential GM coexistence rules (SIGMEA, 2007), and thus takes in account crop rotations as probability matrices (Castellazzi et al., 2008), temporal and spatial restrictions of the crops on the fields and separation distances between crops. The updated model (v2.0) is now able to simulate multi-scale cropping systems (e.g. specifying yearly crop proportions at farm and landscape levels), and with time dependent land capability (e.g. for evolving conditions such as under climate change). A wider range of scenarios and land uses can now therefore be modelled. The model with its front-end, documentation and tutorial are freely available on the internet (LandSFACTS v2 website, 2009, http://www.macaulay.ac.uk/LandSFACTS). Examples of current studies undertaken within the nested-scale assessment of ecosystem services are presented below.

2. Case study of nested-scale land use scenarios

The provisional framework for multi-scale assessments is exemplified with current work on ecosystem services in NE Scotland (Figure 3). Land uses on three scales (Grampian region, Dee catchment and Tarland sub-catchment) are modelled using the same framework (LandSFACTS v.2.0). Studies at each scale focus on different issues relevant to the scale considered; accordingly their modelling inputs are adapted. For example, studies at the Grampian scale (administrative region, see Figure 3) focus on administrative issues such as meeting carbon sequestration targets, and woodland cover. Studies at the Dee catchment scale focus on similar issues but at a smaller spatial resolution (i.e. 250m, LCM2000 (Land Cover Map 2000) scale) and therefore are more relevant to local stakeholders, such as groups and partnerships of land managers. Studies at the sub-catchment scale (Tarland in Figure 3) would be able to investigate detailed cropping systems issues by integrating current practices within the model. Using the same modelling approaches at several scales facilitates interpretation and comparison, with particular emphasis on scale-based issues.

This work has been initiated by the need to assess land use patterns and ecosystem services within the Tarland sub-catchment. However as future land use scenarios need to take in account the targets for woodland expansion (Forestry Commission Scotland, 2006), initial larger-scale scenarios at the Dee catchment were considered important. As forestry administration decisions take place at region (Grampian) scale it was also necessary to integrate this data. From the resultant Dee scenarios, potential cover of new woodland Tarland was then applied for the Tarland scenarios. The creation of land use scenarios at the Dee catchment and Tarland sub-catchment are summarised below. The overall study can be considered as a multi-level governance land use scenario assessment.

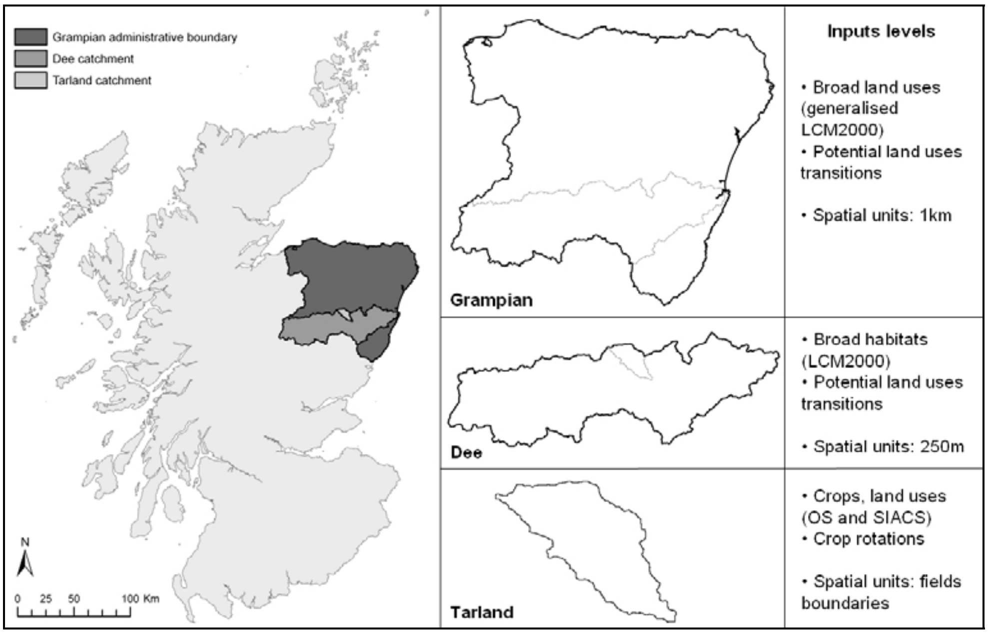

Figure 3: Nested-scale assessment of ecosystem services (LCM2000: Land Cover Map 2000; SIACS: Scottish Integrated Administration and Control System)

2.1. Catchment scale: scenarios of woodland expansion

Woodland cover in Scotland is set to increase from 17.1% up to 25% by 2050 (Forestry Commission Scotland, 2006). Several financial schemes are available to support small scale woodland creation on agricultural land; these incentives are not geographically targeted. Ideally, the expansion of woodland cover should have multi-functional benefits. For the purpose of this study, potential locations for new woodland are investigated in the context of biodiversity, food security and climate change. In North-East Scotland, hotspots where new woodland would enhance habitats for 15 key species (Gimona and van der Horst, 2007) were considered. To secure future food production, 'prime agricultural land' (capability classes 1-3.1) should be preserved from woodland expansion. Climate changes projections imply drier and warmer summers and thus an expansion of prime land within the North-East (Brown et al., 2008). The above spatial targets for woodland expansion are used within the LandSFACTS model to generate land use scenarios of the Dee catchment (Gimona et al., 2009) based upon general land cover classes for the catchment (LCM2000, (Fuller et al., 2002)). Woodland cover is expanded from 16.6% up to the 25% target, by converting land uses (some transitions to new woodland are forbidden such as from current woodland, water bodies, or built-up land). An example scenario is reported in Figure 4. Due to the stochastic process of the LandSFACTS model, running the model many times (e.g. 100 times) allows exploration of potential locations of new woodlands. In those simulations at the Dee scale, woodland areas for the Tarland sub-catchment ranged from 40.2% up to 45.6%. This range of woodland cover and the input maps on the spatial restrictions for new woodlands can then be used to constrain scenarios at the Tarland scale (section. 2.2. Sub-catchment scale: scenarios of cropping systems).

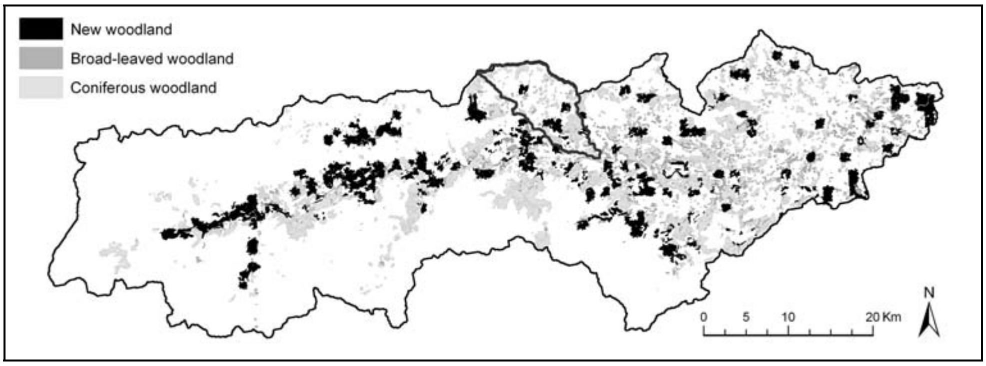

Figure 4: Scenarios of new woodland in the Dee catchment when aiming to enhance woodland network, while considering climate change.

Scenarios at the Dee catchment scale are currently being evaluated for their respective 'strengthening' of the woodland habitat network, and their values for carbon sequestration.

2.2. Sub-catchment scale: scenarios of cropping systems

At small scales, land use can be simulated with regard to crop succession, woodland types and general land management, thus allowing investigation of priority habitats for plants or animals having small dispersal range. Spatial distribution of land use can be explicitly simulated by imposing crop proportions at farm and landscape level. Furthermore, potential adaptations can be simulated as when Joannon et al. (2009) investigated farmer's capacity to manoeuvre crop locations to improve biodiversity, or for climate change responses.

As reported in section 2.1 Catchment scale: scenarios of woodland expansion, total woodland cover and spatial constraints determined respectively at the North-East and Dee catchment scale are incorporated within Tarland scenarios. Due to the smaller extent of the study, a more detailed representation of the landscape and its land uses are developed by using Ordnance Survey (OS) Mastermaps (polygon features). The delimitations between land uses can thus be closer to real decision making units (i.e. fields) than from land cover maps. Definitions of cropping systems, i.e. crop areas and transitions, are derived from the 2001-2008 Integrated Administration and Control System (IACS), which records agricultural land parcels receiving subsidies in Europe. Out of the 27 individual IACS registered crops in Tarland, the three main ones are grass under 5 years (24%), spring barley (13%) and rough grazing (12%), demonstrating the current mixed agricultural system. The integration within LandSFACTS of Tarland specific cropping systems and the general constraints on new woodland allocations provide potential realisations of land use patterns over time (5).

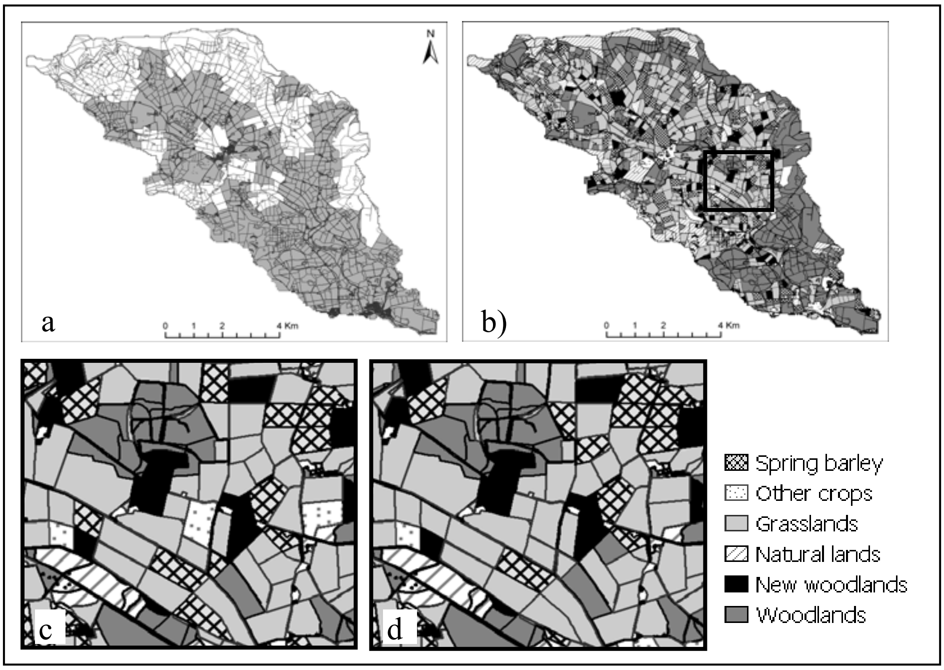

Figure 5: Scenarios of cropping systems and woodland expansion in the Tarland sub-catchment; a) in grey: land available for new woodland (climate, food security and biodiversity constraints); b) one land use allocation for one year; c) close up on the black square in b for year 0; d) for year 1 (for display purposes only 6 land uses categories are represented).

Preliminary conclusion

Preliminary assessments of ecosystem functions and services in the Dee catchment and Tarland sub-catchment have been developed for habitat cover, carbon sequestration, water quality and the cultural landscape. The dependencies between the study areas can be investigated from local to regional (i.e. bottom up approach) or the reverse (top down approach); the order and iterations between both approaches depend upon the decisions being considered at every level and the research purposes. Findings support the need for combining top-down and bottom-up approaches as also reported in Castella et al. (2007) and Houet et al. (2010).

In this framework, the nested scale modelling approach uses the same tool (LandSFACTS) for every scale, but the land use elements, units and constraints are adjusted to the study purposes. Such an approach allows one to investigate the wide range of potential land use patterns within scale-relevant scenarios. The common approach between the scales will support the flows of constraints and conclusions between the individual scenarios, and thus will facilitate a coherent assessment of ecosystem services across scales.

Overall, modelling of the land use scenarios for ecosystem services assessment is not just an end in itself, as the framework itself also provides a “thinking tool” to assist in identifying key issues and knowledge gaps for decision making. It therefore provides the means to design scenarios and to test measures that enhance ecosystem services for a given landscape through a participatory approach. The specialist landscape knowledge of both stakeholders and experts can therefore be dynamically included in the process allowing the identification and co-construction of management solutions to the long term challenges.

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