Landscape and Urban Planning 172 (2018) 29–36

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

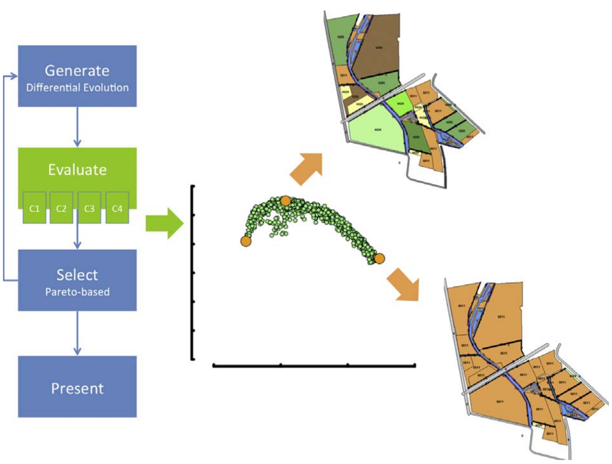
Research Note

Exploring ecosystem services trade-offs in agricultural landscapes with a multi-objective programming approach

Jeroen C.J. Groot*, Seleshi G. Yalew, Walter A.H. Rossing

Farming Systems Ecology Group, Wageningen University & Research, P.O. Box 430, 6700 AK Wageningen, The Netherlands

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Landscape design
Pareto-based multi-objective differential evolution
Ecosystem services
Multifunctional landscapes

ABSTRACT

In this paper, we present the LandscapeIMAGES modeling framework for multi-scale spatially explicit analysis of tradeoffs and synergies among ecosystem services provisioning across agricultural landscapes. The framework generates large sets of spatially explicit land-use and management scenarios to inform discussions among stakeholders involved in landscape planning processes. The generated plans are evaluated and optimized for multiple indicators of ecosystem services provisioning. The framework has been developed with an object-oriented programming approach to allow rapid implementation of new indicators and application to new case study landscapes. The modeling system includes (i) a generic framework for Pareto-based multi-objective optimization to generate a set of land-use and management plans, (ii) an easily expandable collection of modules to quantify indicators of ecosystem services provisioning, which can be used as objectives or constraints in optimization, and (iii) a graphical user interface that allows parameterization of the model and inspection of the original and generated land-use and management plans. This allows visualization of trade-offs and synergies among ecosystem services as a consequence of land-use and management planning choices. LandscapeIMAGES is currently used in projects aiming to improve the provision of multiple ecosystem services within landscapes in Asia, Africa, Latin America and Europe.

* Corresponding author.
E-mail address: jeroen.groot@wur.nl (J.C.J. Groot).

https://doi.org/10.1016/j.landurbplan.2017.12.008
Received 10 January 2017; Received in revised form 22 December 2017; Accepted 30 December 2017

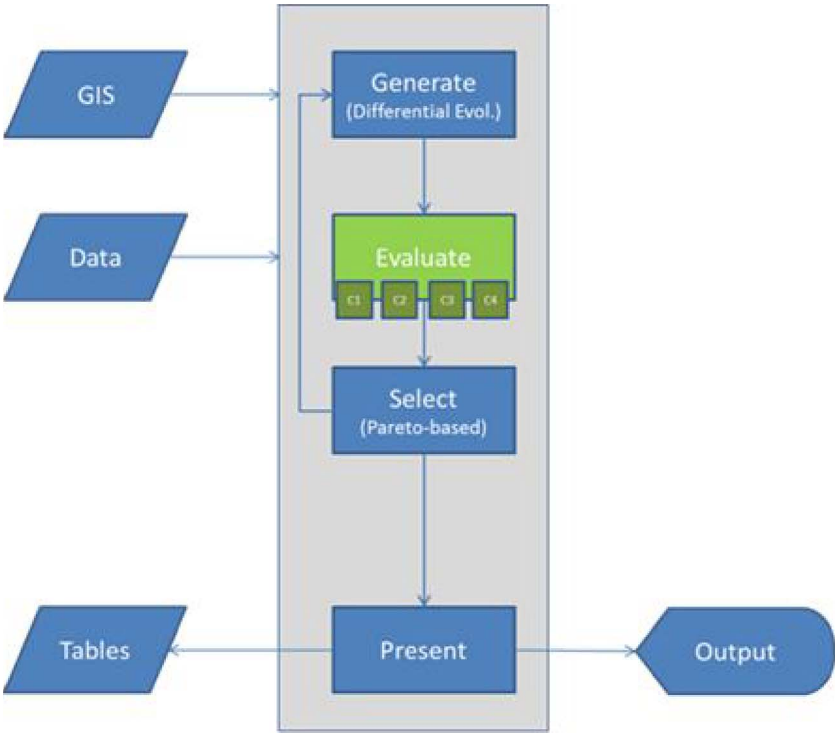


Fig. 1. Configuration of the LandscapeIMAGES framework. 'GIS' represents one or more shape files containing layers with landscape elements and 'Data' represents MS-Access/SQLite database tables storing properties of landscape elements. 'Generate', 'Evaluate' and 'Select' represent procedures in the heuristic generation of land-use and management plans (Generate), followed by indicator computation (Evaluate) and Pareto-based ranking and replacement (Select). The 'Evaluate' procedure comprises a flexible collection of components (indicated as C1-C4) that perform quantification of ecosystem service indicators relevant to the problem studied. 'Present' represents the visualization of solutions in the resulting set of optimized land-use and management plans. The layout of resulting land-use and management plans can be saved as database tables ('Tables') or shown in the graphical user interface ('Output').

1. Introduction

The provisioning of ecosystem services (ESs) by agricultural landscapes is highly correlated with the types of landscape elements and their spatial arrangement (Carrara et al., 2015; Neumann, Griffiths, Hoodless, & Holloway, 2016; Veres, Petit, Conord, & Lavigne, 2013). Thus, not only landscape composition but also landscape structure affect ESs such as biodiversity conservation, erosion control, aesthetic value, carbon sequestration, pollination and bio-control of pests and diseases (Groot, Oomen, & Rossing, 2012; Rostami, Koocheki, Moghaddam, & Mahallati, 2016; Steckel et al., 2014). Identification of desirable alternatives for current structure and composition of agricultural landscapes can be supported by insights from tools that assess trade-offs and synergies among ESs under alternative land-use and management scenarios. Such insights can also support negotiation among actors involved in land-use and management planning (Giller et al., 2011; Mcshane et al., 2011). In-situ experiments to reveal the relation between ecosystem services on the one hand and landscape structure and composition on the other are generally considered infeasible, and recourse has to be taken to in silico approaches. Various software tools have been developed over the past decade to support analysis and design of landscapes. These tools have typically addressed sets of ecosystem services that were fixed by the tool developers (e.g., Mellino & Ulgiati, 2015; Peh et al., 2013; Rostami et al., 2016; Summers et al., 2015; Zambelli et al., 2012) resulting in a lack of flexibility and applicability. Furthermore, these tools generally only enable scenario-based simulations, which, by definition, address only a limited number of land-use and management alternatives (Jackson et al., 2013; Tallis et al., 2011).

Pareto-based multi-objective Differential Evolution (P-MODE), from the family of heuristic optimization algorithms, is well-suited for exploring trade-offs and synergies among indicators of landscape ESs (Behera & Rana, 2014; Groot et al., 2009). The P-MODE algorithm finds a set of Pareto-optimal solutions rather than a single weighted optimal solution for a multi-objective problem (Abbass & Sarker, 2002; Xue, Sanderson, & Graves, 2003). A solution, in this case a possible land-use and management scenario across an agricultural landscape (defined in terms of its structure and composition), is called Pareto-optimal when its performance in terms of a particular indicator cannot be improved without deteriorating the performance in terms of one or more other indicators. The Pareto-optimal set of land-use plans, therefore, represents the trade-off among the chosen indicators of ESs. In some cases, multiple indicators may be improved simultaneously, revealing synergies (Groot et al., 2009). The current land-use across the agricultural landscape is not usually part of the Pareto-optimal set, and options for improvement of multiple indicators (win–win options) by changing land-use and management in the landscape are readily identified in the generated set (Groot et al., 2007, 2012; Groot & Rossing, 2011).

We implemented the P-MODE algorithm in a modeling framework for exploration of Pareto-optimal landscapes, called LandscapeIMAGES. The framework allows incorporation of any number, and type, of indicators of ESs, effectively tackling the limitations of flexibility and applicability of other existing approaches. Here we present the key features of LandscapeIMAGES and its current applications for exploring trade-offs and synergies between multiple objectives for ESs in agricultural landscape design.

2. Modeling system

LandscapeIMAGES (LI; Interactive Multi-goal Agroecosytem Generation and Evaluation System) has been developed using the object-oriented software development paradigm to facilitate maintenance, reuse and easy addition of components, as the tool was intended to be generically applicable in multiple case studies and regions. The framework belongs to metaheuristics (Memmah, Lescourret, Yao, & Lavigne, 2015) and consists of two main parts: (i) the system domain which constitutes the generic framework that incorporates databases, GIS libraries, and the P-MODE optimization algorithm, and (ii) the application domain that is designed to enable implementation of modeling routines and decision rules to address optimization objectives for a landscape (Fig. 1). Each structural element in an agricultural landscape (fields, borders, roads, rivers, etc.) can be represented by a GIS polygon; linear elements like field borders and hedgerows can be represented by GIS line elements. Characteristic data about each landscape element is loaded as an internal attribute table of the GIS file.