Ecosystem Services 26 (2017) 476–482

Contents lists available at ScienceDirect

Ecosystem Services

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

PANDORA 3.0 plugin: A new biodiversity ecosystem service assessment tool for urban green infrastructure connectivity planning

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ARTICLE INFO

Keywords:
Urban planning
QGIS
Landscape connectivity
Open-source

ABSTRACT

Ecosystem services related to landscape connectivity are of paramount importance for biodiversity conservation. However, due to the complexity of urban systems, both landscape connectivity assessment and the analysis of ecosystem services related to landscape connectivity are often inadequately conducted, or even completely lacking, in urban planning. The PANDORA 3.0 model, developed as a QGIS plugin and illustrated here with a study case, is the first free, open-source tool for an integrated evaluation of ecosystem services related to landscape connectivity for biodiversity conservation purposes in urban contexts. The PANDORA 3.0 model plugin aims to be a versatile and innovative tool for assessing Green Infrastructure value in terms of ecological connectivity and biodiversity, useful for the planning of sustainable and resilient landscapes and cities. Its open code availability means that users, scientists, developers and planners involved in urban and landscape ecology will have the opportunity to test the PANDORA 3.0 model in several contexts and even contribute further improvements.

1. Introduction

Well-connected landscapes are more resilient to human and natural disturbances, ensuring a greater stability of biotic functions and of ecosystems service (ES) delivery (De Montis et al., 2016; Liu et al., 2016; Zurlini et al., 2013). The main ESs related to landscape connectivity are attributed to biodiversity, since biodiversity plays a key role at all levels of the ES hierarchy: as a regulator of underpinning ecosystem processes, as a final ES and as an asset that is subject to evaluation (Mace et al., 2012; Pelorosso et al., 2016). Several modelling approaches of landscape connectivity have been developed (e.g., Adriaensen et al., 2003; Cantwell and Forman, 1993; Ferrarini, 2014; Grimm and Railsback, 2005; Loro et al., 2015; Mcrae et al., 2008; Pierik et al., 2016), but a direct evaluation of ESs related to landscape connectivity has not been possible using the previously available models. Moreover, due to the complexity of urban systems, ecological connectivity assessment in urban planning is still challenging (Garmendia et al., 2016; Pelorosso et al., 2016; Tannier et al., 2012). Indeed, spatially explicit indicators for ESs are required to support real urban planning practice (La Rosa et al., 2015) and spatially explicit approaches for biodiversity conservation prioritization of the urban Green Infrastructure (GI) are often lacking or inadequately applied (Garmendia et al., 2016; Snall et al., 2016).

Among the various models available for landscape connectivity assessment, the PANDORA model (Gobattoni et al., 2011) has the potential to become an effective tool in urban planning, since it uses data that are usually available to urban and landscape planners. The PANDORA philosophy considers the landscape as a unique system, responding to thermodynamic laws, in a state of continuous search for a metastable energy equilibrium as a consequence of changes in land use patterns (Gobattoni et al., 2011). PANDORA is based on the graph theory (Cantwell and Forman, 1993) and the energy considered by the model, i.e., Bio-Energy, is linked with vegetation metabolism. First developed in 2011, the model has undergone several changes up to its most recent version (ver. 3.0), in which the contribution of each land cover patch to the global landscape connectivity is also considered in terms of ESs (Pelorosso et al., 2016).

The application of landscape graphs to support land use decisions can be subdivided into three main approaches that correspond to the three planning objectives described by Foltête et al. (2014). These objectives are as follows: (A) to support prioritization within an ecological network from a conservationist perspective, (B) to increase connectivity by identifying the best locations in which to add new elements to the network, (C) to assess the potential impact of a development project in terms of decreased connectivity.

The objective of this short communication is to present the free and

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http://dx.doi.org/10.1016/j.ecoser.2017.05.016
Received 15 June 2016; Received in revised form 23 May 2017; Accepted 31 May 2017
Available online 16 June 2017
2212-0416/

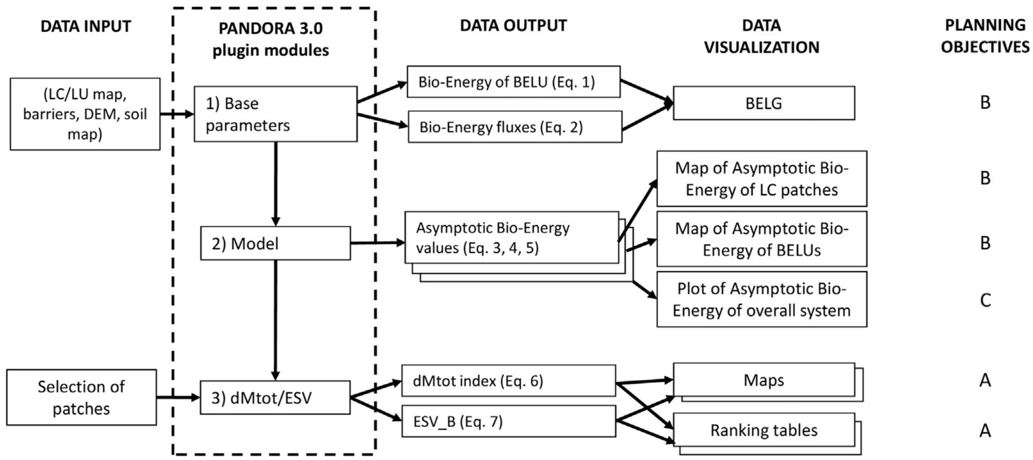

Fig. 1. Theoretical framework of the PANDORA 3.0 plugin. Equation numbers refer to Appendix A.

open-source PANDORA 3.0 model plugin for QGIS as a new tool to incorporate landscape connectivity and related ESs into GI planning practice focused on urbanized contexts. Then, a sample application of the model to the Bari metropolitan area (Southern Italy) is reported to show how the main model outputs can support land use decision making processes following the three planning objectives identified by Foltête et al. (2014).

2. PANDORA model

The PANDORA model assesses the so-called Bio-Energy Landscape Connectivity (BELC) among landscape units, named Bio-Energy Landscape Units (BELUs) (Pelorosso et al., 2016). The energy considered by the model, i.e., Bio-Energy, is linked with vegetation metabolism through the Biological Territorial Capacity (BTC) index. The BTC describes the flux of energy (Mcal/m^2/year) which an ecological system has to dissipate in the environment to maintain its level of metastability (Gobattoni et al., 2011). A BELU is defined as a portion of landscape with variable homogeneity characteristics surrounded by recognizable and significant Bio-Energy flux barriers. Each patch inside the BELU, as well as other physical characters of the BELU such as soil fertility, climate and solar exposition, contributes to the definition of the Bio-Energy level of the BELU, i.e., the flux of Bio-Energy that the BELU has to dissipate in the environment to maintain its level of metastability. The fluxes of Bio-Energy exchanged among adjacent BELUs are then calculated, taking into account the Bio-Energy of each BELU and the permeability of the barriers to energy exchanges. The Bio-Energy Landscape Graph (BELG) is defined by nodes and arcs, where nodes are circles having dimensions proportional to the Bio-Energy of each BELU and arcs describe the fluxes of Bio-Energy between adjacent BELUs. Arc thickness is proportional to the Bio-Energy exchanged among BELUs. A BELG can be used to graphically determine the importance of each BELU for the global BELC as well as to identify their level of connectivity or isolation by analysing the spatial distribution of energy fluxes. The BELG, and the data used to build it, is then used to run the mathematical model on which PANDORA is built. PANDORA is a landscape evolution model based on a system of Ordinary Differential Equations (ODEs) (a kind of Lotka–Volterra model) and on a balance law between a logistic growth of energy and its reduction due to limiting factors resulting from environmental constraints (anthropic or natural barriers, or both). The solutions of the ODEs, until a mathematical asymptotic value of equilibrium is reached, define the ecological quality of the system in terms of Bio-Energy content and BELC. A comparison between different scenarios based on this asymptotic value at landscape scale then allows for the best solutions to be chosen for the preservation of the overall BELC. A plot of Bio-Energy asymptotic values can be used to better visualize the BELC impact of scenarios. Several scenario comparisons have been realized with PANDORA on the basis of the asymptotic Bio-Energy index, as shown in previous papers, in terms of urban sprawl (Gobattoni et al., 2011), road development (Gobattoni et al., 2012), eco-passage realization (Pelorosso et al., 2012) and afforestation (Gobattoni et al., 2014). Moreover, the final asymptotic values can be used to build an asymptotic Bio-Energy map in order to identify critical areas (those having low asymptotic Bio-Energy) due to their bio-physical characteristics (e.g., habitat, soils) and spatial relations with other BELG components, and thus help to prioritize the conservation and restoration measures to be undertaken. Conversely, high asymptotic Bio-Energy values indicate the most important areas for BELC that deserve careful environmental assessment in case of urban development or relevant land use change programs.

The latest version of the model, PANDORA 3.0 (Pelorosso et al., 2016), analyses the contribution of each patch of land mosaic to the global BELC and, consequently, to the functionality and resilience of the entire system to which it belongs. Moreover, PANDORA 3.0 allows the selected patches to be evaluated in terms of ESs for biodiversity conservation considering both habitat type (as defined by information derived from land use and land cover maps) and the BELC in monetary (Pelorosso et al., 2016, 2014) or not monetary form (see Appendix A).

2.1. PANDORA 3.0 model plugin

The PANDORA 3.0 model is now available for free download as an open-source plugin (https://plugins.qgis.org/plugins/pandora/) written in Python language for the Open-source QGIS (QGIS Development Team, 2016). PANDORA currently runs on Linux, Mac OSX and Windows. Moreover, to support model development and users, a tutorial (Pelorosso and Gobattoni, 2016) and community for open discussions are available on Facebook (www.facebook.com/groups/PANDORA3.0/).

Fig. 1 shows the theoretical framework in which PANDORA 3.0 works. PANDORA 3.0 runs in three steps or modules that are defined by the three panels named: *Base parameters, Model* and *dMtot/ESV*. Each module allows sequential evaluations to be carried out, producing separate outputs. Each output has been designed to reach specific goals related to ecological network planning, as defined by Foltête et al. (2014). In particular, BELG and asymptotic Bio-Energy maps can be used to identify the distribution of Bio-Energy fluxes, the barriers to such fluxes and the most important BELUs for BELC. This information can support the spatial planning process in choosing the GI elements (e.g., eco-passages, reforestation) best able to enhance landscape connectivity (objective B). The most important landscape components for BELC can be identified on the basis of the assigned connectivity