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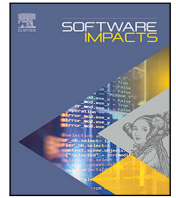
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Graphab: An application for modeling and managing ecological habitat networks



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ABSTRACT

Landscape graphs are increasingly used in ecology, conservation, and landscape planning for modeling habitat connectivity of wildlife species. We present here the follow-up of Graphab, a software application for modeling habitat networks. This application has been recently enhanced by advanced functions of spatial analysis, command-line facilities, and connections with other software applications. It has been used in many studies, first in ecological studies for analyzing the role of landscape connectivity on biological responses measured in the field, second for supporting decisions concerning biodiversity preservation. Future improvements could be made to make the links more realistic with respect to ecological processes.

Code metadata

Current code version	2.6
Permanent link to code/repository	https://github.com/SoftwareImpacts/SIMPAC-2021-11
Permanent link to reproducible capsule	https://codeocean.com/capsule/9363551/tree/v1
Code versioning system	Git
Software code languages	Java
Legal code licence	GPLv3
Computing platforms/Operating Systems	Any OS supporting Java (Linux, MacOS, Microsoft Windows, ...)
Installation requirements & dependencies	Java Development Kit 1.8+
Support email for questions	gilles.vuidel@univ-fcomte.fr

Software metadata

Current software version	2.6
Permanent link to executable of this version	https://thema.univ-fcomte.fr/productions/download.php?name=graphab&version=2.6&username=SoftImpacts
Permanent link to reproducible capsule	https://codeocean.com/capsule/9363551/tree/v1
Versioning system	Git
Software code languages	Java
Legal software licence	GPLv3
Computing platform/Operating systems	Any OS supporting Java (Linux, MacOS, Microsoft Windows, ...)
Installation requirements & dependencies	Java Runtime Environment 1.8+
User manual	https://sourcesup.renater.fr/www/graphab/en/documentation.html
Support email for questions	graphab@univ-fcomte.fr

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1. Introduction

Biodiversity loss that has been reported for several decades now has become a major worldwide concern. Among the main causes of decline are the loss and fragmentation of ecological habitats driven by more intensive farming, urban sprawl, and denser transport infrastructures. Many approaches have been designed for modeling habitat connectivity to better understand how landscape changes impact species and to support the design of land-use policies taking biodiversity into consideration [1,2]. One of the most popular approaches is a graph-theoretic method promoted in ecology by [3] and known as habitat networks or landscape graphs. In these graphs, the nodes are the set of habitat patches occupied by a given species and the links are the potential connections between them, weighted by distances or dispersal probabilities [4]. These graphs provide users with a basis for visualizing ecological networks and characterizing their functional properties by means of connectivity metrics. Given their need for few input data, they have been increasingly used for 20 years in ecology, biological conservation, and landscape planning [5]. Landscape graphs have given rise to several software applications, including mainly Conefor Sensinode [6] and Graphab [7]. While Conefor Sensinode is mostly for calculating connectivity metrics, Graphab was designed as an integrated tool covering all the modeling steps, from graph construction with a wide range of parameters to the implementation of spatial analyses for specific operational applications.

As Graphab has significantly progressed since its first online release, we propose in this paper to review its specific advanced functions and its thematic applications. We also emphasize the recent connections between Graphab and other software applications, before focusing on the future developments that could overcome its current limitations.

2. Description

The initial set of Graphab functions presented in [7] is for constructing landscape graphs and calculating connectivity metrics. Their input data are a land cover map provided by users as a categorized raster layer. The graph nodes are defined from the land cover classes corresponding to the optimal habitat of the species under study. From this set of nodes, users can generate several link sets, controlling for their topology (complete vs. planar) and the type of spatial distance (Euclidean vs. least-cost distance). In the case of least-cost distances, a cost value is assigned to each land cover class or alternatively an external raster cost map is loaded. From the set of nodes and a given set of links, users then define a graph controlling its topology by choosing (or not) a distance threshold beyond which links are removed thereby creating several components (or sub-graphs). Users can easily map all these elements with either a realistic or topological view (Fig. 1).

A wide range of metrics can be calculated from each graph, including indices commonly used in network analysis or specifically designed for landscape ecology studies [8]. These metrics characterize the connectivity of the entire graph (global level), of its sub-parts (component level) or of its basic elements, i.e., nodes and links (local level). Each local metric calculated for nodes can be interpolated to produce a continuous connectivity map that is useful for multi-species approaches [9]. When a set of geolocated points describing biological data (e.g., presence occurrences of a species) is loaded, each point is connected to the closest node according to the spatial distance used for a given link set.

In addition, Graphab allows users to perform sensitivity analyses of graph construction and metric calculation parameters systematically by proposing a batch processing mode [7]. To reduce calculation execution time, Graphab algorithms are parallelized, allowing the use of multiple processors/cores from one workstation or multiple computers in one cluster with an MPI framework.

Additional spatial analyses have been implemented for addressing specific operational purposes of conservation or land planning, like habitat and corridor restoration, or urban sprawl mitigation (Fig. 2). Each graph link is now associated with its corridor, i.e., the area where individual movements may occur. This function provides a view of the spatial extent of corridors whose width depends on the matrix permeability, which gives a relevant outcome for land managers. We made it possible to simulate a land cover change while assessing the resulting impact on graph connectivity using the “patch addition”, “patch removal”, or “land cover modification” functions. Patch addition, for example, scans all possible locations over a defined area and iteratively quantifies the gain in connectivity which would result from implanting a new habitat patch at each location. The best location is selected and the process starts again by accounting for the gain in connectivity cumulatively. The same iterative process can be used to identify the best locations for restoring links, e.g., wildlife crossings along a highway.

As Graphab functions find both research and operational applications, their use has been made more flexible to cover the needs of this wide range of users. First, command-line facilities are available and documented to ease batch processing. Similarly, Graphab functions have recently been included in the R software environment [10], which is frequently used in ecological research, and supplemented by specific functions for landscape genetic analyses through the release of the graph4lg package [11]. Finally, a QGIS [12] plugin has been developed to make basic functionalities available to the wider community of users of this free GIS software. This connection could also make it possible to set modeling outputs against other geographical information layers for interpretation.

3. Impact overview

Graphab’s use in academic research has already contributed to the publication of several tens of scientific papers in various fields. It was first applied in ecological studies to provide knowledge about the effect of landscape connectivity on biological responses measured in the field. This was done at multiple biological levels to explain species presence [13,14], species community richness or similarity [15–18], genetic diversity [19], demographic variations [20,21], individual movements [22], presence of roadkill hotspots [23–26], or even parasite prevalence [27,28].

Graphab has also been frequently implemented in studies to support decisions directed at biodiversity preservation, allowing users to answer questions beginning with “where”. In the field of environmental impact assessment: Where might species be the most impacted by landscape changes [9], climate changes [29–31], or natural disasters [32]? Where will the potential ecological impacts caused by the development of transport infrastructures [33–35] or of a large urban infrastructure [36] occur? Graphab has also proved useful in many biological conservation studies, primarily to identify the priority locations for maintaining the connectivity level of a habitat network [37–43]. Concerning ecological compensation or mitigation, Graphab has been applied in response to the question: Where are the most relevant locations to design or plan actions promoting access to ecological habitats? Studies have been made to establish compensation sites following the implantation of a highway [44] or a sports infrastructure [45], for restoring ecological habitats [46–49], for developing wildlife crossings over a highway [50,51], or even for evaluating the pooling of biodiversity offsets [52]. Graphab has also been used to choose optimal field locations for implementing agroecological measures to reduce habitat connectivity of a rodent whose swarming causes substantial ecological and economic damage [53,54].

At a larger scale of urban planning, Graphab has been used to include ecological connectivity in the impact assessment of urban

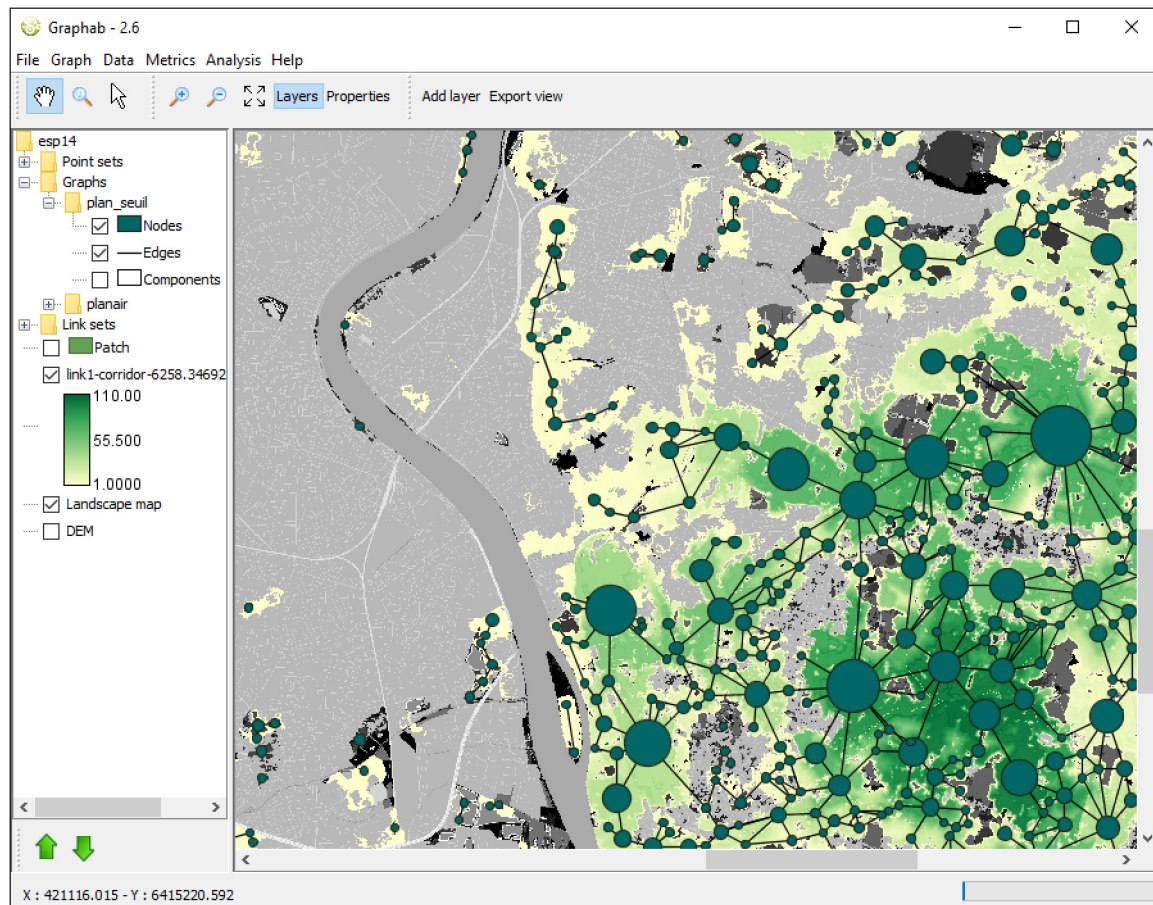


Fig. 1. Screenshot of Graphab with a case study in urban ecology. The nodes (green circles) represent herbaceous patches connected by links (black lines). The size of nodes is proportional to the Interaction Flux index, a connectivity metric outlining the potential of local interaction of the nodes.

development. Most of these planning approaches were based on spatial simulations of urban development scenarios, either for comparing the potential impacts of several urban forms [55–57] or for planning actions to mitigate urban expansion [58]. Other urban planning studies using Graphab have been conducted to evaluate the biological potential of green spaces [42,59] or to assess their permeability as stepping stones [60,61]. Graphab has also been used as a tool to include stakeholders in connectivity analysis [62,63], to initiate public debate in the context of an action against an infrastructure project [62] and to explore the covariations between visual and ecological landscape qualities [64].

Finally, Graphab software has fueled a variety of methodological approaches aimed at proposing or testing new research designs. This mainly concerns multi-species analyses [65], the coupling of landscape graphs with species distribution models [66], and the comparison of several strategies of graph construction [67,68].

4. Limitations and potential improvements

The wide range of Graphab users and their regular feedback have contributed to the diversification of the software functions. Yet, Graphab is not without its limitations and several improvements can already be outlined.

Graphab inherits one of the problems of landscape graph modeling, namely the assignment of cost values. Except for the case of input data derived from a species distribution model [66], such assignment

is usually derived from expertise, raising the question of its validation. This refers to the broader need for validating landscape graph parameters with biological data [69]. From this perspective, specific procedures could be added to help users validate their choices. When field data such as geolocated points characterized by species presence or community richness are loaded, statistical tests could be set up to provide a validity level of the model and a rapid sensitivity analysis.

Further development could improve the relevance of links. To go beyond the classical limitation of the least-cost distances reported by [70] and [71], the goal would be to enhance the link weighting with methods taking account of multiple alternative paths, using either stochastic processes [72] or circuit theory [73]. From the same perspective, it would be worth setting up directional links for considering non-symmetrical fluxes among patches.

An ambitious perspective would be to design a 3D-version of Graphab to account for differences in elevation between landscape features in high-resolution applications. This would make it possible to avoid the limitations of 2D land cover maps where elements overlie each other (e.g., a bridge over a stream) and could be specifically useful in urban ecology when buildings may be covered by green roofs, or when several layers of water are stratified in aquatic ecology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

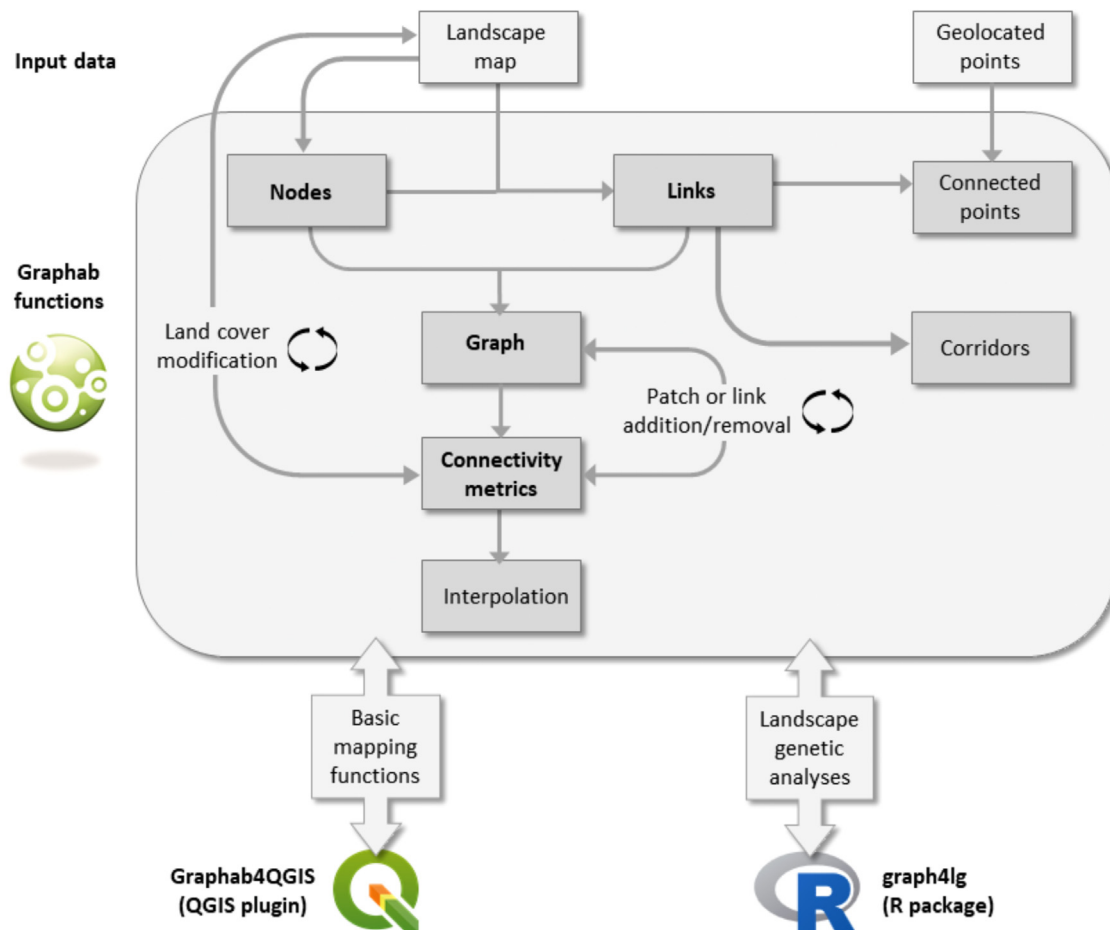


Fig. 2. Flowchart of the main Graphab functions. Nodes, links, and the resulting graph are the central elements from which connectivity metrics are computed, and potentially interpolated. Processes of land cover modification and patch or link addition (or removal) are iterative. Corridors and connected points are specific outcomes.

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