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From static connectivity modelling to scenario-based planning at local and regional scales

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ABSTRACT

Despite the proliferation of connectivity modelling approaches, static models have limited usefulness for decision-making by policy-makers and land managers, particularly where significant changes in land uses might be expected into the future. This study presents a flexible, scenario-based approach for modelling fine-scaled connectivity using graph-theory with least-cost paths for modelling connectivity at the regional scale and circuit theory at the local scale. The method allows for the assessment of a range of scenarios based on varying land use practices. Using the Lower Hunter region, Australia as a case study we tested five scenarios that describe the impact of different development choices on connectivity, ranging from high rates of urbanisation to revegetation of a designated green corridor. The changes in connectivity from the current state were assessed by visualising component boundaries and link locations and calculating patch- and landscape-scale graph metrics. In the Lower Hunter we found the green corridor scenario increased connectivity both visually and quantitatively, as shown by a 105% increase in the integral index of connectivity (IIC) which measures habitat availability (reachability) at the landscape scale. In contrast the urbanisation scenario resulted in a decrease in connectivity, with a 39% decrease in the IIC. The approach outlined in this paper is flexible, enabling a range of interests to be included, depending on the datasets available and the issues that need to be addressed. Such methods can be readily and rapidly applied by consultants or government agencies, in this region and elsewhere, to incorporate connectivity modelling into development plans.

1. Introduction

Changes to the extent and condition of native vegetation due to human land use results in an altered mosaic of habitat for native species. The constriction of species movement caused by increased habitat fragmentation or decreased connectivity reduces population viability and increases extinction risk beyond that caused by habitat loss alone (Brook, Sodhi, & Bradshaw, 2008; Caughley, 1994; Fischer & Lindenmayer, 2006). Management of the patterns and types of land cover is thus important for reducing the impact of fragmentation on connectivity.

Despite the proliferation of connectivity modelling approaches, static outputs from these models characterising existing connectivity networks may have limited usefulness for decision-making by policy-makers and land managers (Bergsten & Zetterberg, 2013; Whitten, Freudenberger, Wyborn, Doerr, & Doerr, 2011), particularly where significant changes in land use might be expected into the future (McHugh & Thompson, 2011). It is critical for these models to be flexible and able to be readily modified and updated in response to future land use planning decisions, changes in available spatial data and knowledge of species dispersal characteristics.

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A scenario planning approach can be useful for considering the potential impact of land use changes on connectivity across a region and at local scales. Different scenarios, representing a range of stakeholder interests, can be simulated by modifying the spatial data inputs to the connectivity model (Lechner, Brown, & Raymond, 2015a). Land use change can have a positive or negative influence on connectivity by changing the number or size of patches; changing dispersal costs as a result of altering land cover types (e.g. converting grazing land to urban), or by adding or removing elements that are important for structural connectivity, such as scattered trees (Fig. 1). The impact of different scenarios can be visualised qualitatively, as well as quantified using metrics such as patch-scale graph metrics, and landscape scale graph metrics (Clauzel, Girardet, & Foltête, 2013; Foltête, Girardet, & Clauzel, 2014; Zetterberg, Mörtberg, & Balfors, 2010). The scale of impact assessment for land use planning ranges from regional assessments that identify critical wildlife corridors linking a region to local scale assessments such as for an environmental impact assessment that identify whether remnant vegetation found as paddock trees are critical for connecting two habitat patches.

Land use decisions are frequently made in the absence of data or using coarse resolution modelling across large extents, describing connectivity at resolutions inappropriate for answering the questions being asked by these land use planners. In most cases there is little or no capacity to update mapping outputs and assess land use scenarios (Bergsten & Zetterberg, 2013; Whitten et al., 2011). Therefore where existing connectivity mapping is used land use scenario assessments cannot be made quantitatively. However, connectivity needs to be assessed as a system, modelling the emergent property of the patches and the network of linkages. Impacts are best assessed through modelling these linkages in response to a scenario. For example, conserving half a threatened species habitat is likely to provide positive conservation outcomes, however, conserving half a corridor is ineffectual. A common approach with static connectivity maps is to overlay impacts of land use change with connectivity pathways. This may be useful where the impacts are simple such as on a single linkage or patch. However, when complexity increases and multiple areas of habitat and linkages may be lost or gained, these methods may not adequately assess impacts at a landscape scale.

In this study we describe a flexible connectivity modelling framework targeted at land use planners. The framework is based on an existing fine-scaled connectivity modelling framework (Lechner et al., 2015a,b) which uses graph-theory with least-cost paths for modelling connectivity at the regional scale (Foltête, Clauzel, & Vuidel, 2012), and circuit theory for modelling connectivity at the local scale (McRae, Dickson, Keitt, & Shah, 2008). In the methods section we describe the components of the framework: (i) fine-scale connectivity modelling methods, (ii) land use scenarios simulation, and (iii) methods for assessing connectivity modelling scenarios outputs. We demonstrate the framework's utility for assessing the impact of different land use scenarios on connectivity networks using the Lower Hunter region (NSW, Australia) as a case study. This paper provides an example for how land use planners can operationalise connectivity outputs from existing graph-metric and Circuitscape modelling software. The emphasis of this paper is on providing a simple and robust framework for the rapid assessment of connectivity for land use planners who do not have the time or expertise for the complex analyses that are commonly described in the academic literature.

2. Methods

2.1. Fine-scale connectivity modelling methods

In this paper we utilise the General Approach to Planning Connectivity from LOcal Scales to Regional (GAP CLoSR) framework originally described by Lechner and Lefroy (2014). The GAP CLoSR framework describes how local and regional scale connectivity models can be used and interpreted to support land use planning through scenario analysis. The framework characterises connectivity based on fine-scale dispersal behaviour and includes: (i) a workflow that starts with identification of key ecological connectivity parameters; (ii) pre-processing spatial data based on these parameters; and (iii) a method for running these spatial data within existing connectivity modelling software. A critical component of this framework is the ability to rapidly re-process data for running multiple scenarios.

The regional scale model is based on Graphab (Foltête et al., 2012), a graph-network connectivity model that uses least-cost paths, though modified to account for threshold dynamics in dispersal behaviour. Graphab is used to characterise connectivity between patches based on a threshold distance between adjacent patches. Where connectivity exists between patches a single optimal least-cost path is identified between patches.

In contrast Circuitscape characterises connectivity for all pixels in the area of interest between all dispersal sources (patches or groups of patches) but does not allow dispersal thresholds to be used. Circuitscape models the landscape as analogous to an electrical circuit, characterising movement across a resistance surface as

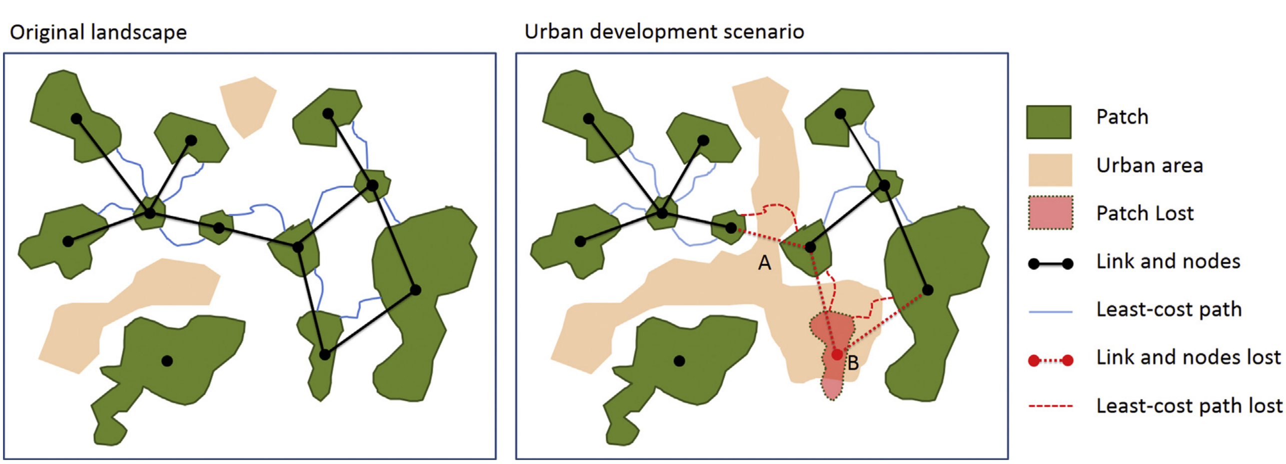

Fig. 1. Graph theory is used to represent patches as nodes and connected patches as links. Actual paths between patches can be represented as least-cost paths. Graph metrics are useful for characterising the contribution of individual patches to connectivity and characterising overall connectivity. This diagram presents a development scenario that results in the expansion of urban areas. The impact of this scenario can be described through the lost links and nodes which can be quantified using graph metrics.