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Effects of uncertain cost-surface specification on landscape connectivity measures

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A B S T R A C T

Estimates of landscape connectivity are routinely used to inform decision-making by conservation biologists. Most estimates of connectivity rely on cost-surfaces: raster representations of landscapes in which cost values represent the difficulty involved with traversing an area. However, there is considerable uncertainty in the generation of cost-surfaces that have not been widely explored. We investigated the effects of four potential sources of uncertainty in the creation of cost-surfaces: 1) number of landscape classes represented; 2) spatial resolution (grain size); 3) misclassification of edges between landscape classes; and 4) cost values selected for each landscape class. Following a factorial design we simulated multiple cost-surface pairs, each comprising one true surface with no errors and one surface with uncertainty comprised of some combination of the four error sources. We evaluated the relative importance of each source of uncertainty in determining the difference between the least-cost paths (LCPs) costs and resistance distances generated for the true and erroneous cost-surfaces, using four model evaluation metrics. Errors in the underlying geospatial layers produced larger inaccuracies in connectivity estimates than those produced by cost-value errors. Incorrect grain size had the largest overall effect on the accuracy of connectivity estimates. Though the removal of an element class was found to have a large effect on the configuration of connectivity estimates, and the addition of an element class had a large effect on estimates configuration. Our results highlight the importance of minimising and quantifying the uncertainty inherent in the geospatial data used to develop cost-surfaces.

1. Introduction

Understanding how landscape features affect the movement of organisms is important for mitigating the impacts of habitat fragmentation (Fischer and Lindenmayer, 2007), preventing the spread of invasive species (Margosian et al., 2009), designing wildlife corridors (Beier et al., 2009; Minor and Lookingbill, 2010), and facilitating dispersal in response to environmental change (Heller and Zavaleta, 2009; Hodgson et al., 2009). Landscape connectivity (hereafter 'connectivity') is the degree to which different landscape structures and elements facilitate or impede the movements of organisms among resources or habitat patches (Taylor et al., 1993), and is, therefore, central to many conservation plans (Rayfield et al., 2011). However, obtaining direct measures of connectivity is difficult and costly (Kindlmann and Burel, 2008), and so a variety of algorithms have been developed (e.g. least-cost paths modelling and circuit theory) to indirectly estimate a landscape's connectivity. The majority of these connectivity models are underpinned by a cost-surface (often also referred to as a resistance-surface).

Cost-surfaces are raster representations of landscapes that characterise the difficulty for an individual of some species of interest to traverse a grid cell (Etherington, 2012). The cost value assigned to each cell is based on its landscape elements or features. Cost values represent a range of species-specific factors that influence movement including, mortality risk, energy expenditure, or behavioural aversion, with higher cost values typically indicating greater impediment to movement (Etherington, 2016).

Cost-surfaces usually are produced in four steps (Fig. 1; Spear et al., 2010): 1) A usable representation of a landscape of interest is generated, or more commonly selected from an existing geospatial database. Layers are usually derived from remotely-sensed satellite or aerial imagery, and typically are not generated explicitly to inform connectivity studies

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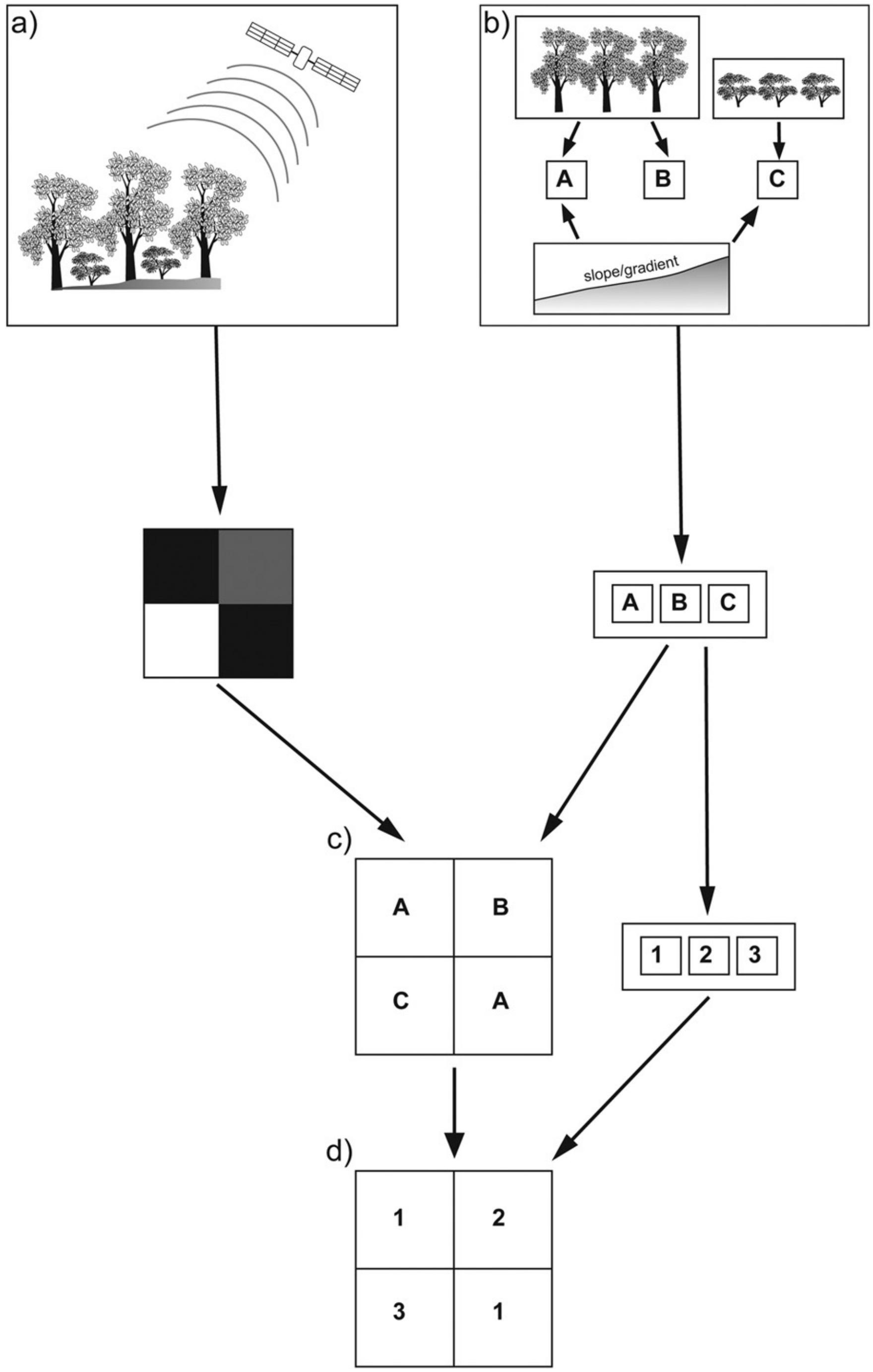

Fig. 1. Depiction of the stages involved in construction of a cost-surface. a) Initially a raster (or multiple raster) depiction of a landscape (a 'thematic map') is obtained, typically by remote sensing. b) A number of landscape variables believed to influence species movement are then selected and used to generate a list of element classes (A, B, C). These parameters may be categorical (e.g. landscape cover type) or continuous (e.g. hillslope). c) Cells in the raster depiction of the landscape (from [a]) are then classified into classes, reflecting groupings such as land cover type, d) Each class is then assigned a cost value representing the difficulty associated with moving through a cell of that class, and these values are used as the cell costs in the raster surface.

(Sawyer et al., 2011; Zeller et al., 2012); 2) each cell (or polygon in a vector representation) is assigned to a thematic class (e.g. type of land cover), either manually or by semi-automated classification methods to derive a 'thematic map' (Mairota et al., 2015; Zeller et al., 2012); Cost-surfaces frequently integrate multiple such thematic maps, which may represent either categorical or continuous data. 3) a suite of variables believed to influence the movements of the target species is then selected for inclusion in a model of cost used to parameterise the cost-surface. Cost-surfaces may incorporate just one (e.g., land-cover type or slope) or multiple parameters, with in the latter case each having an associated weight (Graves et al., 2014); 4) the difficulty associated with moving through a cell is described by the cost of that cell, which reflects the variable(s) represented within the cell. The choice of parameters and associated cost values often relies on expert opinion, though methods utilising empirical data for the creation and