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Designing recreational trails in a forest dune habitat using least-cost path analysis at the resolution of visitor sight distance

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ABSTRACT

Dune plantation forests are typically used for recreation. However, the soil and vegetation of these forests are sensitive to trampling. Therefore, recreational trails should have clearly defined boundaries. The aim of this study was to test a cell-based survey for the alignment of interpretative trails in sand dune plantation forests, where each cell of a sampling grid is surveyed in the field at a grain size of 10-m, which is an appropriate scale for both visitors and to accurately assess vegetation and stand structure. The alignment of the trail was then performed using a combined least-cost path algorithm with GIS-based land suitability analysis. Using this approach, sets of key factors for land suitability and visibility which are generally applicable to dune plantation forests were identified. Specific criteria were adopted to score and weigh each factor in this case study, where each of the 284 cells of a 10-m grid were surveyed for two weeks in a coastal urban reserve located in one of the major tourist beach resorts of the Mediterranean basin (Bibione, Northern Italy). The factors surveyed in the field were used to calculate the potential trail index, and the least-cost path method was used to optimally align the trail in order to achieve the lowest cumulative resistance value possible. The novel cell-based survey did not require the conversion of any land suitability layers to their raster counterpart grids, as the grain and resulting alignment of the trail were scaled to the neighbourhood of the users. In addition, we did not focus on the concept of the patch, as we were not interested in reclassifying the surveyed attributes, as features were originally collected at the scale of the walking paths. We conclude that the proposed method is a feasible approach, and amenable to situation where a fine-grained alignment of recreational trails is required, and/or when a careful assessment of a trails' environmental impact is needed.

Introduction

Dune plantation forests have primarily been established for stabilising sand dunes or protecting coastal lands against wind erosion and marine aerosols. The total extent of dune plantation forests worldwide is unknown, but they are known to cover a large proportion of coastlines of different continents (Gadgil and Ede, 1998; Malagnoux et al., 2007; Wilkie, 2002). Dune plantation forests are often located near major touristic seaside resorts, where these areas have a high potential for recreational uses (Everard et al., 2010), while also having a high degree of biodiversity (Sturgess and Atkinson, 1993). Dune plantations have often been established on low and flat beach plains, where sand or gravel deposits form flat or ridged accumulations a few metres above sea level and spread inland from the shore. The accessibility of these sites also make them attractive locations for touristic resorts, and educational and recreational uses. However, the soil and vegetation of these areas are sensitive to trampling and vehicular traffic (Rickard et al., 1994), particularly over long periods of use (Kutiel et al., 2000). One method which has been used to reduce trampling effects in these sites is to clearly define trail boundaries (Kutiel et al., 1999).

A well-established method for identifying trail boundaries is to utilise a GIS-based least-cost path algorithm for the analysis of land suitability in trail alignment planning (Xiang, 1996). Land suitability analysis is commonly used to determine the fitness of a given area for a specific use, such as establishing walking trails in sensitive areas (Hopkins, 1977; Steiner, 1983). This analysis is based on the selection and mapping of environmental and economic factors that influence the use of land for a specific purpose. Some of these factors define how appropriate the land is for a specific use, while other factors determine the ability of the land to physically support a specific use (Jankowski and Richard, 1994). The path with the lowest accumulated cost between two locations in a raster model of a cost surface for these factors results in a string-like, thin, and

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long sequence of cells (Gonçalves, 2010). For example, Snyder et al. (2008) showed that all-terrain vehicle trails could be planned using this method to provide rigorous and structured selection processes.

Trail alignment can facilitate the identification of the most significant physical and natural features (e.g., Brody and Tomkiewicz, 2002; Gustke and Hodgson, 1980; Wandersee and Clary, 2007), which can assist hikers in cognitive learning along the route (Nichols, 1989) and increase their perception of environmental problems (Curthoys and Cuthbertson, 2002; Ferreira, 1998; Taylor, 2006).

The least-cost method has been frequently applied to the alignment of recreational trails (e.g., Rees, 2004; Tomczyk and Ewertowski, 2013; Xiang, 1996). Xiang (1996) developed one of the earliest formulations for the application of this algorithm to trails. According to Xiang (1996), the cost is equal to the resistance r, which is the inverse of the trail potential index (π) of the cell (see Appendix A). This value derives from the weighted combination of the suitability, visibility, and cost estimation ratings of each land parcel cell.

The trail resistance index expresses the friction encountered when passing through different cells to establish a "cost surface" from the starting point outwards, followed by tracing the least-cost path from the target point back to the origin. An important step in this method is the selection of the origin and destination cells. The origin cell could be designated based on different aspects, such as ownership, accessibility to the site boundaries, existing facilities (parking lots, buildings, etc.), or from other points of interest. The destination cell can be selected based on important natural landmarks, considering a maximum or minimum length for the path or construction costs. Another important aspect is the trail configuration, which, in small properties, can be shaped as a loop, permitting the user to begin and end at the same location without repeating any part of the trail, which makes the alignment process easier. However, although the use of GIS and the least-cost method for trail planning has been implemented for more than fifteen years, the majority of studies on this topic have represented the landscape as a patch pattern, which is incapable of intercepting the fine-scale neighbourhood of a visitor walking on an interpretive trail, which requires small-grain analysis.

The aim of this study was to test a cell-based survey for the alignment of interpretative trails in sand dune plantation forests where each cell of a raster has been surveyed on the field adopting a grain size appropriate for a visitor scale. The alignment of the trail was then implemented by combining a least-cost path algorithm with a GIS-based land suitability analysis, following the approach of Xiang (1996). The primary concerns for the trail alignment included preserving the semi-natural habitats, minimising the impact of recreational pressure, and making the site accessible for educational purposes.

Alignment planning scaling problems

While this approach has been utilised in trail planning since the nineties (Balstrøm, 2002; Douglas, 1994; Xiang, 1996), we propose that the selection of an appropriate scale of analysis has not been sufficiently considered by previous studies. The consideration of issues related to selection of scale of analysis is well established in ecology (Levin, 1992), particularly with respect to the selection of a survey method (Legendre et al., 2002), since the scale of analysis will invariably influence the interpretation of ecological systems (Dungan et al., 2002).

The classical method involves the development of a database where existing layers are overlaid and subsequently converted to corresponding raster grids, whose grain size should be equal to the minimum acceptable sight distance for hikers, which is approximately 15 m (Xiang, 1996). However, the simple conversion of the vector layers to a raster of this grain size does not guarantee the reliability of the final alignment. Indeed, the latter depends on both the scale of the original data collection and the manner in which the areal units are aggregated into zones or 'patches' under the same conditions (Jelinski and Wu, 1996), which is a phenomenon called the 'modifiable areal unit problem' (Openshaw, 1977). We suggest that this simplification is acceptable for wide areas and with long trails, but not for short interpretive trails, which require a more detailed analysis of the environmental setting. Under these conditions, the above theoretical framework is appropriate, but the dimension of the survey and the resolution of the collected data should be scaled to the neighbourhood of a walking person, without any subsequent classification aimed at identifying patches. Many aspects defining the potential for trail alignment, such as landscape heterogeneity, adjacencies, and interactions, can be studied at the neighbourhood scale of a single visitor.

Land suitability and visibility factors in sand dune plantation forests

Sand dunes have commonly been afforested with conifer and broad-leaved trees of the genera *Pinus* (e.g., Kachi and Hirose, 1983; Leege and Murphy, 2001; Malavasi et al., 2013; Smith et al., 1994; Sturgess and Atkinson, 1993), *Abies* (Wilkie, 2002), *Casuarina* (Mailly and Margolis, 1992), *Acacia* (Avis, 1989), and *Eucalyptus* (Lückhoff, 1955), among others. Many other exotic and native tree taxa have been established, which have had contrasting impacts on the ecosystems according to the varying geographical, morphological, and biological range of conditions of the sandy coastal sites worldwide (Martínez et al., 2013). Despite this range of conditions however, the afforestation of natural non-forest ecosystems is widely accepted as detrimental to biodiversity. The assessment of these impacts is frequently a difficult task, due to the complexity of evaluating a mosaic of natural, semi-natural, and artificial habitats. For example, rich assemblages of open-habitat species might occur in clear-cuts and gaps (see Brockerhoff et al., 2008 for a review). To make an accurate assessment, enough detailed information on these ecological patterns and processes must be collected to develop a set of land suitability factors $F = \{f_k\}$ and a set of visual attractions $T = \{\tau_l\}$ required for land suitability assessment, visibility assessment, and environmental cost estimation (see Appendix A). The sets should include not only habitat and plant diversity, but also other areal, linear, or point elements that may impact biodiversity, be a site of interest, or function as an anchor points for the trail (Hermy and Cornelis, 2000). These factors and attractions should be unambiguously defined, leaving no confusion concerning their identification in the field. The weight of the land suitability factors and visual attractions should be proportional to their importance for selected categories of decision makers or stakeholders, depending on the complexity and the length of the trail. Cost estimation factors are locally influenced, and hence we will not further analyse these factors in this study.

In the context of forest plantations, several factors are important for recreational value. Positive recreational value is associated with indicators of stand structural diversity (i.e. trees size and its variation within a stand), the number of tree species, the variation of forest stand types, and (if not too high) the amount of natural dead wood (Axelsson-Lindgren and Sorte, 1987; Edwards et al., 2012; Heyman, 2012). The succession towards potential native woodland might follow the natural opening of small gaps, taking advantage, to some extent, of the canopy cover of planted and spontaneous woody species (Carnevale and Montagnini, 2002). In general, plantation management which contributes to biodiversity conservation (Hartley, 2002) has not negative influence on