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Restoration prioritization framework for roadway high cut slopes to reverse land degradation and fragmentation

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ABSTRACT

Land degradation is one of the most critical global environmental threats. The EU Biodiversity Strategy to 2020 has appointed land degradation and ecosystems fragmentation caused by transport infrastructures as crucial threats to biodiversity. Implementing environmental criteria in roadway project conception phase for restoring large cut slopes will prevent this threat. There is a lack of decision support systems to implement environmental criteria in the decision making procedure to restore high cut slopes. The major difficulties have been building consensus and ensuring traceability and transparency from the panel of experts. This paper presents a hybrid framework capable of dealing with environmental criteria and also with conventional territorial and economic criteria. The decision support procedure combines the Analytical Hierarchy Process with the Delphi technique and the VIKOR procedure. The experts' consensual decision-making process is properly documented, unambiguous and verifiable. The results of this study yielded that the functional and environmental criteria are the key factors in the decision-making process of large cut slope restoration projects. And it has been found the suitability of the cut-and-cover tunnels despite their higher cost and complexity of its construction.

1. Introduction

In the report 'Our life insurance, our natural capital: a European Union (EU) biodiversity strategy to 2020', the European Parliament stated that biodiversity degradation is one of the most critical global environmental threats (EUPAR, 2012). Biodiversity and landscape management have become crucial pillars of EU policies (Cervelli et al., 2017). There are continued and growing pressures on Europe's biodiversity: land-use change, over-exploitation of biodiversity and its components, transport infrastructures, spread of invasive alien species and pollution among others. In addition, indirect drivers such as population growth, little awareness about biodiversity and scarcity of environmental criteria in decision making, are also taking a heavy toll on biodiversity. These actions result in the degradation of landscapes with important consequences for the provision of ecosystem services. In this context, land degradation and ecosystems fragmentation caused by transport infrastructures are key threats for biodiversity (EEA, 2011). Regarding this issue, the EU's strategy has appointed the objective of restoring at least 15 per cent of degraded ecosystems before 2020 (EUPAR, 2012). Thus, EU member states should restore fragmented habitats by existing roadways in order to accomplish the established goals before 2020. Habitat fragmentation and land degradation by roadways has been studied from different points of view by many researches, either directly on the roadway or indirectly, through the study of green corridors for habitat fragmented connection (Shapira et al., 2013). It is also necessary to study the restoration under the action 6b of EU Biodiversity Strategy to 2020, that is, developing Green Infrastructure including from ecoducts to stepping stones in order to reconnect artificially divided natural areas by roadways (IENE – Infra Eco Network Europe Stering Committee, 2013). Making optimal decisions in the project conception phase of infrastructure will improve sustainability. Decision-makers need to use defined and measurable procedures (Hunt et al., 2013; Laurila-Pant et al., 2015). This research work has focused on implementing environmental criteria in the decision making of roadway project assessment to restore existing large cut slopes. There is a lack of decision support frameworks to implement environmental criteria in the selection of strategies to restore high cut slopes using a panel of experts and capable of achieving consensus in the final solution.

This paper presents a hybrid model capable of dealing with environmental criteria together with traditional territorial and economic criteria. The decision support system proposed is a hybrid method

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combining the Analytical Hierarchy Process (AHP) with the Delphi method and the VIKOR technique. The traceability and transparency of the decision support system are essential for ensuring a fair procedure. All stages have been duly documented to guarantee traceability and transparency (EUDirective, 2014). The AHP method allows the utilization of linguistic variables (Saaty, 2008). And therefore, this technique is very suitable for complex decision problems in which intangible factors cannot be neglected (Martin-Utrillas et al., 2015; Palmisano et al., 2016). The different indicators implemented will be environmental, functional, territorial and economic criteria. All of them, with their different weights, will be analyzed in relation to the possible restoration alternatives to develop. The AHP is based on paired comparisons from panelists and is capable of dealing with intangible criteria. Participatory methods should play an important role in combating land degradation (Tikkanen et al., 2016). The AHP methodology is a suitable technique for structuring the relevant knowledge in complex multicriteria problems (Giri et al., 2016). The Delphi method has been used to collect data from the panel of experts. The Delphi technique is performed to facilitate an efficient panel of experts' dynamic process. Finally, the VIKOR method obtains the compromise solution in decision problems with conflicting and no commensurable criteria that is the closest to the ideal (Opricovic and Tzeng, 2007). The alternatives are evaluated according to all established criteria, and the achieved compromise solution provides a maximum utility of the majority, and a minimum individual regret.

2. Decision hierarchy structure analysis

Using anonymous questionnaires, the Delphi method gathers the experts' opinions on the criteria and restoration strategies studied (Curiel-Esparza et al., 2016; Canto-Perello et al., 2017). For this analysis, a panel of twelve experts has been chosen among environmental and transport engineers with recognized competence and knowledge in the field under study. Each expert could provide additional restoration strategies or criteria/subcriteria, if considered. Afterwards, their proposals will be returned to them for new reconsideration. With this anonymous feedback, experts with different points of view help to facilitate the understanding of the issues discussed, allowing a consensus to be reached between all of them. In addition, it is also possible to remove the least significant criteria and restoration strategies for integration of linear transport infrastructure into the surrounding landscape.

To achieve the objective, several factors have been proposed: perceptual environment, physical environment, together with functional, territorial and economic factors. These core factors were further decomposed in eleven subfactors which were used for the analysis (see Fig. 1). The transport infrastructures should always be considered from the point of view of the sustainability (Canto-Perello and Curiel-Esparza, 2006; Canto-Perello et al., 2009; Rajak et al., 2016). The ecosystem health and sustainability are key endpoints and should be desired goals to be taken into account when developing the decision support system (Costanza, 2012; Curiel-Esparza et al., 2015). The stability of high cut slopes has not been a criterion in the proposed method as it is mandatory to guarantee the safety of all the restoration strategies proposed (Sun et al., 2012; Sun et al., 2013). They are described as follows:

- Perceptual environment (PEE), i.e. operational environment that humans are conscious of through organic-sensory. It can be divided into two subfactors. The first one, landform impact (LA), because roads have an effect on the different variables affecting the generation of landscape (Liu et al., 2008). The second subfactor is the visual impact (VI) on potential observers. The roadway should be coordinated with the landscape structure (Hu et al., 2012). An optimal cut slope restoration can ensure healthy environments and, as a consequence, physical and psychological health benefits to the people living within them (Tzoulas et al., 2007).
- Physical environment (PHE), which is structured in two subfactors: abiotic environment (AB) and biotic environment (BI). Abiotic subfactor takes into account many environmental indicators including local hydrology and geological conditions. In cut slope case and especially when existing water-limited conditions, it is important to consider geotechnical and geological parameters, but also erosive phenomena and soil loss, because of the strong relationship between rill erosion and vegetation (Moreno-de las Heras et al., 2011; Lee et al., 2013). For the second subfactor, biotic environment, the existence of great cut slopes enhances habitat loss. Furthermore, Benítez-López et al. (2010) have shown that the populations of mammals and birds are reduced as the distance to infrastructure becomes smaller. The effect on bird populations extended over distances up to about one kilometer, and for mammal populations up to about five kilometers.
- Functional factor (FUN), for which two subfactors have been developed. The first one, road safety (SA), is an important indicator for selecting the optimal solution in hilly lands (Fu et al., 2011). Calvi et al. (2012) have studied the effects of tunnels on driving performance that should be taking into account in the cut-and-cover tunnels. On the other hand, driving impact on users while construction (US) has been considered.
- Territorial factor (TEC) is divided into three subfactors: territorial planning coordination (TE), horizontal occupation area (HO) and ecosystem fragmentation (FR). Yu et al. (2012) have pointed out the requirements of territorial sustainable development are intertwined with the problems of land use intransigence, fragmentation and deterioration of natural systems. In addition, the European Commission have developed guidelines for the choice of different types of fauna passages (Iuell et al., 2003). These guidelines are based on landscape, habitats and target species, which are the mean factors within the ecosystem fragmentation problem.
- Economical factor (ECO), structured in two subfactors, such as construction costs (CO) and maintenance costs (OM).

On the other hand, there are different possible restoration strategies for integration of linear transport infrastructures into the surrounding landscape. Moreover, restoration of cut slopes is a wider problem that includes different territorial alterations. In ecosystem fragmentation problem, a recent study shows that the tendency has been to design and build underpasses (95.4%) instead of overpasses (Sorolla and Solina, 2013). Only 1.6% of underpasses were specific for wildlife, whereas for overpasses, near 45% were ecoducts and specific wildlife passages. Dry ledges can be useful to favor certain species that could use different types of modified drainage culverts and similar structures (Bager and Fontoura, 2013). Usually, the economic criterion is the key factor in selecting the final solution. And therefore, the enhancement of drainage culverts is always less expensive than other solutions. However, there is a lack of knowledge on the effectiveness of dry ledges in drainage pipes, even when combining fencing for vertebrates (Villalva et al., 2013). The objective should be to avoid the economic factors as the decisive excluding other criteria.

Different strategies have been proposed to reach the goal of cut slopes restoration. These strategies allow to solve the problem of territorial integration of cut slopes. Restoration strategies should ensure the sustainability of the restoration design and achieve synergy between stabilization and landscape integration of the slopes avoiding territorial fragmentation (Bortoleto et al., 2016). The proposed decision support technique is able of dealing with this complex problem and its synergistic factors. The following six restoration strategies for large road cut slopes are analyzed:

- Rock outcrops generation (ROO): This strategy combines, on one hand, a soft solution on the cut-slope acting on the shape for becoming irregular, naturalizing it to avoid visual impacts. And,