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Decision-making for the selection of a best wood extraction method: An analytic network process approach

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ABSTRACT

The importance of environmental and economical aspects in sustainable forest management (SFM), demands a continuing need for the application of efficient methods in this field. In this paper, we applied analytic network process (ANP) with benefits, opportunities, costs, and risks (BOCR) to evaluate four existing wood extraction methods (rubber-tired skidder, tracked skidder, cable logging and animal skidding) and select the best one based on SFM strategies in the Caspian (Hyrcanian) Forest, in northern Iran. The required data were obtained either from the previous studies or through pairwise comparisons conducted by a panel of forest engineering experts. Based on the BOCR subnetworks and their corresponding criteria, four alternatives were synthesized. ANP analysis indicated that the benefits and risks were more important in terms of decision-making, compared to the opportunities and costs. Finally, the alternative of 'rubber-tired skidder' was selected as the most suitable method for meeting SFM strategies. The decision framework proposed in this study offers a means for the reorganizing and planning of timber harvesting operations as an integral step toward SFM. By making minor adjustments for local conditions, this decision framework can be adapted for many other regions and countries.

1. Introduction

Timber harvesting is one of the main objectives of sustainable forest management (SFM), the overall efficiency of which depends heavily on the selection of an appropriate wood extraction method. Decisions for selecting a method is based on a wide variety of criteria including site condition, density of skid trails, suitable equipment and machines, skilled forest labors and an effective resource management strategy. Such a decision-making process can cause difficulties when reacting to change in terms of benefits, opportunities, costs, and risks (BOCR) of the alternatives. To date, economic efficiency has been the most important criterion for selecting harvesting and/or extraction methods. However, the non-consideration of ecological and social criteria may impose negative side-effects and risks that revoke this economic advantage (Kühmaier and Stampfer, 2012). There are many quantitative and qualitative criteria related to harvesting operations that should be measured or estimated and then integrated. This makes forest management planning processes more complex, creating a need for effective decision analysis methods that are able to take into account criteria that have been to date ignored in conventional planning methods (Laukkanen et al., 2005). Various research can be found in the literature that shows the use of multi-criteria decision-making (MCDM) methods that greatly improve the efficiency of the forest management planning process (e.g., Pukkala, 2002; Ananda and Herath, 2005, 2008; Kangas and Kangas, 2005; Hayati et al., 2013; Pellegrini et al., 2013). The concepts and methods of MCDM present a framework that incorporates several conflicting criteria into planning (Miettinen, 2006). The MCDM approaches range from addressing simple technical issues to complicated socio-economic problems (Lu et al., 2007). These approaches provide a set of systematic procedures for analyzing complex decision problems involved in SFM (Samari et al., 2012).

A forest management solution needs to be unique and based around capitalizing on the strengths and mitigating weaknesses. In terms of forest management, it cannot with certainly be indicated what type of wood extraction method is best, since the selection of a certain method involves the consideration of different conditions such as slope, terrain shape, skidding distance, soil, tree size, volume per hectare, weather, cost of road construction, cost of logging, and productivity goals. In this sense, selecting a wood extraction method is a MCDM problem. In this study, we attempt to evaluate wood extraction methods and select the best one by applying analytic network process (ANP) with BOCR based on SFM strategies in the Caspian Forest, in northern Iran. The research underlines the importance of providing a multi-criteria decision-making tool for more efficient forest management in the given conditions.

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2. ANP and related studies

As one of the decision-making techniques, analytic hierarchy process (AHP) appears to be a comprehensive technique that aims to remove, to a great extent, the problems associated with traditional methodologies (Kangas and Kangas, 2005; Samari et al., 2012). However, many decision-making problems cannot be structured as hierarchical, because they involve the interaction and dependence of higher-level elements in a hierarchy on lower level elements. Therefore, by dissolving the structural boundaries toward a network structure covering interdependencies and feedback between elements of different clusters, ANP was proposed (Saaty, 1999). In the ANP, relations among criteria and sub-criteria are involved in the evaluation process, allowing for dependencies both within a cluster (inner-dependence) and between clusters (outer-dependence) (Saaty, 2001). Pairwise comparison for both weighting the clusters (i.e., criteria) and for estimating the direction and importance of influences between elements is conducted and numerically presented as ratio scales in a so-called supermatrix (Saaty, 2001). The supermatrix represents the influence priority of an element in the left of the matrix on an element at the top of the matrix, with respect to a particular control criterion.

Although the AHP has been successfully applied to a wide range of decision-making problems during the past number of years, the ANP is yet a promising approach with limited number of applications and publications in the literature (Niemiraa and Saaty, 2004; Erdoğmus et al., 2005). However, the number of applications is continuously increasing. Some of the recent ANP applications regarding decision-making problems include analysis of SFM strategies in Austria (Wolfslehner et al., 2005), evaluation of high-tech alternatives in Turkey (Erdoğmus et al., 2005), development of a model for supplying poplar wood to Iranian paper and wood factories (Azizi, 2008), the appraisal of farmland in Spain (García-Melón et al., 2008); and selection of the best management alternative for entertainment businesses and the expansion of Disney amusing parks (Saaty, 2009). Gómez-Navarro et al. (2010) assessed the sustainability of tourism strategies using ANP approach. They argued that "although the ANP procedure is not free of criticism, it is a suitable tool for assessing sustainable tourism development strategies for the coastal national parks of Venezuela." Ghajar and Najafi (2012) addressed the issue of evaluation in the context of the harvesting systems in the Caspian Forest. They concluded that "ANP provides a suitable framework to incorporate all calculable and incalculable variables in the decision model and helped to achieve the goal of formulating forest policy." To the best of the authors' knowledge, there is no evidence in the literature regarding the application of ANP for choosing the best wood extraction method. Therefore, this paper aims to fill this gap in the research.

3. Materials and methods

3.1. Case study: the selection of a best wood extraction method in the Caspian Forest

The Caspian Forest is located south of the Caspian Sea. This region covers approximately 18,500 km^2 and comprises 15% in the total of the Iranian forests. Due to its humid temperate, climate and fertile soil, the region is highly productive and made up of a wide variety of plant communities (Jaafari et al., 2014a). Approximately 60% of the Caspian Forest is used for timber production. Trees (alive and dead) are harvested using a single-selection or group-selection system. Given that state controls this area, forest's management objectives are conservation, rehabilitation, development and utilization according to SFM.

The wood extraction alternatives used in the Caspian Forest are as follows:

i. Animal skidding
In the Caspian Forest, animal skidding is traditionally limited to small logs, lumber, pulpwood and fuelwood from steep areas and wherever road networks have not been developed, and using machinery in these areas is not practical. Animal skidding in the Caspian Forest usually includes a group of five or six people and seven or eight mules. Recently, with increasing environmental concerns and a focus on environmentally sound timber extraction and small-scale forest harvesting, the proportion of animal skidding has increased in the Caspian Forest (Jourgholami, 2011).

ii. Rubber-tired skidder
The rubber-tired skidder is the most common type of skidding machine used in the Caspian Forest. This skidder is typically an articulated steering, four-wheel-drive vehicle weighing 10–15 t and engine power of 110–140 kW and a maximum speed of 25–30 km/h (Sessions, 2007). It is equipped with a small, adjustable, push-blade on the front for the pushing of light obstacles and the stacking of logs. The rubber-tired skidders are a flat ground system, but with winches they can be effectively used on flat to moderate slopes. Thus, the rubber-tired skidder is normally used where the ground conditions are moderate, log size is not excessive, and the skidding distances are long.

iii. Tracked skidder
In the Caspian Forest, tracks are usually used in both road construction and wood extraction. Although the tracked skidder is slower and more expensive than the rubber-tired skidder, it can develop traction and pull vary large loads. Tracks are best used where short, steeper slopes prohibit overland rubber-tired skidding. Due to its slower traveling speed, skidding distance is limited and roads should be either existing or inexpensive to construct. Tracked skidders can be used on wetter sites or in moderately inclement weather.

iv. Cable logging
In the Caspian Forest, cable logging systems are best applied where, due to steep sloping, ground-based systems require excavated skid roads to operate, when harvesting is necessary in inclement weather and where environmental factors should be taken into account.

Each of the methods introduced above differ in terms of cost, productivity and environmental damage. Although many studies have been carried out on all aspects of wood extraction operations in Iran (e.g., Mousavi, 2009; Agherkakli et al., 2010; Ezzati et al., 2011; Jaafari et al., 2014b), forest managers still need a framework for selecting the best option. Moreover, to continue the progress of forest management in terms of sustainable management, decision-making within a MCDM framework is required. To address these problems, we propose a multi-criteria-based approach for selecting the best wood extraction method using an ANP with BOCR.

3.2. The proposed ANP model for the case study

In this study, development of the ANP model was supported by the latest research results reported as part of PhD dissertations focused on timber harvesting operations in the Caspian Forest (Mousavi, 2009; KeivanBehjou, 2010; Jourgholami, 2010; Ghajar and Najafi, 2012). The possible criteria that were included into the ANP model were determined according to SFM (Ghajar and Najafi, 2012; ITTO, 2002) and the FAO model code of forest harvesting practices (Dykstra and Heinrich, 1996). The final set of criteria and connections used in the ANP model were then decided with the cooperation of the management. The ANP model for the decision problem was developed around connections between the elements of clusters. The developed ANP model was a coupling of two parts. The first part, the ANP was designed as a control hierarchy that consists of a goal ("choosing the best wood extraction method") and three strategic criteria (ecological, economical and social). Each cluster included a group of indicators and management strategies that were each a fully functional ANP-model within the whole model (Fig. 1). It should be noted that it is useful to involve a conceptual

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