Journal of Environmental Management 210 (2018) 71–86

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Use of interactive data visualization in multi-objective forest planning

Arto Haara [a, *], Jouni Pykäläinen [b], Anne Tolvanen [c], Mikko Kurttila [a]

[a] Natural Resources Institute Finland, P.O. Box 68, FI-80101 Joensuu, Finland
[b] University of Eastern Finland, School of Forest Sciences, P.O. Box 11, FI-80101, Joensuu, Finland
[c] Natural Resources Institute Finland and Department of Ecology, P.O. Box 413, FI-90014, University of Oulu, Finland

ARTICLE INFO

Article history:
Received 29 November 2016
Received in revised form
8 December 2017
Accepted 1 January 2018

Keywords:
Decision aid
Multi-objective forest planning
Interactive visualization

ABSTRACT

Common to multi-objective forest planning situations is that they all require comparisons, searches and evaluation among decision alternatives. Through these actions, the decision maker can learn from the information presented and thus make well-justified decisions. Interactive data visualization is an evolving approach that supports learning and decision making in multidimensional decision problems and planning processes. Data visualization contributes the formation of mental image data and this process is further boosted by allowing interaction with the data. In this study, we introduce a multi-objective forest planning decision problem framework and the corresponding characteristics of data. We utilize the framework with example planning data to illustrate and evaluate the potential of 14 interactive data visualization techniques to support multi-objective forest planning decisions. Furthermore, broader utilization possibilities of these techniques to incorporate the provisioning of ecosystem services into forest management and planning are discussed.

1. Introduction

The challenging nature of decision making and the number of decision alternatives in forest planning vary considerably depending on the planning problem at hand. For example, spatial scale may vary from the level of a tree to the level of the whole country and even to the whole continent. The time scale of planning can range from an operative decision that will be implemented immediately to strategic-level planning, where the development of a forest area is predicted several hundreds of years into the future (e.g. Kangas et al., 2015). Numeric and detailed inventory data form the basis for operational and tactical planning, whereas aggregated data dominate in strategic planning. In addition, qualitative data have a remarkable role in normative (political) planning when, e.g. the needs of the society are considered.

Forest management decision problems are often simplified by applying traditional growth and yield tables or general forest management recommendations (e.g. Äijälä et al., 2014). In this approach, the decision maker (DM) utilizes directly the forest inventory data supplemented with some variables derived from these data such as the total timber volume or saw log volume of the stand. In addition to the simple approach, empirical models and simulation and planning systems have been developed to predict the outcomes and effects of future forest management alternatives (e.g. Borges et al., 2014). In modern planning systems, optimization methods are also utilized to construct alternative forest plans for a planning area.

A challenge in forest management planning is that several, often conflicting criteria, need to be taken into account when making decisions. Some decision problems are exploratory by their nature, i.e. instead of directly implementing the results, they are utilized in learning and providing understanding of forest dynamics for a given decision situation. Hence, the DMs' learning from the data and planning calculations needs to be properly supported before a well-argued decision can be made. The data must be managed so that meaningful comparisons and searches among decision alternatives are enabled.

Decision and planning problems can also be approached using data visualization. "Interactive visualization" refers to an information visualization process that supports the formation of mental image data, and this formation is further augmented (Ware, 2004) by allowing the user to interact with the data (Siirtola, 2007). For example, bar charts, scatterplots, multidimensional scaling, parallel coordinates and glyphs are typical techniques used for interactive visualization (e.g. Miettinen, 1999; Siirtola, 2007). Interactive data

* Corresponding author.
E-mail addresses: arto.haara@luke.fi (A. Haara), jouni.pykalainen@uef.fi (J. Pykäläinen), anne.tolvanen@luke.fi (A. Tolvanen), mikko.kurttila@luke.fi (M. Kurttila).

https://doi.org/10.1016/j.jenvman.2018.01.002
0301-4797/

visualization is an increasingly popular approach for improving the interpretability of multidimensional data and supporting decision making in science and business (e.g. Oghbaie et al., 2016).

In operational forest planning, interactive visualization may support decision making for example in searching for appropriate forest stands from which energy wood or high-quality logs can be procured. In tactical and strategic forest planning, characteristics of alternative forest plans can be illustrated using interactive visualization, which helps also in the selection among the alternatives. The need to use interactive visualization in forest planning is also connected to the use of large datasets in calculations. These data could be examined in more detail and more efficiently by using visualization techniques that are not yet commonly used.

The ongoing bioeconomy development emphasizes the use of renewable natural resources such as wood, to produce energy and material (Spatial Foresight et al., 2017). Simultaneously, multi-objective land use is increasingly seen as an option to concurrently produce ecological, social, and economic benefits (de Groot, 2006). In the forest planning context, these ongoing, partially divergent trends emphasize the need to incorporate new criteria into calculations and visualizations. For example, the synergies and trade-offs of biodiversity, carbon balance and recreational services in relation to timber production can be illustrated to the DM. This helps in the forest management decision-making process, during which different forest management operations are targeted to the areas where they are best suited.

There are a few applications generated for multi-objective forest planning purposes, which utilize interactive visualization tools. For example, Pasanen et al. (2005) introduced an application of parallel coordinates for tactical planning of non-industrial private forests, and the same web-based tool was also used in strategic-level participatory planning of the use of natural resources in northern Finland (Hiltunen et al., 2009). Chertov et al. (2002) suggested the integration of forest simulation models with spatial-temporal interactive visualization into interactive maps that aid in landscape-level decisions. Rammer et al. (2013) introduced an adaptive web-based forest management tool, which included a graphical user interface in which a shifting between several graphical variants to explore climatic factors and management alternatives on the performance of ecosystem services was enabled. However, to our knowledge, there have not been any extensive surveys of the visualization techniques and applications that could be used rather straightforwardly in the forest planning context.

The aim of this paper is to introduce and evaluate the potential of existing interactive data visualization techniques to support decision making in increasingly challenging multi-objective forest planning situations where more outputs are demanded from forest ecosystems. To do this, we first present a forest planning framework related to the data characteristics corresponding to the planning situation. Second, we demonstrate 14 potentially suitable data visualization techniques using forest planning test data from example stands, and evaluate their strengths and weaknesses. When selecting the potentially suitable techniques, the aim was to select a diverse group of techniques potentially suitable for the forest planning framework presented below. Finally, we discuss the broader usability of interactive visualization techniques in the context of the renewable natural resources management planning.

2. Planning framework using interactive visualization

The planning framework applied in this study includes three levels, which are connected to different data that are typically available at these levels (Fig. 1). At the first planning level, decisions are made at the stand-level and they are based on the current state of the forest stand. Thus, available forest resource data are used at this level. At the second level, decisions are still made at the stand-level, but there are possibilities to use more elaborated data, such as simulated treatment schedules for forest stands. At the third level, decisions are made based on holding-level data. Often, the first level serves the needs of operational planning, the second level, supported with planning system that includes optimization technique, serves often the needs of tactical planning. Finally, the third level that can include comparisons of holding-level alternatives is more strategic by nature. At all three levels, the planning process follows the steps of the multi-objective planning process defined by Kangas et al. (2015):

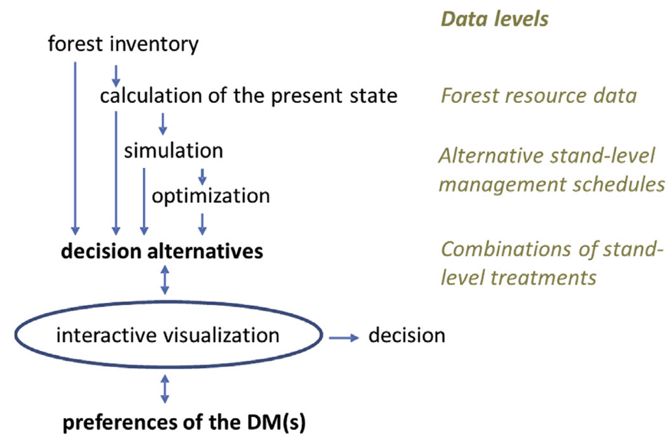

Fig. 1. The three-level forest planning data framework using interactive visualization of data.

(i) Defining the decision situation and the decision problem. For example, the planning area and the DM(s) are defined during this phase.
(ii) Clarifying the preferences of DM(s) regarding the use of forests. This planning step provides forest management goal variables and the corresponding goals to be strived for by applying interactive visualization techniques.
(iii) Defining the decision alternatives and their outcomes regarding the goals of the DM(s). Depending on the planning level and the availability of data, outcomes may consist of (1) the calculated present state of forest stands based on inventory data, (2) outcomes of stand-level simulated treatments or (3) of alternative combinations for the stand-level treatments (Fig. 1).
(iv) Evaluation of the decision alternatives by using interactive visualization.
(v) Choosing the best decision alternative.

All the above phases help the DM in the multidimensional task of defining how, when and where to manage the forests in different spatio-temporal planning situations. The DM can be a forest owner, a forest planner offering forest services for forest owners, or a wood procurement expert working for the forest industry.

The first data level, *forest resource data*, is often collected in field inventories. The data describe stand characteristics such as the stand area and boundaries, site fertility, and the main characteristics of the growing stock such as the tree species, their mean diameters, basal area, age, etc. These data are often further processed and updated to the present state so that, e.g., the inventory that was carried out in 2013 is updated to the year 2016 by predicting the growth of trees (e.g. Hynynen et al., 2002). In addition, several other variables can be calculated at this phase. For example, total volume and saw log volumes by tree species, growth and cutting value can